Okavango River Basin Transboundary Diagnostic Analysis Technical Report

OKACOM

The Permanent Okavango River Basin Water Commission

Okavango River Basin: Transboundary Diagnostic Analysis Project: Environmental Flow Assessment Module Specialist Report Country: Namibia Discipline: Geomorphology

Colin Christian & Associates CC
Colin Christian Soils
E.B. Simmonds

February 2009

Environmental protection and sustainable management of the Okavango River Basin

EPSMO

BIOPHYSICAL SERIES

Colin Christian & Associates CC
Environmental Consultants

3 Gordon Day St
PO Box 81182
Olympia
Windhoek
Namibia

Tel: 061 – 302296
Fax: 061 - 302297
Cellphone: 081 1490037
Email: colinchr@iway.na
Reg. No: CC/2006/1209

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Author: Colin Christian Soils input: E.B. Simmonds

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EXECUTIVE SUMMARY

INTRODUCTION

An Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project is being implemented under the auspices of the Food and Agriculture Organization of the United Nations (UN-FAO). There are two linked components of this project. These are:

a. A Transboundary Diagnostic Assessment (TDA) -an analysis of current and future possible causes of transboundary issues between the three countries of the basin: Angola, Namibia and Botswana.
b. An Environmental Flow Assessment (EFA) -to predict possible development-driven changes in the flow regime of the Okavango River system and the impacts on ecosystems, as well as consequent impacts on resources used by people.

Teams of specialists in all three basin states contributed to these studies for various disciplines. This report serves to fulfil the requirements for the EFA and TDA for the Geomorphology and Soils component in Namibia.

STUDY AREA

The study area for the EFA and TDA is the entire Okavango River catchment and Delta, but excluding the Makgadikgadi Pans and Nata River. “Fossil river” systems in Namibia are theoretically included but in practise they play no significant role in the functioning of the Okavango River system.

Since the entire river cannot be studied in detail, specific sites were selected for more detailed study. These sites were considered to be representative and relatively homogeneous in terms of both biophysical and socio-economic characteristics. Angola has three representative sites, Namibia two sites, and Botswana three sites. In Namibia, the two sites are Kapako and Popa Falls. A general overview of these two sites is provided, followed by a detailed account of the geomorphology and sediment processes. Site specific data on soils could not be obtained, but data on soils from similar sites are provided in the literature review in a later section of this report. A third site was nominated in Namibia – the ecologically important and relatively pristine islands and riverine forests of the MukweAndara-Divundu section. However, time and budget constraints did not allow for this area to be included in the study.

IDENTIFICATION OF INDICATORS & FLOW CATEGORIES

For each discipline, indicators were selected that can be expected to change in response to potential changes in the river flow regime. The selected indicators are usually important as habitat for various species (which will be considered by other specialists) and/or they have implications for people and their use of natural resources. A maximum of ten indicators per site per discipline was permitted. The following table lists the ten indicators selected for geomorphology, nine of which apply in Namibia. (No.2 applies only in Angola.)

Indicator Number	Indicator name	Sites represented	
		Kapako 4	Popa Falls 5
1	Extent of exposed rocky habitat in main channels.	No	Yes
2	Extent of coarse sediments on the bed	No	No
3	Cross sectional area of bank full channel	Yes	Yes
4	Extent of backwater areas (slow/no flow areas)	Yes	No
5	Extent of exposed sandbars at low flow	No	Yes
6	Extent of vegetated islands	No	Yes
7	Percentage silt & clay in the top 30cm of the floodplain	Yes	No
8	Extent of the floodplain flooded each wet season	Yes	No
9	Extent of inundated pools/pans on floodplain at the end of the dry season	Yes	No
10	Extent of cut banks along the active channel	Yes	No

Hydrological data were supplied to the specialists in each discipline for each study site. The hydrograph was divided into important flow categories: -namely the dry season, transitional season 1 (rising limb), flood season, and transitional season 2 (falling limb).

LITERATURE REVIEW

A review of the limited available literature was conducted relating to geomorphology, sedimentology and soils along the Okavango River in Namibia. In this context it was found that there was almost no literature on fluvial geomorphology. A recent study of sediment transport at Divundu provides valuable information on sediment transport below the confluence of the Cuito River. There is, however, a large volume of literature on geomorphology, and sedimentology in the Okavango Delta. Limited data on soils exists for the Namibian reach, but very few relate soils to the flow of the river.

The Okavango River is an extremely unusual river in terms of the nature of its sediment load, and the ecological implications of this fact are often not understood. Most importantly, the major load that the river carries is fine sand (0.25 – 0.43mm) of aeolian origin that has been reworked by water. This is transported as bedload, by saltation and not in suspension. (Saltation is the process whereby sand grains are picked up and dropped repeatedly.) This sand will be trapped in any weirs or dams and will not be easily moved through such impoundments. The sand has important ecological implications for the Delta – an issue that has been well studied and documented in Botswana.

The much smaller load of silt and clay particles has important implications for the fertility of soils on floodplains. These fine particles will not be replaced on floodplains or terraces that no longer flood. This would not bode well for the sustainability of agriculture, because the soils can be expected to deteriorate rapidly over time. The inherently poor nutrient status of these quartzitic soils also means that considerable amounts of artificial fertilisers must be added, which can adversely affect water quality in the river.

PREDICTED RESPONSES OF INDICATORS TO CHANGE IN FLOW REGIME

For every indicator that was applicable at each site, an analysis was made concerning the expected response of that indicator to potential changes in the flow regime.

FLOW-RESPONSE RELATIONSHIPS FOR USE IN THE OKAVANGO EF-DSS

At the Knowledge Capture Workshop in April 2009, an effort was made to enter descriptive data (in terms of the predicted responses of indicators) into the EF-DSS. The Environmental Flows – Decision Support System is a computer programme developed on a base of hydrological data for each study site. It enables some form of “quantification” to be made based on the available knowledge and experience of the specialist teams. The output is a series of graphs that indicate how each indicator can be expected to respond to potential changes in river flow. The flow-response curves are not included in this report as it was decided at the workshop that they would be collated and compiled in a separate report by the EFA project leaders.

An important limitation of the EF-DSS is that it was not able to take into account the effects of sediment trapping in dams or weirs. Due to constraints of the study scope and budget, only the effects on river flow and the associated secondary impact on local sediment transport will be considered under various development scenarios. However, in reality, dams and weirs will trap sediment and have a geomorphological impact downstream that is more severe than that expected from the hydrological changes alone. This is due to the release of sediment free water that would rapidly erode the beds and banks of the river downstream of the dam. In areas where easily erodible extensive floodplains are present, such as at Kapako, or where the driving riverine processes are critically dependent on inflowing bedload, such as Okavango Delta, the sediment trapping effects of upstream dams are likely to outweigh the hydrological impacts. Sediment trapping by dams or weirs should thus be carefully evaluated in any future studies.

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ABBREVIATIONS

ABBREVIATION	MEANING
DSS	Decision Support System
DTM	Digital Terrain Model
EFA	Environmental Flows Assessment
EIA	Environmental Impact Assessment
EPSMO	Environmental Protection and Sustainable Management of the Okavango River Basin
FAO	Food and Agriculture Organization
IUAs	Integrated Units of Analysis
m.a.s.l.	Metres above sea level
OBSC	Okavango Basin Steering Committee
OKACOM	Okavango River Basin Commission
TDA	Trans-boundary diagnostic Assessment
UN	United Nations
CEC	Cation Exchange Capacity

ACKNOWLEDGEMENTS

Ms. E.B. (Sophie) Simmonds provided input on soils and soil indicators and compiled part of Section 4.3 on soils.

Sections 2.3.1 and 2.3.2, being the overviews of the Kakapo and Popa Falls sites, were written by Ms. Shirley Bethune and are shared in common with the other specialist reports.

Mr. Mark Rountree provided discussions on defining geomorphological indicators. He also helped us at the Knowledge Capture Workshop in Windhoek to interface with the computer model in drawing up the response curves, and provided comments on a draft of this report.

Ms Jackie King provided helpful comments on a draft of this report.

Ms. Celeste Espach from the Ministry of Agriculture kindly assisted with GIS work and maps.

Prof. Terence McCarthy kindly supplied reprints of research papers by the Okavango Working Group at WITS University.

1 INTRODUCTION

1.1 Background

An Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project is being implemented under the auspices of the Food and Agriculture Organization of the United Nations (UN-FAO). One of the activities is to complete a transboundary diagnostic assessment (TDA) for the purpose of developing a Strategic Action Plan for the basin. The TDA is an analysis of current and future possible causes of transboundary issues between the three countries of the basin: Angola, Namibia and Botswana.

The Okavango Basin Steering Committee (OBSC) of the Okavango River Basin Water Commission (OKACOM) noted during a March 2008 meeting in Windhoek, Namibia, that future transboundary issues within the Okavango River basin are likely to occur due to developments that would modify flow regimes. The OBSC also noted that there was inadequate information about the physico-chemical, ecological and socioeconomic effects of such possible developments. OBSC recommended at this meeting that an Environmental Flow Assessment (EFA) be carried out to predict possible development-driven changes in the flow regime of the Okavango River system, the related ecosystem changes, and the consequent impacts on people using the river's resources.

The EFA is a joint project of EPSMO and the Biokavango Project. One part of the EFA is a series of country-specific specialist studies, of which this is the Geomorphological Report for Namibia.

1.2 Okavango River Basin EFA: Project Objectives

The goals of the EFA are:

To summarise all relevant information on the Okavango River system and its users, and collect new data as appropriate within the constraints of the EFA

a. to use these to provide scenarios of possible development pathways into the future for consideration by decision makers, enabling them to discuss and negotiate on sustainable development of the Okavango River Basin;
b. to include in each scenario the major positive and negative ecological, resource-economic and social impacts of the relevant developments;
c. to complete this suite of activities as a pilot EFA, due to time constraints, as input to the TDA and to a future comprehensive EFA

.
The specific objectives are:

a. to ascertain at different points along the Okavango River system, including the Delta, the existing relationships between the flow regime and the ecological nature and functioning of the river ecosystem;
b. to ascertain the existing relationships between the river ecosystem and peoples' livelihoods;
c. to predict possible development-driven changes to the flow regime and thus to the river ecosystem;
d. to predict the impacts of such river ecosystem changes on people's livelihoods.

e. To use the EFA outputs to enhance biodiversity management of the Delta.
f. To develop skills for conducting EFAs in Angola, Botswana, and Namibia.

Layout of this report

Chapter 2 contains an overview of the Okavango Basin in Sections 2.1 and 2.2. Section 2.3 contains overviews of the two sample/study sites in Namibia -Site 4: Kapako and Site 5: Popa Falls. Sections 2.4 and 2.5 provide some details of the geomorphology of these two Namibian sites.

Chapter 3: Section 3.1 provides a list of indicators used in relation to the two sample/study sites and explanations of these indicators. Section 3.2 provides selected graphs showing of river discharge and the four stages in the annual cycle.

Chapter 4 is a brief account of the very limited literature available for geomorphology and soils along the Okavango River. Unfortunately none of the available literature relates directly to the flow indicators.

Chapter 5 provides some limited descriptive data and sketchmaps based on aerial photos and the fieldwork. Due to the limitations of time and budget, it was only possible to attend the flood season fieldtrip in February 2009.

Chapter 6 was to have presented the response curves that were developed at the Knowledge Capture Workshop in March/April 2009. However, it was decided at that workshop that the response curves would be handled outside of the specialist reports. Therefore Chapter 6 is limited to a few remarks that must be taken into account in further consideration of the response curves and any further development of the model.

2 STUDY AREA

2.1 Description of the Okavango Basin

The Okavango River Basin consists of the areas drained by the Cubango, Cutato, Cuchi, Cuelei, Cuebe, and Cuito rivers in Angola, the Okavango River in Namibia and Botswana, and the Okavango Delta (Figure 2.1). This basin topographically includes the area that was drained by the now fossil Omatako River in Namibia. Outflows from the Okavango Delta are drained through the Thamalakane and then Boteti Rivers, the latter eventually joining the Makgadikgadi Pans. The Nata River, which drains the western part of Zimbabwe, also joins the Makgadikgadi Pans. On the basis of topography, the Okavango River Basin thus includes the Makgadikgadi Pans and Nata River Basin (Figure 2.2). This study, however, focuses on the parts of the basin in Angola and Namibia, and the Panhandle/Delta/Boteti River complex in Botswana. The Makgadikgadi Pans and Nata River are not included.

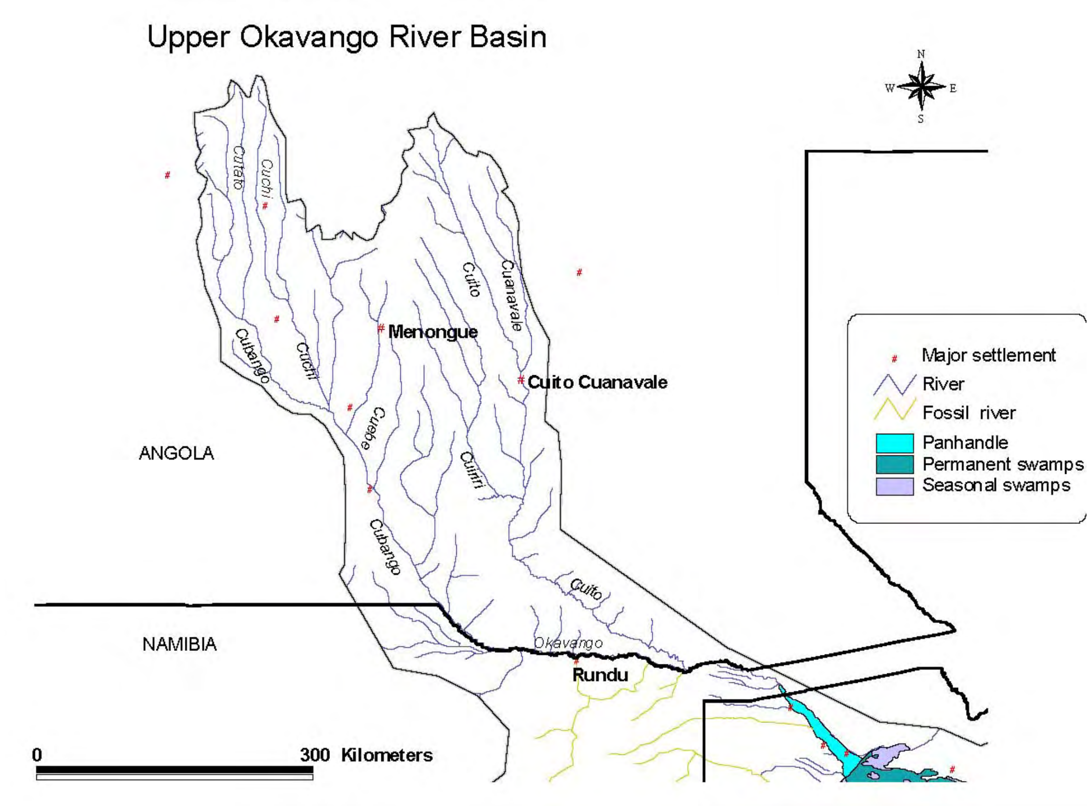


Figure 2. 1: Upper Okavango River Basin from Sources to the Northern end of the Delta

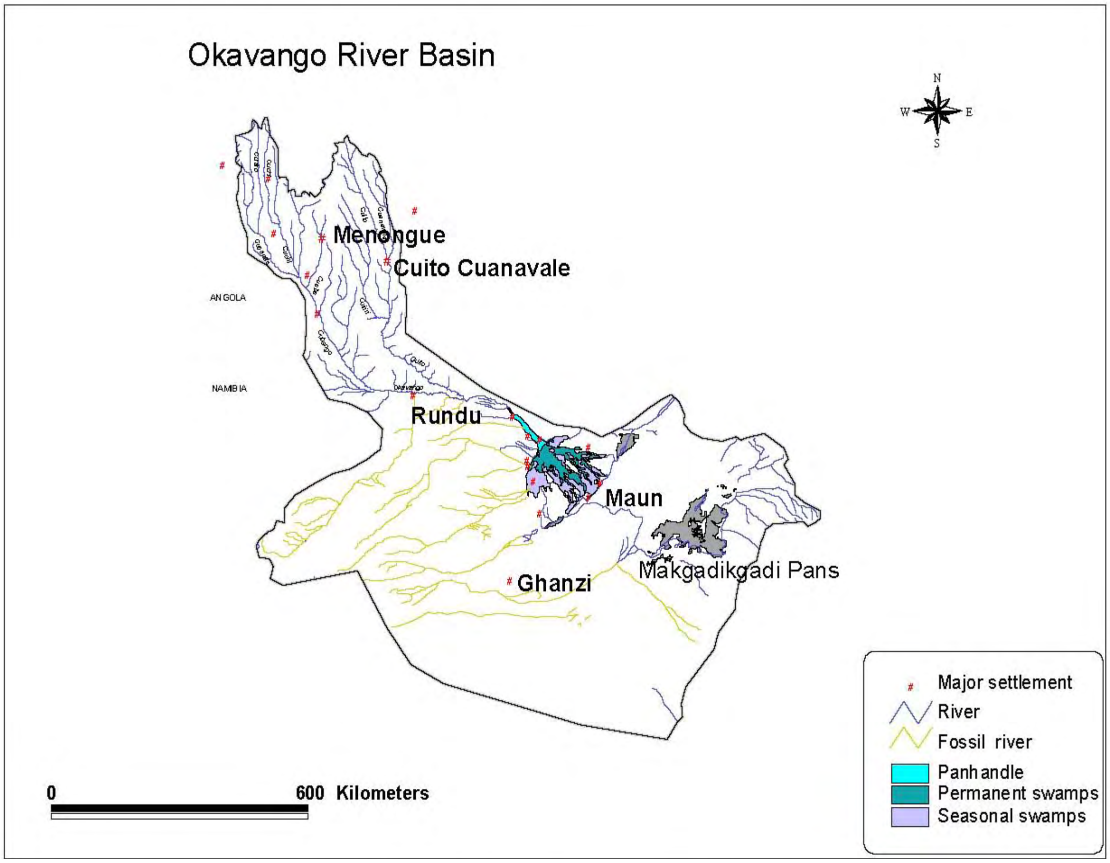


Figure 2. 2: The Okavango River Basin, Showing Drainage into the Okavango Delta

Delineation of the Okavango Basin into Integrated Units of Analysis

Within the Okavango River Basin, no study could address every kilometre stretch of the river, or every person living within the area, particularly a pilot study such as this one. Instead, representative areas that are reasonably homogeneous in character may be delineated and used to representative much wider areas, and then one or more representative sites chosen in each as the focus for data-collection activities. The results from each representative site can then be extrapolated over the respective wider areas.

Using this approach, the Basin was delineated into Integrated Units of Analysis (EPSMO/Biokavango Report Number 2; Delineation Report) by:

a. dividing the river into relatively homogeneous longitudinal zones in terms of:

- hydrology;
- geomorphology;
- water chemistry;
- fish;
- aquatic invertebrates;
- vegetation;

b. harmonising the results from each discipline into one set of biophysical river zones;

c. dividing the basin into relatively homogeneous areas in terms of social systems;

d. harmonising the biophysical river zones and the social areas into one set of Integrated Units of Analysis (IUAs).

The 19 recognised IUAs were then considered by each national team as candidates for the location of the allocated number of study sites:

- Angola: three sites
- Namibia: two sites
- Botswana: three sites.

The sites chosen by the national teams are given in **Table** 2.1.

Table 2. 1: Location of the eight EFA sites

EFA Site No	Country	River	Location
1	Angola	Cuebe	Capico
2	Angola	Cubango	Mucundi
3	Angola	Cutio	Cuito Cuanavale
4	Namibia	Okavango	Kapako
5	Namibia	Okavango	Popa Falls
6	Botswana	Okavango	Panhandle at Shakawe
7	Botswana	Khwai	Xakanaka in Delta
8	Botswana	Boteti	Chanoga

Overview of Units of Analysis and Study sites

In the Namibian section of the Okavango River, the majority of the human population lives along the river and the main road, with several hot spots such as Rundu, Divundu and Nkurenkuru which have a high population density. The river can be divided into four clear units of analysis:

1) The longest unit extends from where the river enters Namibia at Katwitwi to the Cuito confluence. This unit is typified by the meandering mainstream and large seasonally-flooded floodplains on either side of the river. Kapako, site 4, was chosen as a typical meandering floodplain site to represent this unit;

2) This unit is immediately downstream of the Cuito confluence and is characterised by permanent swamp areas and large islands. No sites were selected in this preliminary survey, but it would be essential to include the assessment of this unit in any future more detailed EFA studies;

3) The unit from Mukwe to just below the Popa Falls is a southward flowing, rocky, braided section. The river is largely confined to the mainstream and flows around several sand and rock based islands. Popa Falls Site 5, was chosen as a typical rocky river site to represent this section.

4) The protected section of the river downstream of Popa Falls to the border with Botswana at Mohembo that lies within the newly declared Bwabwata National Park is the last unit within Namibia. Two core conservation areas on either side of the river, the Buffalo core area on the west bank and the Muhango core area on the east bank. This area has extensive floodplains and represents the beginning of the transition to the Panhandle part of the Okavango Delta.

2.3.1 Site 4: Kapako -Overview

The main focus point for socio-economic work at the Kapako floodplain site 4 is Kapako village: S-17.94 E–19.56, situated some distance inland from the river on the other side of the main road (**Figure 2.3**). Kapako is approximately 20km west of Rundu by road.

The main villages close to Kapako village are Mupini to the east (downstream), Mukundu to the south, Ruugua and Sinzogoro to the west (upstream).

The floodplain site itself is situated on the Okavango River and three main sites on the floodplain and the mainstream were used for sampling. They were:

a. Kapako site 1 S-17.87775 E-19.58200 (start south bank) S-17.87850 E-19.58211 (end of site 1)
b. Kapako site 2 S-17.86557 E-19.58057 (start at floodplain – only 3 observations due to flooding)
c. Kapako site 3 S-17.86209 E-19.57855 (deep pool).

The riverine landscape includes the main Okavango River channel or mainstream, the annually flooded floodplains with several braided side channels and deeper pools or backwaters, as well as the higher fluvial terrace with alluvial deposits that are very seldom flooded. There is a steep, well vegetated bank at the edge of the floodplain close to the main road that rises to several meters above the floodplain.

Kapako area has a population of approximately 2,500 people within 10 km of Kapako village. The greatest density of people (over 100 per km^2) live alongside the river in the area just west of the Kapako study site whilst at the site itself the density varies from no people on the floodplain, 6 – 25 / km^2 at the Ebenezer mission, to a density of 25 – 50 /km^2 closer to the road and 51 – 100 /km^2 on the other side of the main road, rapidly decreasing again with distance inland. (See Map 3 in Populations Demographics Report prepared by Celeste Espach). We can assume that some of these people make some use of the floodplain site at Kapako and elsewhere along this stretch of river.

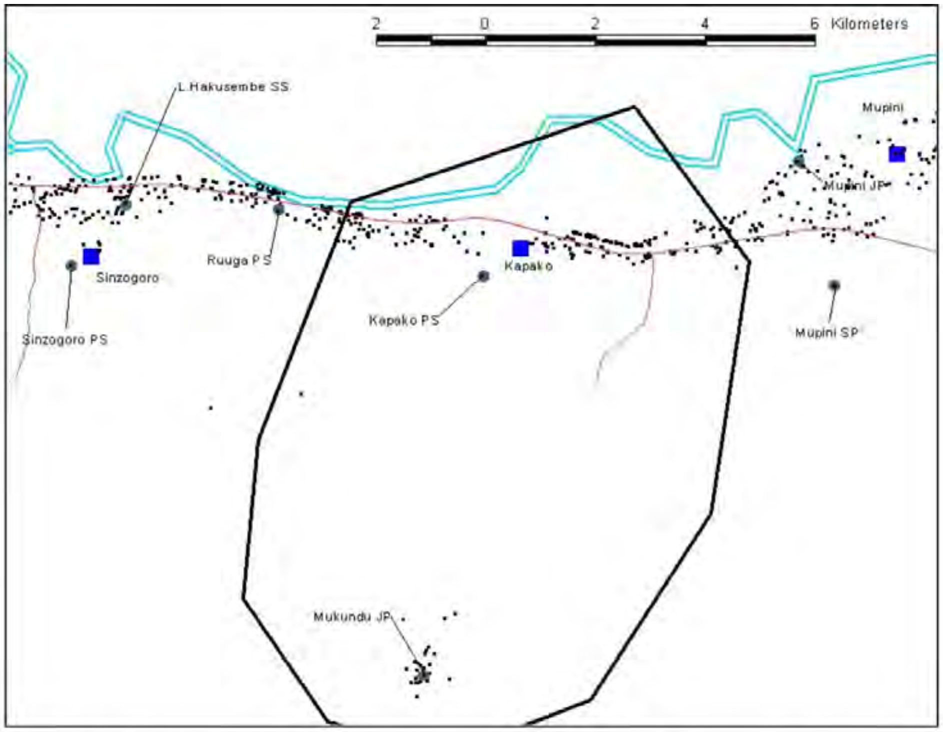
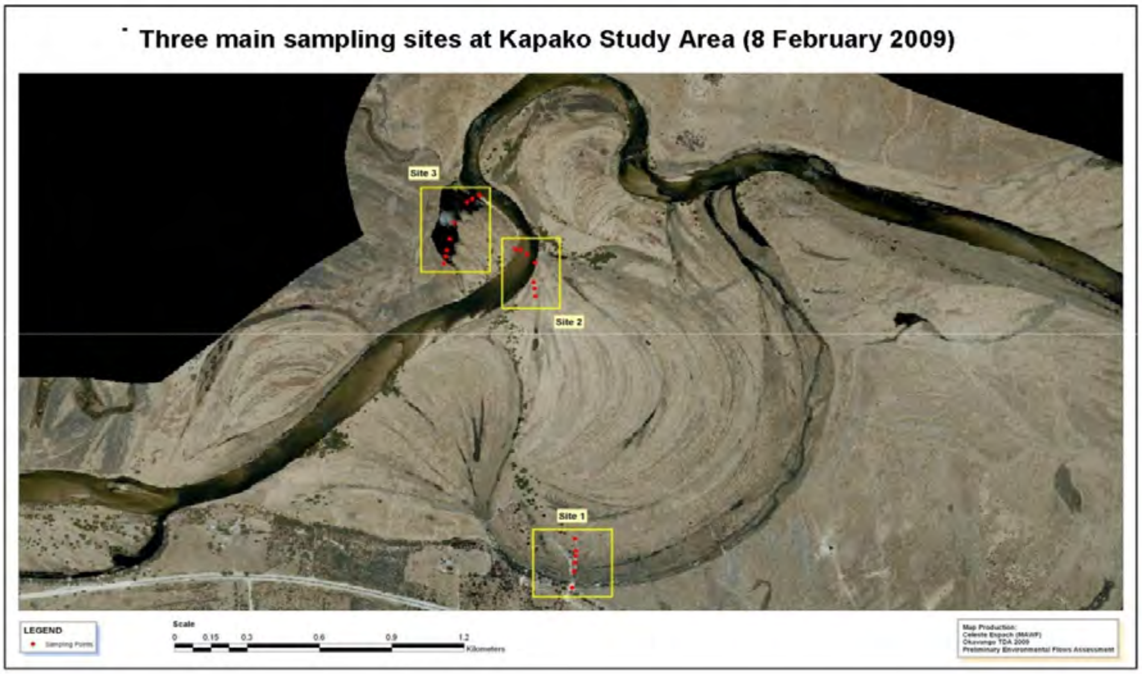


Figure 2.3 Site 4: Kapako showing the village of Kapako, the main road and surrounding settlements in relation to the river. Most of the area between the road and the river is floodplain. The border shows the

Figure 2. 3: Kapako Village



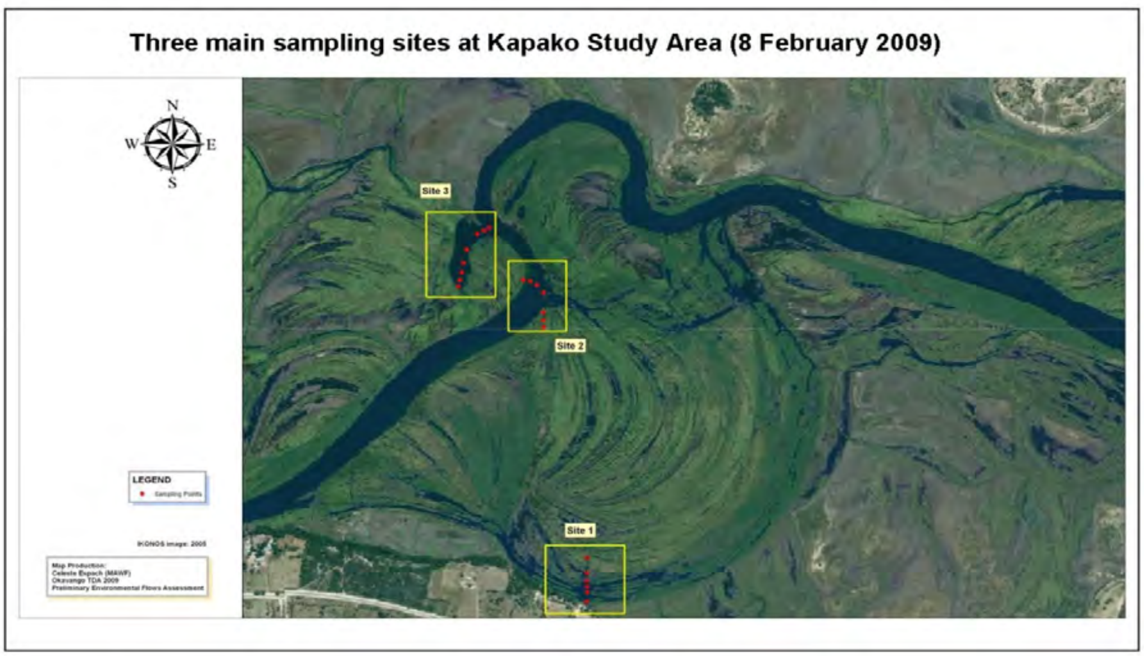


Figure 2.4 shows two satellite images of the Kapako floodplain Site 4, one in the dry season and one in

Figure 2. 4: Satellite images of the Kapako Flood Plain

During the focus group discussion held at Kapako village, the basin residents mentioned that the flooding starts when the rising river waters push out over flat surrounding ground and the biggest floodplains form in years when river levels are highest. They said that the most important feature of the flooded areas is that they are rich in nutrients. The floodplains also offer the young fish refuge from larger, predatory species and thus offer the greatest survival of young fish. They had noted that an overall increase in fish population occurs in years when water levels are high and flooding lasts longest. Local people have recognised that water quality and fish resources are decreasing in the Okavango River. Fish and fishing remain significant features in the lives of people at Kapako, who fish for food or to earn incomes by selling their catches. In addition some earn money by providing trips for tourists. They estimate fish stocks in the floodplains to be four times higher than in the main channel.

About 47% of households at Kapako catch fish, and each person consumes an average of 10-20 kilograms of fish per year. September to December is the peak fishing period at Kapako when the river is at its lowest and fish are concentrated in the mainstream. The kinds of traps or gear used to catch fish are separated into traditional and modern methods. The most used traditional gear are fish funnels, kraal traps, scoop baskets, push baskets, bows and arrows, set fish hooks and spears. Modern gear consists of line and hooks, wire mesh fykes, illegal mosquito nets, and gill and seine nets. The use of fish for recreational angling forms part of the tourism value associated with the river. Biophysical response curves for the angling species would feed into the tourism values for the river reducing them partially. Only a small part of tourism value is attributable to angling.

At Kapako, as elsewhere along the Namibian section of the river, the ever -increasing human population and clearing for crops and livestock has put increasing pressure on the natural resources along the main channel. The vegetation along the river bank is overgrazed and in some areas depleted, thus at Kapako the residents graze their livestock across the river on the Angolan floodplain. Cattle were routinely seen being swam across the river at this site during fieldwork. Associated with this population growth, has been an increase in livestock, fire frequency as well as the area of land cleared for crops and fuel. These associated land use changes are an undeniable factor of increasing settlement and development at a Kapako and indeed all along the Okavango.

The road westwards from Rundu has been upgraded and is currently being tarred. It runs parallel to the Okavango River all the way to the border post with Angola at Katwitwi. This has opened up the region allowing people to exploit the land alongside the road. As expected, highest densities are alongside the road parallel to the river. As the population continues to increase, exploitation of the land that new roads have opened up should disperse the pressure on the Okavango River floodplains and its resources to land further inland from the river, although the river will always remain the main source of water even for livestock watering.

The extent of erosion and clearing and thus of bare ground has also increased, yet the people perceive the overall water quality not to have declined substantially. The only exceptions mentioned were an increase in phosphate concentrations, a decrease in water clarity and a related increase in suspended sediments. There are more short term, seasonal variations in water quality particularly in the floodplain pools, than any long term water quality change. So far there does not seem to have been an excessive exploitation of the water resources in the main channel, although the basin further inland has some serious water shortages at times and a lack of deep boreholes.

The Kalahari sands that overlay the area are deep.

2.3.2 Site 5: Popa Falls -Overview

The Popa Falls site is approximately 5km south of Divundu bridge by road.

The main focus for the socio-economic work at the Popa Falls Site 5 was the village of Popa and the Popa Falls Rest Camp run by Namibia Wildlife Resorts. The main transect used for the physical and biological field survey work was a transect across the river immediately above the Popa Falls from the irrigation water draw-off point used by the Prison Services on the eastern bank (West Caprivi) where a gauge plate was put up to the protected section close to the Popa Falls Rest Camp on the western bank.

Popa Falls rest camp: S 18.15316
E 21.6045 Popa Falls gauge plate:
S 18.11603 E 21.57900

Figure 2.5 shows the main villages. **Figure 2.6** shows two satellite images of Popa Falls.

About 3,000 people live in the area surrounding Popa. The highest population density in the area is immediately upstream of the Popa Falls at the Bagani/Divundu settlement, within an area of over 12 km2. At the Popa Falls site itself the population density is much lower at 6 – 25 people/km2 and it must be remembered that the Popa camp is within an 8 km2 park, the islands are uninhabited and the opposite bank supports a community campsite reserved for tourists. Immediately downstream of Popa camp the riverside population increases to 26-50 people/km2 and includes several lodges. See Map 3 in the Population Demographics report prepared by Celeste Espach for the TDA.

At the Popa Falls, the entire width of the river cascades down four meters before resuming its normal slow and leisurely flow. The quartzite rocks were formed from sediments deposited in rift valleys about 900 million years ago, (Mendelsohn el Obeid, 2004).

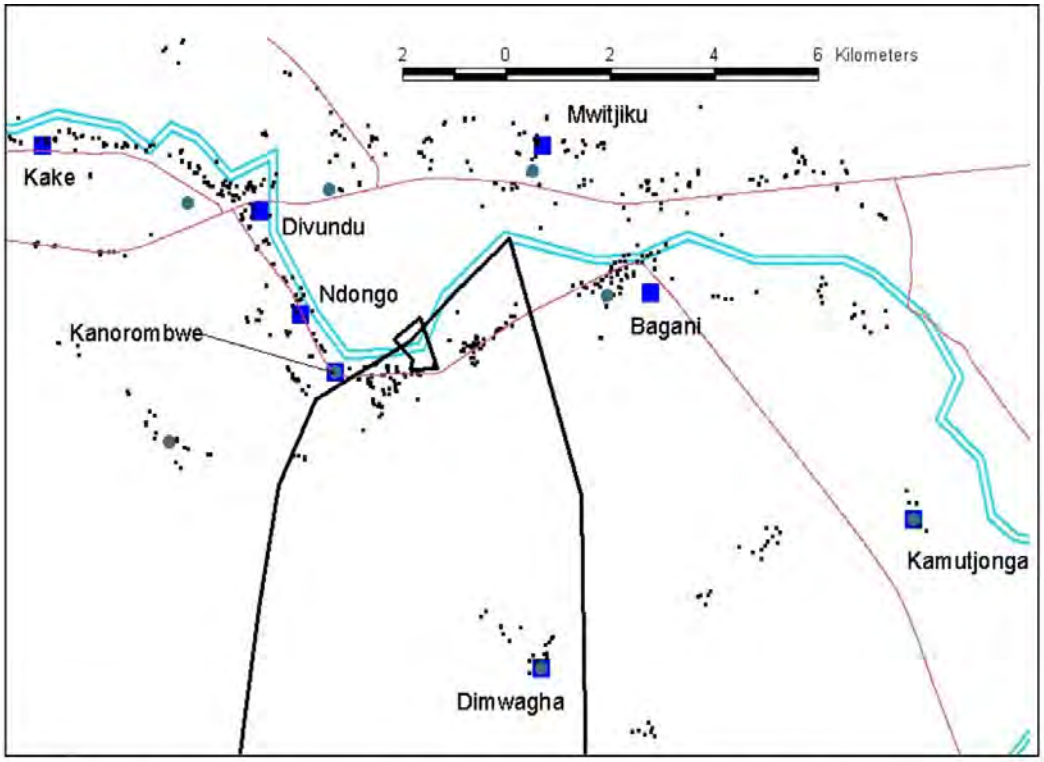
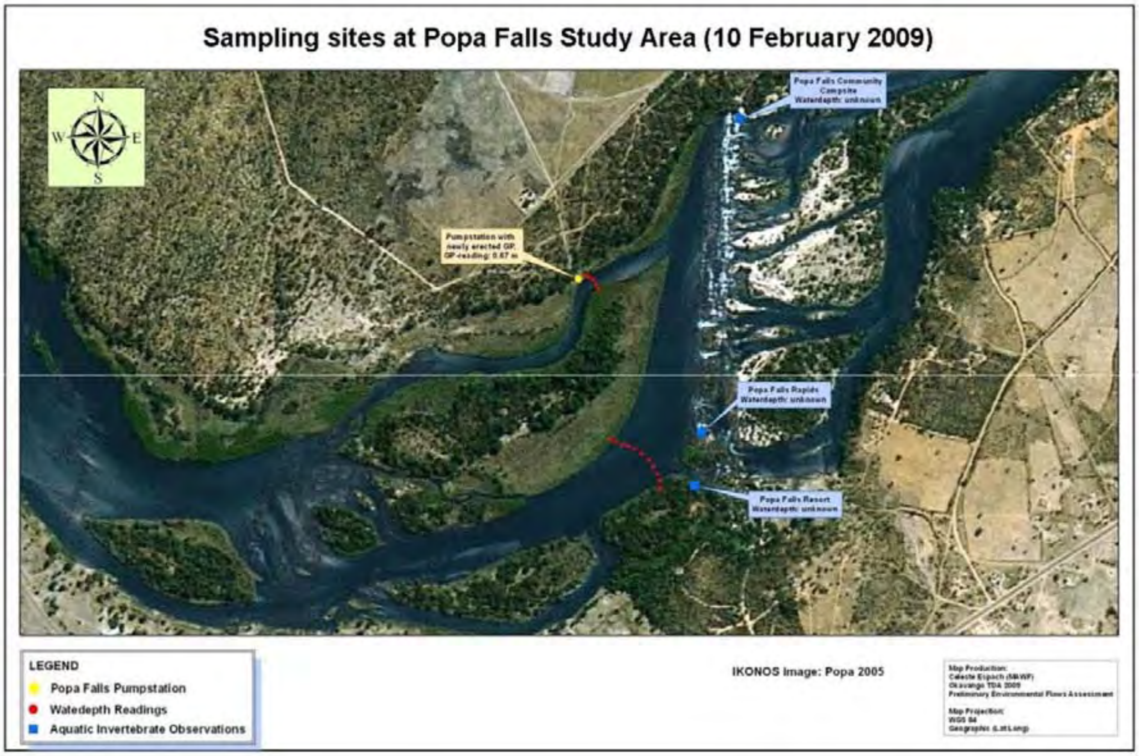


Figure 2. 5: Site 5, Popa Falls. the majority of the population lives along the river



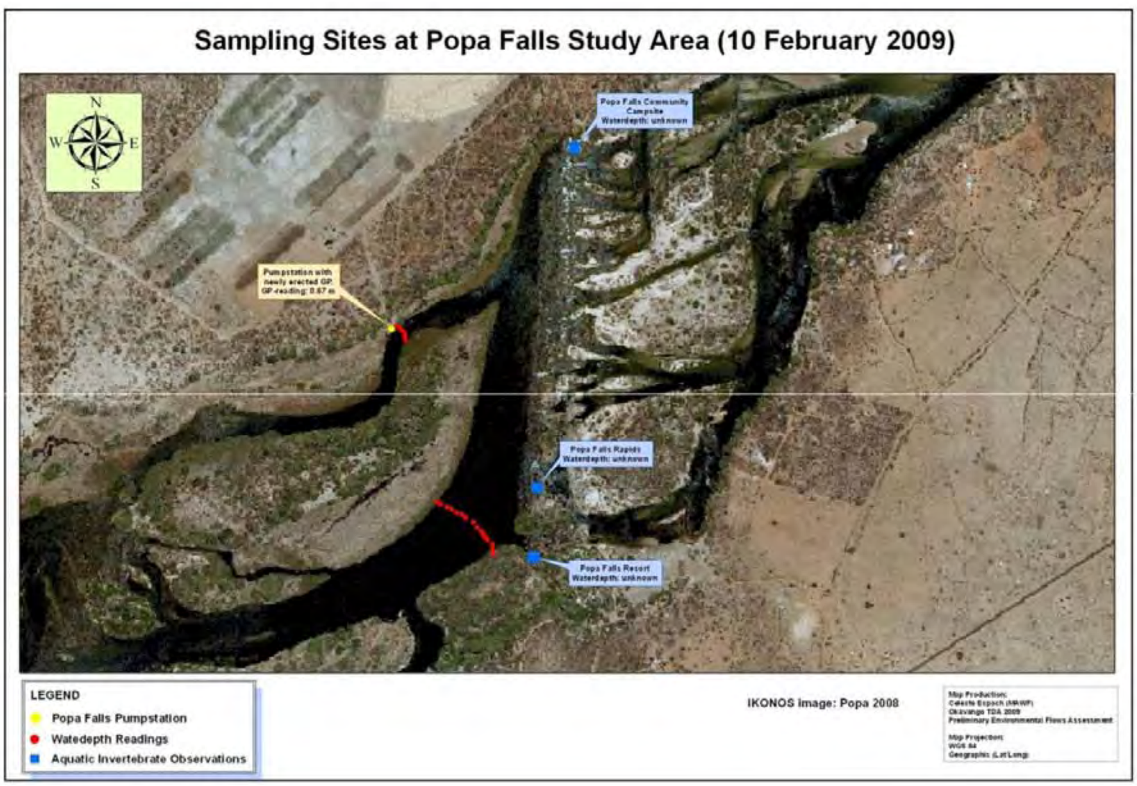


Figure 2. 6: Satellite image of Popa Falls showing wet and dry transects and main sampleing sites

During the focus group discussion, it was mentioned that due to the Popa Falls and rocky areas, it's difficult for the local fishermen to catch fish as desired. Therefore, only a few individuals that own local mukoros, hook and line, and gill fish nets have access to fish catches in the main channel. Thus fishing is a secondary activity for most people at the Popa area, contributing little to the overall cash or in-kind incomes of the majority of households. People also pay much less attention to fishing than to farming and business activities. Each household depends on a different mix of incomes derived from wages, business earnings, pensions and remittances.

Papyrus cyperus (papyrus) dominates the deepest water margins alongside the main channels. Water can seep through the walls of papyrus to the reedbeds behind the papyrus and in places into backwaters and side channels. The sandy sediments are confined to the channels. These are flanked by reed beds of Phragmites, Typha capensis or bulrushes and the sedge Miscanthus junceus in the shallower waters. The residents do not experience floods as there are no floodplains in this area. They depend in the main channel for most of their water and wetland resources. Most houses at Popa village are thatched with grass and reeds, while reeds are used extensively to make sleeping mats, walls, palisades, courtyards and fences.

Farming activity is an important source of income; households are engaged in both crop and livestock farming. Planting is staggered through the raining reason and is initiated only after a good rainfall event. This increases the chance of crop survival during the hot dry periods. Livestock farming is dominated by cattle and goats, not kept within fields but are moved for grazing and between water sources, mainly the Okavango River.

Tourism is a major source of income to the Popa residents; most of them are employed within the lodges around the Popa area. They value tourism as their major source of income.

The maps below (Figure 2.6) show the Popa Falls Site 5 in both wet and dry season. The main field survey transect and sampling sites are indicated by red dots.

2.4 Geomorphological Description : Site 4 Kapako

2.4.1 Methods

The site visit to Kapako was undertaken on 8-9 February 2009. A high water mark on banks and vegetation showed that the flood had already peaked and then subsided by about 0.5m. The flood was overflowing the banks by about half a metre and almost the entire active floodplain was inundated at the time. (Note that a much higher peak followed in March but we were not present.)

The water level was too high to allow walking on most of the active floodplain, and not high enough to allow the floodplains to be traversed by boat. Therefore the inspection of the area was restricted mainly to a boat trip on the main channel and viewing from there. Where possible we got out onto higher banks and viewed from there. Photographs were taken where possible, but the complete lack of high vantage points was a limitation. Thus the extent of flooding could not be properly determined.

Photos were also taken by Mark Paxton at the Kapako site from December 2008 to February 2009 in order to show the rising flood levels in relation to the floodplains. However, the lack of high vantage points from which to view substantial areas of the floodplain limited the usefulness of these photos in showing the extent of inundation in relation to the rising stage of the river.

Depths were measured from the boat or on foot in channels and backwaters using a surveyor's pole at locations shown by red dots in Figure 2.4. Details and cross sections are provided in a report by Celeste Espach.

Other information provided in the following sub-section was drawn from the author's experience of the Okavango River in Namibia, topographic maps, and the satellite images provided as Figure 2.4. Interpretation of the landforms was made based on the satellite images, with rough contours superimposed, and observations and photographs in the field. This information was mapped in Figure 2.7. Areas of water features were measured by a simple squares method on a much larger scale print of the same map. Schematic cross sections were made and presented as Figure 2.8.

Information from the literature also contributed to the following section.

2.4.2 Geomorphological Description & Data for Kapako

Figure 2.7 is an orthophoto of the Kapako site, with contours generated in a GIS programme. The contours are not accurate because the small contour interval of 1m, which was chosen in order to define such a flat area, is too fine for the satellite images. However, the contours give some indication of the topography and elevations of the landscape.

Figure 2.8 shows two schematic Cross Sections through the floodplains. The location of these cross sections is shown in Figure 2.7 by the lines marked A – A1 and B -B1.

Photos 1 – 6 show parts of the Kapako site as seen from a boat on the river. The floodplains were mostly too deeply inundated to allow access on foot, but not deeply enough for a boat to move about.

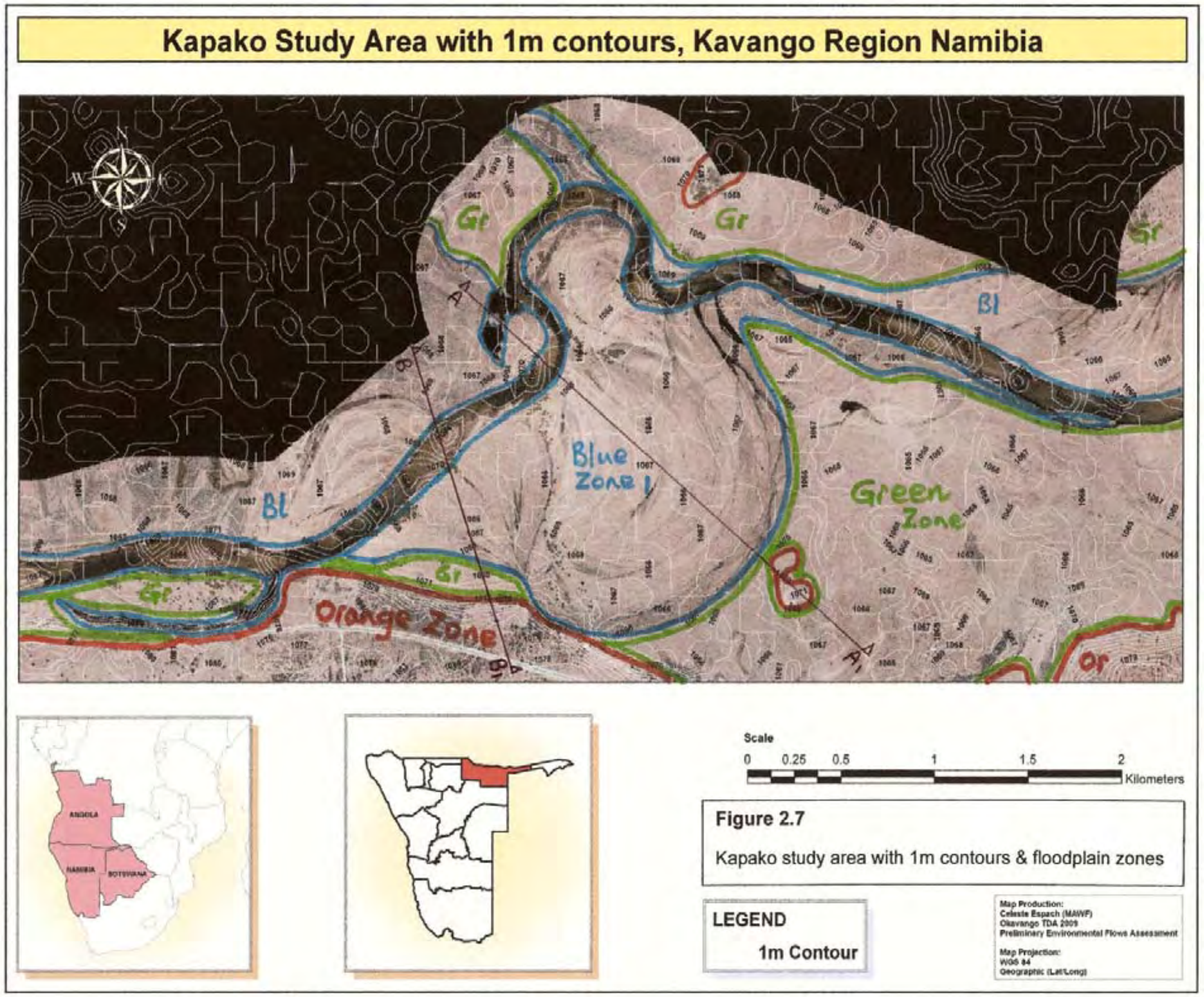


Figure 2. 7: Kapako Map with Countours

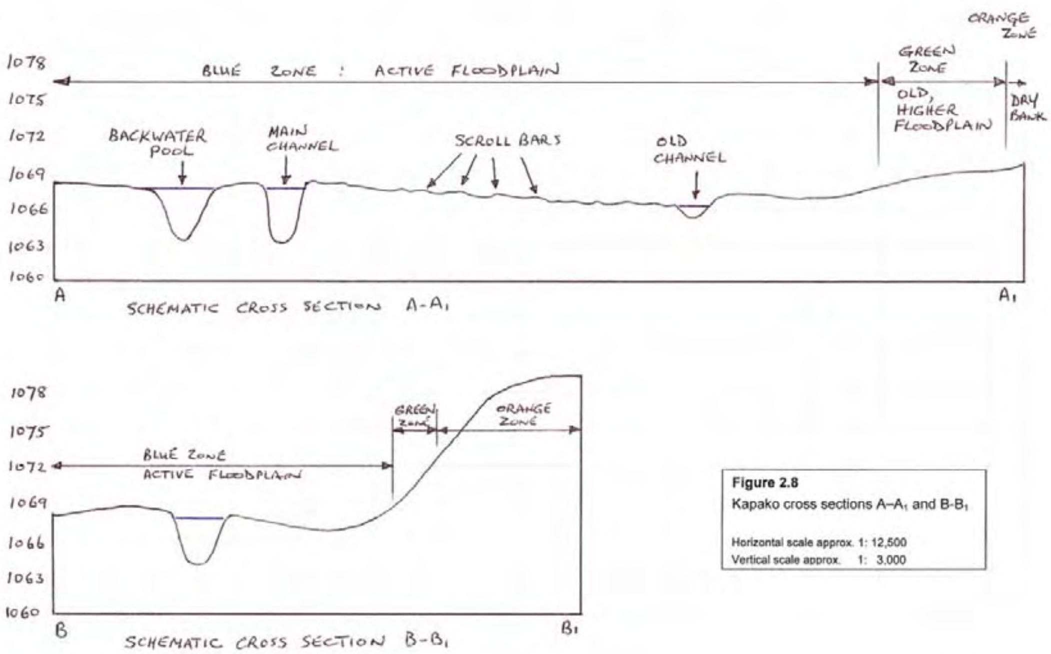


Figure 2. 8: Kapako Cross Section

Photo 1: Aerial view of the western part of Kapako floodplain from the Angolan side looking southwards (low flow, October 2006). When the water overflows its banks, it deposits large amounts of sand in the channel due to reduced flow velocity. As seen here, however, most of the resulting sandbars are not normally exposed. A few pools on the active floodplain remain throughout the year. The dry banks are indicated by the tree line in the background.

Photo 2: A view from the main channel south-eastwards over Blue Zone 1. In the background the dry banks are shown, covered with trees and bush except where they are disturbed by cultivation – note the bare patches at the base. In the foreground the water is flowing about 0,5m deep out of the main channel and into a grassy floodplain.

Photos 1: 1-3

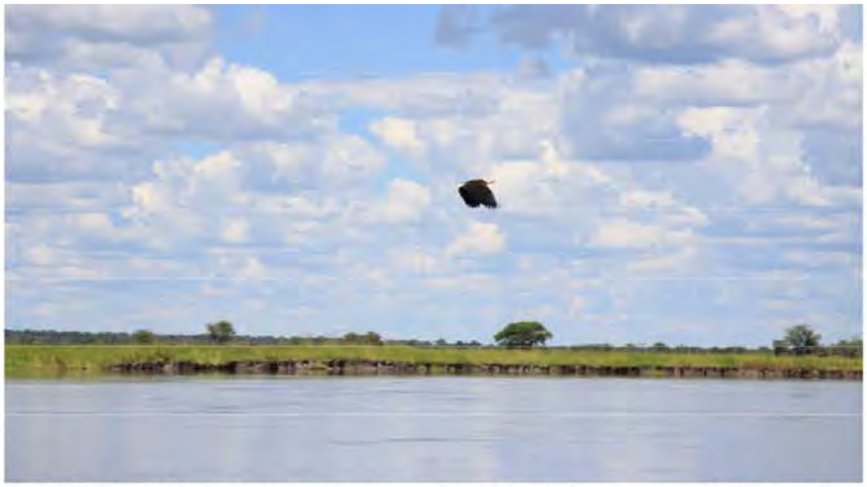


Photo 4: Floodplain in Angola, with dry banks in the distance covered with woodland.

Photo 5: Green zone, active erosion of banks on the outside of the oxbow loop.

Photos 2: 4-6

The floodplains

The flood plains at Kapako are extensive on the Namibian side. At its northern and southern extremities within the study site, the river cuts into the dry banks, but for the most part, ongoing changes in the river course occur within the floodplain. Many scroll bars mark the former courses of the river across the floodplain (Figure 2.7).

The floodplains are covered in wetland grasses and reeds which gives some stability to the landforms in the study area. Patches of trees are very limited in extent, often confined to river banks of the main channel or old channels.

Local human impacts on the geomorphology of the floodplain appear to be very limited. The population is moderately dense on the Namibian side, but sparse on the Angolan side. Most of the human disturbance, such as agriculture occurs outside of the dry banks of the river, and mostly on the Namibian side. Aerial photos show little or no evidence of cultivation on the active floodplain. Cattle graze on the floodplains during the dry season, and fish are caught on the floodplains and main channel. However, there are no human activities on the floodplains that would result in significant impacts on the geomorphological features here. At very limited localities, vehicular access to the river has led to deep erosion of the sandy material over very small areas.

The overall floodplain on the Namibian side of the river varies in width from almost nothing to approximately 2,2km. The exact extent is difficult to determine because the images supplied were cut off such that they do not show the entire length of the dry banks on either side of the river. This is particularly true for the Angolan side. Based on the Namibian 1: 250,000 topographic map (2002) and Figure 2.4, the floodplain is shown to be almost as wide in Angola as on the Namibian side but only slightly further upstream.

The dry banks of the valley are outlined in orange in Figure 2.7. On the Namibian side these banks rise at least 10 metres above the floodplain (typically 1070 m.a.s.l. at the base rising to 1080 m.a.s.l. at the top). The material that comprises these dry banks is Kalahari sand. Because the entire area is comprised of these paleo-dunes, it is reasonable to assume that the dry banks on the Angolan side are of a similar elevation. The dry banks vary in gradient, becoming steepest where they are being actively eroded at the base. In that case the gradient can be as steep as 8%. In Namibia, in the far west of Figure 2.7 it can be seen that the main river channel comes close to eroding the dry banks.

At the base of the dry banks, deposits of “calcrete” are common – overlain by the dune sand. These deposits would have been formed in situ. The river water, although very pure, nevertheless contains low concentrations of salts, silicates and carbonates. The margins of the floodplain (the bases of the dry banks) are subject to seasonal wetting and drying. In this region where average evaporation exceeds average rainfall in every month of the year (Mendelsohn & el Obeid, 2004) there is a net loss of water from the floodplains to the dry banks, followed by evaporative and transpirative losses to the atmosphere. Before intense human settlement and clearing of woodlands, transpiration by large trees probably accounted for water being actively drawn out of the floodplain and into the dry banks – even more so than today. McCarthy, Ellery & Dangerfield (1998) described a similar process on islands in the Okavango Delta. The dissolved load in that water is left behind in the sandy dry banks as carbonate and silicate deposits, loosely referred to here as “calcrete”. Outcrops of this material, which is whitish in colour, are sometimes visible and are sometimes exploited for building material or road construction. It is the author’s observation that these deposits may play a role in limiting the horizontal erosion of the dry banks of the river. However whether or not these calcrete deposits are continuous beneath the dry banks has not been established.

The dry banks vary in condition. Near Kapako they are mostly disturbed to a degree by grazing livestock, people walking down to the river, and in places where they are less steep, they are sometimes cultivated in the rainy season.

In elevation, the floodplain is very flat. From dry bank to dry bank, the elevation typically varies by only 4 metres (from 1066 m.a.s.l. to 1070 m.a.s.l.). Within the floodplain two zones can be identified. This was confirmed during the field trip in the high flow season, February 2009. A comparison between Photo 2 and Photo 5 shows the banks overflowing in the former case and a bank of about 1m in the latter case – reflecting the two discrete levels of floodplains.

The active floodplain zones are outlined in blue in Figure 2.7 and will be referred to as the “Blue Zones”. These zones vary in elevation by only 2m (typically 1066 m.a.s.l. – 1067

m.a.s.l. but occasionally reaching 1068 m.a.s.l) and are repeatedly being reworked by the river during every flood season. Numerous scroll bars mark the progress of former river channels as the river meandered over the floodplain. Blue Zone 1 (Figure 2.7) covers an area of approximately 288ha. The extent of the other active floodplain zones cannot be determined from the cropped images that are available. Some of the deeper old courses become active channels during flooding – e.g. the obvious channel that borders Blue Zone1 on its southern to eastern sides in Figure 2.7.

The older passive, relict floodplain zones are outlined in green in Figure 2.7 and will be referred to as the “Green Zones”. In some places these abut the river, but usually they are separated from the river by an active floodplain zone (indicated in blue). The relict floodplains are at an elevation of at least a metre or two higher than the active floodplain zones (typically 1067 m.a.s.l. to 1068 m.a.s.l. but reaching up to 1069 or 1070 at the base of the dry banks). The relict floodplains appear more homogeneous, the scroll bars having been levelled by rainfall, wind and livestock. These relict floodplains also have a few depressions in them of 1m or 2m depth. In some places the contours suggest these depressions are as low as the level of the main river channel. They can fill with water even if the river does not flood into them. In the case of pools that are somewhat remote from any active channels, the filling of such pools is probably explained by a combination of rainfall and seepage from an elevated groundwater table during the flood season. In other words water seeps through the sandy substrate into the pools, either from rainfall or from the river, or both – while the elevated groundwater table prevents drainage through the sandy substrate.

Various hypotheses are suggested by the author to explain the older and higher “relict” floodplains.

Hypothesis A: In a period of much higher rainfall and greater seasonal extremes, the active floodplains may have been far more extensive. Reduced rainfall and flooding would have shrunk the area of active floodplain. According to regional modelling research at Oxford University, the Kavango Region lies within a climate change zone where warming and drying is the current trend (BBC News / Science-Nature / African sands ‘set for upheaval’ (30 June 2005). However, this trend may be only about 100 years old, which may be too recent to explain the existence of the older floodplain. The ages of these floodplain zones are not known.

Hypothesis B: Tectonic processes probably also played a role. It is known that the Delta area is seismically active and that the Delta lies between two faults trending south-west to northeast while the panhandle is a graben structure between two parallel faults (McCarthy, Green and Franey, 1993; McCarthy et al, 1997; Gumbricht, McCarthy and Merry, 2001; McCarthy et al, 2002). Downward movement of the lower Okavango Basin would also have resulted in slight downward cutting of the river.

Hypothesis C: Changes in the sediment yield from the catchment may also explain the older, higher floodplains – which may represent a period of much greater transport and deposition. This would have to have been followed by a period of reduced transport and deposition so that the River cut into the older floodplain.

Sediment: origins and transport

Both the active and passive floodplains are all made of the same fine sand as the dunes. The Kalahari dunes were deposited under a paleo-climate that was much drier than the present. These dunes are visible on large scale aerial or satellite photos, trending roughly east-west in the northern Kavango Region (Mendelsohn & el Obeid, 2004). They cover the whole Kavango Region, much of southern Angola, Zambia and Botswana. Almost the entire catchment of the Okavango River in Angola is covered in a deep layer of Kalahari sand, and these dunes still form the dry banks of the river valley.

Because of its aeolian origin, the particle size is in a narrow band. Previous studies of the sediment load at Popa Falls (EcoPlan, 2003) indicate that almost 90% is fine sand (Table 2.2) – making the Okavango an extremely unusual river with regard to its sediment load. The river carries very little silt-or clay-sized particles – a fact that explains the clarity of the water. What little clay there is in the system has important implications for soils and soil fertility, but very little importance for landforms because there is so little of it.

Table 2. 2: Grain Size distribution of the dominant sediments

Grain size (mm)	Percentage of sample
>0.43	0.0%
0.25 – 0.43	**89.6%**
0.13 – 0.25	1.4%
0.11 – 0.13	0.8%

These results concur closely with the study by McCarthy (2003) who found that the sediments were predominantly in the range 0.25 – 0.39mm and are transported as bedload. The sand grains are too large to be carried along in suspension, so they are moved along the bed of the river in a process known as saltation. McCarthy (June, 2003) has described the relationship between bedload sediment transport and flow velocity by the following equation.

Qs = 0.15U3.4 where Qs is bedload discharge in kg/m/s and U is average flow velocity in m/s.

No study of sediment transport on the Cubango/Okavango River has been found. All the available studies have been done below the confluence with the Cuito River. The most up to date study of sediment transport was carried out at Divundu / Popa Falls. McCarthy (2003) measured and estimated annual bedload sediment discharge at 117,000 tonnes (about 70,000m3). With regard to suspended sediment, McCarthy & Ellery (1998) estimated the volume passing through Mohembo into the delta to be only 39,000 tonnes.

Since there are no figures available for sediment transport in the Cubango/Okavango River upstream of the confluence with the Cuito, one can only get an indication from the following analysis. The Cubango /Okavango River contributes 55% and the Cuito River 45% of all the water flowing to the Delta (Mendelsohn & el Obeid, 2004). River discharge and gradient are both related to flow velocity. Flow velocity, in turn, has been shown (McCarthy, 2003) to be related to the third power of the average flow velocity. Two implications of these facts need to be considered in making an educated guess as to the relative volumes of sediment contributed by each major tributary.

a. The gradient of the Cubango/Okavango River is steeper than the Cuito for most of its length. Therefore greater discharge and gradient imply higher flow velocity and therefore higher sediment transport.

b. The Cubango/Okavango River has much higher *peak* discharges than the Cuito. Because bedload sediment discharge is related to the cube of the flow velocity, most of the sediment discharge will occur in the flood season.

c. The Cuito River has more extensive wetlands in its lower reaches. This may act to reduce sediment discharge due to greater deposition.

These three factors all act in the same direction, so it is reasonable to assume that the Cubango/Okavango River carries considerably more sediment than the Cuito River.

If the above equation is applied to historical flow data, it should be possible to estimate how much sediment is coming down each of these major tributaries. However, the above equation should be tested by means of direct measurement of sediment transport in these tributaries.

The river channel, levees & scroll bars

The river channel itself varies in width from 60m to 140m at the Kapako site. In February 2009, depths across the channel were recorded by sounding from a boat. It reached 4.2m deep with about 0,5m overflowing its banks at “Site 2” (Figure 2.4).

Figure 2.4 shows satellite images of the Kapako study area in wet and dry seasons. Three locations are indicated by red dots where depths were measured. These were: “Site 1” A transect of the old channel to the south of the floodplain, “Site 2” The main channel and adjacent active floodplain on the south side, “Site 3” A major backwater area upstream of the oxbow loop.

Figure 2.8 shows two schematic cross sections of the floodplain, the location of which is shown in Figure 2.7 by the lines marked A – A1 and B -B1. In cross section A – A1 note the long slope from the main channel to an old channel, with numerous scroll bars that mark the former positions of the old channel. The formation of scroll bars is explained as follows.

Since flow velocity is the most important factor, most of the bedload transport of sand occurs in the flood season. In high flow conditions, when the river is overflowing onto the floodplains, sand is picked up in the water column briefly before being deposited on the bed again. As soon as the water leaves the deep channel and enters the floodplain, its flow velocity drops substantially (due to reduced depth and vegetation). As a result any sand that it is carrying gets deposited immediately on the banks next to the main channel. The river banks are thus slightly higher than the adjacent floodplain. These raised banks are called levees.

In any cross section of a river bend, the water flows faster on the outside of the bend and slower on the inside of the bend. The result is erosion of the outside of the bend and deposition on the inside of the bend. Thus the bend is extended outwards. In this process the levees that were on the inside of the bend remain as scroll bars. These are very evident on the active floodplains (Blue Zones) in Figure 2.7.

During the flood season field trip in February, water was seen overflowing strongly out of the main channel onto the active floodplain (at, Blue Zone 1 in Figure 2.7). A bit further upstream, the over-bank flow has been sufficient, over a number of successive floods, to obliterate the old scroll bars to form a "reverse fan" shape. The water that leaves the main channel on the south side, eventually reaches the old channel that fringes the active floodplain. This flows northwards, and eventually discharges into the main channel downstream of the oxbow loop. Minor flow probably continues in the old channel long after the flood has receded, fed by seepage out of the floodplain. The levees on the south side of the river appear to have been lowered over a bank length of about 1,6km -resulting in overbank flow to feed the old channel mentioned above. If this process continues, it is possible that the old channel could be reactivated.

Backwaters and pools

Remnants of old channels that remain connected to the main channel are visible as backwaters that are filled by river flow backing up into them. Only during the flood season, when the active floodplain is inundated, do these experience some through-flow. The depth of the backwaters will initially be the same as that in the original channel. With time these features become filled in so that their depth gradually decreases.

From west to east in Figure 2.7, these are found at the following locations:

A. A long backwater is found at the base of the dry bank in the south west of the map. Its area is estimated at approximately 50,000 m^2.

B. A deep backwater is adjacent to the upstream side of the oxbow loop. This is of particular interest due to the process of sedimentation that is in progress, which will be discussed later in this section. The area is estimated at 36,000 m^2, and the maximum depth was measured at 4m.

C. Two remnants of an old channel, which is still partially active, intersect the main channel just downstream of the oxbow loop. Their combined area is approximately 31,000 m^2.

D. East of Blue Zone 1 in Figure 2.7 and within the relict floodplain (Green Zone) there is a small **pool** of approximately 7,000 m^2. This is also a remnant of an old channel but it is no longer connected by surface flow. We will refer to this type of feature as a pool rather than a backwater.

Numerous small pools are scattered about on the active floodplain as well. It has not been possible to determine how many of these might hold water throughout the dry season.

Sandbanks and sand movement in the main channel

Figure 2.7 and shows large sandy bedforms that are of interest, particularly upstream of the oxbow loop. These bedforms are the result of sand being moved as "dunes" along the bed of the river. During the dry season some of these bedforms may be exposed as sand banks, but they are dynamic features in the main channel – constantly changing and moving on.

An interesting sedimentary process is evident in backwater B (mentioned above) adjacent to the oxbow loop. Here five or six lobes of sand can be clearly seen pushing into the pool from the southeast. There is a submerged sandbank on the inside of the bend to the southeast, and from there, sand overflows into that backwater during the flood season. This is clear visual evidence of rapid sedimentation in progress.

Slightly further upstream, more extensive submerged sandbanks are seen in Figure 2.7. These are adjacent to the “reverse fan” mentioned above. These banks are due mainly to the large loss of water to the floodplain mentioned above, which would reduce the river’s carrying capacity at that point. A slight widening of the river here would also contribute to reduced flow velocities here.

There are no islands in the main channel within the Kapako study site.

Two alternative scenarios are possible concerning the next stage in channel migration.

In Scenario 1, the oxbow loop would continue to be accentuated by the erosion on the outside of the bends that is in progress. Ultimately the loop would be cut off and the river course shortened here. That is the normal progress of such an oxbow loop.

In the alternative, Scenario 2, the large volumes of water that overflow the east bank into the active floodplain may progress and continue to erode that bank. The old channel that borders Blue Zone 1 (in Figure 2.7) may thus become reactivated as the main channel due to an increasing volume of water that it receives.

At the upstream side of the oxbow loop, active sedimentation of backwater B is in progress as explained above. The loss of water here aggravates the deposition of sediment in the channel. This could have the effect of aggrading the bed of the main channel, reducing flows through the oxbow, and favouring reactivation of the old channel to the east.

Whether the oxbow loop will progress, or the old channel be reactivated, is very hard to predict. A very detailed and precise survey of the whole area using Differential GPS would help to make an assessment of the most likely trends into the next few decades, but predicting changes in such a dynamic landscape can never be an exact science.

Erosion and deposition are continually in a state of dynamic equilibrium – erosion more-orless balancing deposition in the floodplain locally with a net transport of sand from upstream onwards to the Okavango Delta.

Soils on the floodplain

Soils on the floodplain are comprised almost entirely of sand. The river, however does carry very low concentrations of clay and silt sized particles. These remain suspended in the main channel, but when flow velocities are sufficiently reduced, these particles are differentially deposited. For example in reeds or thick grass on the floodplain, where flow velocities are reduced due to friction, muddy patches can be found. Silt, clay, organic matter and dissolved minerals enrich the floodplains each year that they are inundated. In time these get mixed with the sand and the nutrients are leached out and need to be replaced by the next flood. Any activity upstream that prevents flooding or reduces the extent of floodplain inundation will have a detrimental effect on the soils of the floodplain.

Rock structures across the channel

Along the section of the Okavango River that forms the border with Angola, linear rock structures occur at irregular intervals across the river. Elsewhere, these have the appearance of igneous dykes, but in fact are made of hard sandstone. These usually form riffles or minor rapids in the low flow season but are often drowned during the annual flood. Given the high flow conditions at the time of the field trip in February 2009 it was not possible to locate such structures in the area of the Kapako site. However, where they occur, these structures limit the downward erosion of the river bed.

Further research

A detailed land survey with Differential GPS is recommended as a basis for measuring changes in future. This would need to cover the whole study site, from the top of the dry bank on one side to the top of the dry bank on the other side. Highly accurate contours at 0,5m intervals (or better) would be needed. That can only be done in the low-flow season. At the same time records of the processes evident in the field need to be mapped.

Measurement of sediment transport in the Cubango/Okavango River is recommended. It may be possible to estimate the sediment transport from the known relationship between transport and flow velocity on one hand, and historical flow records at Rundu on the other hand. However the equation relating bedload sediment discharge to flow velocity should be verified for the flow conditions at or near Kapako.

2.5 Geomorphological Description : Site 5 Popa Falls

2.5.1 Methods

The site visit to Popa Falls was made on 10-11 February 2009.

Both banks were visited on foot – e.g. at the pump station for the Correctional Services Farm, and within the Popa Falls resort, where small side streams were flowing strongly.

A trip was also made by boat upstream to the riffles above the first group of big islands and along both major channels. Photographs were taken. The water level was high but small areas of rock at the top of Popa Falls were still exposed. Later photos by Mark Paxton on 14 March 2009 showed that the flood had risen much higher and the rocks at the top of the falls were completely covered by water, as well as parts of the islands above and below the falls.

Depths were measured from the boat across the two main channels above the falls. The locations of these depth measurements are shown by the red dots in Figure 2.6. Details are provided in a report by Celeste Espach.

Other information was provided from the author’s experience of the area, which was studied for the Popa Falls Hydro Power Project (Eco.plan 2003), from the satellite images – larger scale prints of the same map as Figure 2.9. The areas of individual islands were measured by a simple squares method. Relevant information from the literature is also summarised in the following sub-section.

2.5.2 Geomorphological Description & Data for Popa Falls

Figure 2.9 shows part of the study site, with the river flowing from west to east. The sandstone structure that forms Popa Falls is orientated north-south in the middle of the satellite photo. GIS generated contours at 1m intervals are provided but they are not accurate because the small contour interval was not supported by the resolution of the satellite photos. For this reason making a useful cross section was not possible.

A digital laser survey with contours at 0,5m intervals was carried out for Water Transfer Consultants (WTC, 2003) for the Popa Falls Hydro Power project. If the study proceeds to a greater level of detail it is recommended that these be obtained for the purpose of accurate contours.

Popa Falls itself is a ridge of hard sandstone that is exposed for almost 1km. Gaps that have eroded through the ridge allow the water to pass so that the entire ridge is completely overtopped only during above-average floods. The drop across the falls is only about 4m during the low flow season and 2,5m during the high flow season. Immediately above and below them are large islands.

Photos 7 – 10 are aerial views of the Popa Falls study site in high and low flow seasons (see photo captions). Photo 11 is a view of the foot of the falls in the low flow season. Photo 12 is an aerial view of the river between Popa Falls and below Divundu Bridge during the flood season, illustrating the bedload transport of sediment.

Photos 13-15, taken from a boat on 10 February 2009, offer closer views of the banks, islands and falls from the river upstream of the falls.

Photos 9 and 15 show that the islands have a base of bedrock. Other photos by Mark Paxton during low flow conditions in October and November 2008 confirm this observation (not included in this report).

The original riverine vegetation was Riverine Forest, which is now scarce along the Okavango River in Namibia. At Site 5, remnants of this habitat are found on the south bank around the Popa Falls wildlife resort and around lodges below the falls. On the north bank more extensive woodlands occur as far as the Divundu Bridge. A small Community Campsite exists close to the falls but the small clearings have made for little disturbance there.

Elsewhere, the banks have been considerably disturbed by cultivation and grazing. Cattle have even grazed most of the fringing reedbeds adjacent to fields. North of the falls a farming project operated by the Department of Correctional Services can be seen on the aerial photos.

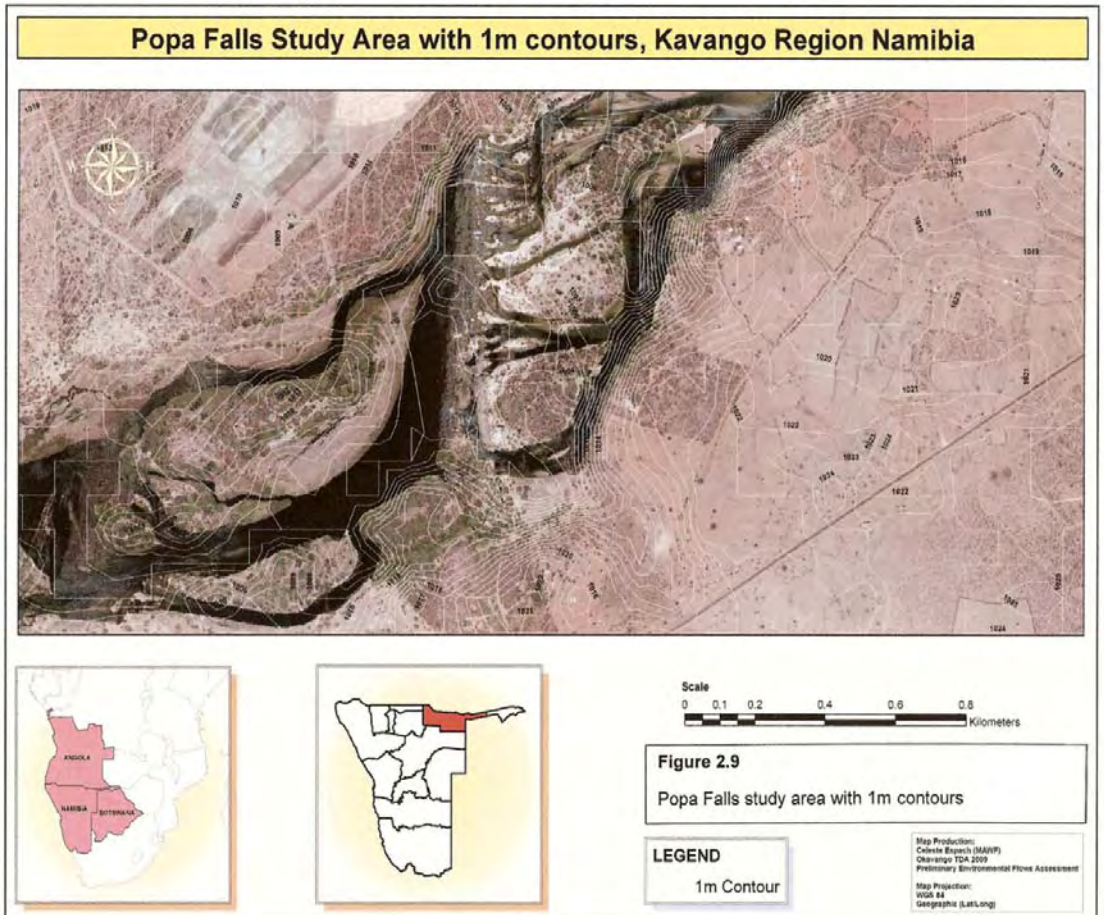


Figure 2. 9: Popa Falls Map with Contours

Photo 7: A view northwards up the Okavango River towards Divundu and beyond. The trans Caprivi road runs left-right in the background. Popa Falls is out of the frame to the right. The photo was taken during the high flow season in 2003.

Photo 8: A view down the river showing Popa Falls at the centre. The road to Mohembo runs to the right. High flow season in 2003.

Photos 3: 7-9

Photo 10: This view to the south over Popa Falls shows submerged sandbars below the falls. Organic matter (dark "shadows") has accumulated on the downstream side of the bedforms. October 2002.

Photo 11: The foot of Popa Falls on the north bank in October 2002 – low flow.

Photo 12: Bedload transport is demonstrated here downstream of Divundu Bridge two weeks after the flood peak in April 2003. The sand is stirred up around rocks due to locally higher velocities, but within 100m it settles out into bedforms and proceeds to move as bedload. The photo shows clearly that the dominant form of transport is bedload transport. Furthermore, the fact that the bed (at 3 –

Photos 4: 10-12

Photo 13: A view of the largest island above the falls from the northern-most channel. Fringing reeds and papyrus protect this island from erosion. February, 2009.

Photo 14: The islands above Popa Falls viewed from upstream of them. Riffles in the mid-right are largely covered in these high flow conditions - February, 2009.

Photo 15: A view down Popa Falls on the south side. The drop varies from

Photos 5: 13-15

Soils outside the dry banks are the typical reddish Kalahari sands. The dry banks support Kalahari woodlands where they have not been cleared for agriculture. Only on the north side, below the falls, there is an old floodplain where exposure to water has reduced the iron and the soil is whitish in colour (refer Photo10).

Upstream from the falls:

Channels

Because of the impounding effect of the sandstone ridge that creates the falls, the river channels are at their deepest just upstream of the falls, even in the low flow season. Because the river is contained by fairly steep dry banks, the lateral spread of water between low and high flow conditions varies little upstream from the falls.

Above the falls there are two main channels and a small distributary channel that flows adjacent to the Popa Falls wildlife resort on the south bank. The widths of these three channels from north to south are typically 50m, 100m, and 30m respectively. They all converge just above the falls.

Depth measurements were made on 10 February 2009 across the two larger channels at the locations indicated by the red dots in Figure 2.6. Depths of up to 4.5m were measured in the largest (middle) channel, and of only 2.2m in the northern channel.

An additional, much smaller channel also exists at Popa Falls wildlife resort but it is concealed on Figure 2.6 by overhanging trees. This small side-stream has much steeper gradients and flows over rocky substrates with small rapids, joining the river again only below the falls.

There are no big pools in the Popa Falls study site. A few small pools, alternating with rapids, occur on the small side-stream through the wildlife resort that was mentioned above. There are also no real backwaters – all the channels are active.

Levels are very difficult to determine from the inaccurate contours on the orthophoto. However, the (low flow) water level was at approximately 1002 – 1003 m.a.s.l. Upstream of the falls, the tree line on the north bank suggests that the dry banks are at about 1007 – 1008 m.a.s.l. – i.e. about 5m above the low flow level. The dry banks rise to 1020 m.a.s.l. within 400m on the south side and reach that level within 800m on the north side.

Islands

The islands above the falls are very stable for two reasons. Firstly they have a base of hard sandstone, with sand on top. Secondly, they are stabilised by vegetation – trees in the interior and sometimes on the margins, while reeds and/or papyrus stabilise the margins of the islands.

The four large islands upstream from the falls measure, in approximate area, 23.0ha, 3.1ha, 1.9ha, and 7.0ha. These areas of the islands are listed in sequence from north to south respectively.

Floodplains

Unlike Kapako, there is very little area that can be called floodplain in this study site. The exceptions are a few small areas of bright green floodplains in Photos 7, 8 & 9 that are more or less permanently wet. These are covered in papyrus, or reeds and papyrus. There are no grassy floodplains here. The tree line suggests an upper limit of historical flooding.

Conditions above the falls appear to be in a state of equilibrium. No evidence was found of progressive (net) erosion or deposition in this area. The rate of change at the study site is slow, compared to Kapako.

Downstream from the falls:

Islands

The sandstone ridge that forms Popa Falls also forms the base of islands immediately below the falls. Channels, incised into the sandstone, separate a number of islands. Sand has been deposited on top of these islands and is stabilised by vegetation, including reeds and trees. The three largest islands immediately below the falls measure approximately 8.2ha, 5.8ha, and 7.0ha.

Channels, Sandbars & Floodplains

The channels below the falls are less well defined than upstream as the deposition of sand results in constantly changing bedforms (see Photo 10).

Extensive sandbanks form below the falls as a result of the drop in flow velocity. In this area these sandbanks are seldom exposed. However, more extensive banks form downstream, where they become more exposed in the low flow season and are important for breeding African skimmers.

Below the falls, the river is contained on its south bank by wooded banks a few metres high, but the north bank has small areas of both active and passive floodplains. In the foreground of Photo 10, the active floodplain is indicated by the area that is obviously wet, without bush or trees. A slightly higher floodplain adjacent to that is indicated by whitish soil with scattered bush and trees. The fact that the trees there are still small suggests that a major flood event removed larger trees at some stage in the last decade or two. The dry bank is indicated by a clear transition from white soil and sparse trees to reddish soil and densely spaced trees – next to the wing strut in Photo 10. The area of this floodplain was not determined because it is omitted from the satellite images that were supplied.

Sediment transport

The Okavango River is well known for the unusual nature of its sediment load. It is characterised by low dissolved solids, low turbidity (even in the flood season) and bedload transport of most of its solid load. Photo 10 shows how clear the water is at low flow, and Photo 12 shows the river bed some 3 – 4m deep during an average flood.

McCarthy and Ellery (1998) studied the load carried by the River into the Delta at Mohembo. They estimated the following figures, which can be assumed to be the same as for Popa Falls as there are no significant inflows between Popa and Mohembo:

a. Total dissolved solute load: 380,000 tonnes per year,
b. Total bedload transport: 170,000 tonnes per year,
c. Total suspended sediment: 39,000 tonnes per year.

The dissolved load is of little importance to geomorphology in Namibia and it simply passes through the system. (It does become important in landforms in the Delta, however).

The low level of suspended load is very unusual for such a large river, consisting mainly of clay-sized particles, with some organic matter. A little of the clay and mud sized particles gets trapped in reedbeds, where muddy patches can be found. However there is no major deposition of clay or silt-sized particles in progress in the Popa Falls study area.

By far the major part of the solid load is fine Kalahari sand in the range 0.25 – 0.43mm. Particles of this size are too large to be carried in suspension. As evidence of this, Photo 12 shows sand moving as “dunes” on the bed of the river during an average flood (April 2003). Where flow velocities increase locally around rocks, the sand is stirred up and carried in suspension for about 50 before settling out again and resuming its progress as bedload.

McCarthy and Ellery (1998) measured bedload transport and estimated a total transport of 170,000 tonnes entering the Delta at Mohembo. This estimate was later revised by McCarthy (2003) during a study for the Popa Falls hydro power project, where longer term hydrological records were used.

As part of the Premilinary Environmental Assessment for the proposed hydro power project at Popa Falls (Eco.plan 2003), McCarthy (2003) undertook a specialist study and measurement of sediment transport from 24 to 27 April 2003 – close to the peak flow period for that year. The site used was approximately 300m downstream from the Divundu bridge and approximately 4,4km upstream from Popa Falls. This was a relatively straight section of river, with few rocks and an active channel width of 152m. The depth across the channel at the time varied from about 3m to 4m, with an average depth of 3.4m. The bedload sediment was comprised mostly of fine sand with particle size in the narrow range 0.25 – 0.43mm.

Suspended sediment was at a very low level, such that visibility was 2 – 3 metres below the surface of the river. Flow velocity was measured at intervals and depths across the channel and found to average 0.60 m3/s across the entire active channel. The discharge was calculated at 313 m3/s.

McCarthy, Stanisstreet and Cairncross (1991) had previously established a relationship between flow velocity and bedload discharge of sediment, which was further refined by McCarthy, Ellery, and Stanistreet (1992). As mentioned under the section on Kapako, above, this relationship is defined by the equation:

Qs = 0.154U3.40 where Qs is bedload discharge per unit width (kg/m/s) and U is the flow velocity (m/s).

McCarthy (2003) found that this relationship held for the study upstream from Popa Falls as well. He used 30-year historical flow data provided by the Namibian Directorate of Water Affairs to calculate the annual bedload sediment discharge. The result was a revised estimate of:

Total bedload transport: 117,000 tonnes (or about 70,000 m^3)

Bedload sediment transport is notoriously difficult to measure reliably. Yuquian (1989) noted that the Helley-Smith bedload sampler (used by McCarthy) is one of the better methods to achieve this, but recommended that the instrument be calibrated in situ. In order to gain an independent measurement, Eco.plan (2003) commissioned the Marine GeoScience Unit, Council for GeoScience, South Africa to undertake separate measurements using side-scan sonar and high resolution bathymetry. Coles (2003) presented the results. The method enabled the bedforms to be imaged, and measured to an accuracy of 2cm. Three sets of data were made over a period of 28 hours. Then computer programmes were used to compare these data sets and arrive at a measurement of sediment transport. The measured transport was 49.94 m3/day during the measurement period 25 to 27 April 2003. However, the main disadvantage of this method is that it can only measure transport in that part of the river where large bedforms exist. The data had to be interpolated across the rest of the channel, where bedforms were not prominent. The resulting estimate was 113m3/day for the river discharge at the time. In the end, the limitations of this method proved to be a significant disadvantage in measuring sediment transport, but it did provide an accurate bathymetric survey of the bedforms. For comparison, Mc Carthy (2003) measured 197m3/day but this was over the full width of the active channel.

The deep channels immediately upstream of the falls are thought to be the result of an increased hydraulic gradient there so that the bed is locally scoured by turbulence during high flows. The main channels reached depths of 4.5m in February, 2003. Below the falls, however, the hydraulic gradient drops and deposition occurs forming the large bedforms as explained above.

Where bedforms can be seen (e.g. below the falls in Photo 10, and upstream in Photo 12) organic sediment (dark material appearing like shadows) collects on the downstream side of bedforms.

Both bedload and suspended sediment appear to be in a state of dynamic equilibrium in the Popa Falls area. Erosion of sediment is balanced by deposition, while erosion of bedrock is very slow due to the hard nature of the sandstone.

2.6 Habitat integrity of the sites in Namibia

The geomorphological features of both the Kapako and Popa Falls sites have been very little affected by human activities to date. One exception may be the relict floodplains at Kapako where cultivation and livestock has probably accelerated the natural process of flattening of the original scroll bars due to rainfall, wind and soil organisms.

Vegetation, however will have been modified as a result of cultivation on the higher relict floodplains, and cutting of firewood and timber (stands of larger trees may have been more common years ago).
The river and floodplains still support a wide diversity of bird species including some red data species (Paxton, pers comm.), and populations appear to be in a relatively good state considering that there is a substantial human population living adjacent to the floodplains.

3 IDENTIFICATION OF INDICATORS AND FLOW CATEGORIES

3.1 Indicators

3.1.1 Introduction

Biophysical indicators are discipline-specific attributes of the river system that respond to a change in river flow by changing in their:
abundance;
concentration; or
extent (area).
Social indicators are attributes of the social structures linked to the river that respond to changes in the availability of riverine resources (as described by the biophysical indicators).
The indicators are used to characterise the current situation and changes that could occur with development-driven flow changes.
Within any one biophysical discipline, key attributes can be grouped if they are expected to respond in the same way to the flow regime of the river. By example, fish species that all move on to floodplains at about the same time and for the same kinds of breeding or feeding reasons could be grouped as Fish Guild X.

3.1.2 Indicator list for Geomorphology

In order to cover the major characteristics of the river system and its users many indicators may be deemed necessary. For any one EF site, however, the number of indicators is limited to ten (or fewer) in order to make the process manageable. The full list of indicators was developed collaboratively by the country representatives for the discipline – in Namibia this was done by Colin Christian with input from Sophie Simmonds and Mark Rountree - and is provided in **Table 3.1** below.

Indicator Number	Indicator name	Sites represented –no more than ten indicators per site	
		Kapako 4	Popa Falls 5
1	Extent of exposed rocky habitat in main channels.	No	Yes
2	Extent of coarse sediments on the bed	No	No
3	Cross sectional area of bank full channel	Yes	Yes
4	Extent of backwater areas (slow/no flow areas)	Yes	No
5	Extent of exposed sandbars at low flow	No	Yes
6	Extent of vegetated islands	No	Yes
7	Percentage silt & clay in the top 30cm of the floodplain	Yes	No
8	Extent of the floodplain flooded each wet season	Yes	No
9	Extent of inundated pools/pans on floodplain at the end of the dry season	Yes	No
10	Extent of cut banks along the active channel	Yes	No

Table 3. 1: List of indicators

3.1.3 Description and location of indicators

(Geomorphology) Indicator 1

Name: **Extent of exposed rocky habitat in main channels**
Description: Along the length of the Namibian reach of the river, there are numerous rocky structures that cross the river. They are seldom or never exposed on floodplains. These low rocky ridges form riffles or rapids in the channels.

At the Kapako site a minor riffle suggested such a feature on the east side of the oxbow loop during the high flow field trip in February 2009. However, this was not considered a significant feature and was further ignored.

Popa Falls is a very prominent exposure of one of these rocky ridges, accentuated by faulting. Smaller ridges occur both above and below the falls, where they form riffles and are visible on aerial photos, at least in low flow conditions. Rock pratincoles use this habitat for breeding in the low flow season, and for feeding for as long as the water is low enough.

Flow-related location: The rocky sandstone outcrops have similar directional trends e.g. north-east to south-west. This suggests that they are the product of geological processes on a large scale. It is therefore reasonable to assume that they underlie the floodplains and

Kalahari dunes as well. In the main channels they are often covered by water during the high flow season, but partially exposed during the low flow season. In small side channels they may be seasonally covered by water or sediment.

Known water needs: Low flow seasons are necessary to expose these rocky structures – e.g. for nesting Pratincoles. Medium and high flow seasons are necessary to inundate large areas of rock for certain species of catfish that prefer rapids.

(Geomorphology) Indicator 2

Name: **Extent of coarse sediments on the bed**
Description:
The sediment in the Namibian reach of the river is typically fine sand of aeolian origin (Kalahari sand) that has been reworked by water. The particle size range is 0.25 to 0.4mm. Coarser sediments are almost entirely absent.

Occasional large pebbles may occur where
they have become lodged in holes in the river bed, but we have not found any place where these form a different habitat from the usual sandy bed. Coarse sediments were therefore rejected as a potential indicator in the Namibian reaches. They may occur only in the headwaters in Angola.

(Geomorphology) Indicator 3

Name: **Cross sectional area of bank full channel**
Description: The cross sectional area of the active channels between clearly defined banks that mark the edge of the floodplain, or in some cases the edge of dry banks. For most of the Namibian reaches of the river there is a single channel about 150m wide and an estimated maximum depth of some 4 metres at bank full capacity, shallowing towards the inside of the bends.

Flow related location: Edges of clearly defined main channels.

Known water needs: Channel cross section is a function of high flow conditions. If peak flows are regularly increased, channel enlargement can be expected. This can happen rapidly if the peak flows exceed the historical maxima. If peak flows are regularly decreased, for example, due to dams upstream, the channel will gradually get narrower, or a misfit river will form. Vegetation (e.g. reeds) will probably stabilise the banks and sandbanks. During the (reduced) high flow seasons, sediment will get trapped by this vegetation, thus building up part of the bed of the river. In time the channel will get shallower and narrower.

(Geomorphology) Indicator 4

Name: **Extent of backwater areas (slow / no flow areas connected to the main channels)**
Description: The backwaters are sections of old channels that are directly connected to the main channel.

As water levels in the main channel rise and fall, the backwaters respond immediately in the same way. The backwaters are usually quite well defined at Kapako, and their slopes – being originally river banks – are fairly steep. Therefore, the area of the backwaters does not increase a lot when the floods are high.

(Note that there are significant backwater pools in bedrock in the Mukwe-Andara-Divundu section of the river and some of minor lesser extent in the side channels just upstream of Popa Falls. However, these are excluded from our definition here.)

Known water needs: Since the backwaters are, by our definition, connected to the main channels, this connection needs to be maintained. If that connection is blocked, the backwaters would become pools as defined under indicator No.9, below.

(Geomorphology) Indicator 5

Name: **Extent of exposed sandbars at low flow**
Description: Sandbars are sometimes exposed in the river channels during the low flow season. The extent of such sandbars could increase or decrease in response to changes in flow of water and sediment discharge.

Flow related location: Sandbars form where a reduction in flow velocity occurs for some reason. Most often they form on the inside of bends, but extensive bars also occur immediately below Popa Falls and downstream near Mahangu. These are exposed during the low-flow season. They are important for breeding African skimmers in the low flow season. The high season field trip at Kapako indicated that the sandbars are inundated at high flows, but aerial photos show some exposed sand bars during low flow conditions.
If sediment is impounded upstream, e.g. by a dam or weir, but the flow of water is unaltered, then erosion of the river bed and loss of sand bars can be expected.

Known water needs: Sandbars are a function of the complex interaction of water flows and sediment transport. It would be impossible to make predictions based on changes in water flow alone. If sediment is impounded without a change in water flow, the sediment-hungry river will pick up sediment until its carrying capacity is reached. The extent of erosion downstream depends on distance, flow velocity, slope and the amount of sediment available downstream from the impoundment. If water flow increases without an increase in the supply of sediment, then erosion can be expected downstream, resulting in the removal of sandbars. Conversely, if water flows decrease without the supply of sediment decreasing, deposition will occur downstream of the perturbation and sandbars can be expected to grow.
NB. For the purposes of generating the response curves, the supply of sediment was ignored because the model was unable to take that factor into account independently of the flow of water. The response curves therefore do not reflect the impacts of sediment-trapping dams or

weirs. This is a significant shortcoming of the approach that would need to be addressed in future studies.

(Geomorphology) Indicator 6

Name: **Extent of vegetated islands**
Description: In areas dominated by depositional features, such as extensive floodplains, islands are usually comprised only of sediment (mainly fine sand). However, the islands immediately above and below Popa Falls are comprised of sand on a base of bedrock. (More extensive islands of this type occur in the Mukwe-Andara-Divundu section of the river, which are not considered here.)

Flow related location: Islands, whether all-sand or sand-on-bedrock occur in the main channel. They are, however absent from the Kapako site.

Known water needs: Islands that consist entirely of sand probably started as sandbanks that were shallow enough for long enough so that vegetation such as reeds could become established on them. Thereafter, their elevation could be increased due to floods that deposited sand on top of the island where it was trapped by vegetation. Thus the island grew in elevation, and possibly in area as well. All-sand islands may need normal flooding in order to be maintained as islands. Conversely, excessively high floods would erode such islands, especially if the high levels are maintained for longer than normal.
The origin of sand-on-bedrock islands is less clear.

They may have formed in a similar way to that described above. Alternatively, they may be remnants of dunes that were colonised by riverine woody vegetation and never eroded. They appear to be higher relative to water levels and they support woodlands, which suggests that they are not fully inundated by floods. These islands would be at risk of erosion if peak flows are significantly increased above historical levels. If the islands were partially submerged, e.g. in an impoundment, then the margins of the islands would also be eroded due to water loosening the sand and possibly due to die-off of some less hygrophilous trees along the margins.

Reduction in flow should not affect the sand-on-rock islands, as long as there was enough moisture from the river to sustain the vegetation. In the case of all-sand islands reduction in flow consistently in high and low flow seasons can be expected to result in island growth.

(Geomorphology) Indicator 7

Name: **Percentage of silts and clays in the top 30cm of the floodplain on active floodplains**

Description: An increase or decrease in the percentage of clay and silt-sized particles in the top 30cm of soil on the floodplains. The floodplains are comprised mainly of sand in the particle size range approximately 0.25 – 0.4mm. Clays (< 2µ) and silt (2 -53µ) also occur, but in very low concentrations in the Okavango River. Some of this fine material is deposited on the floodplains during overbank flooding. Despite low concentrations, the volumes of clay and silt can be considerable due to the large volume of water moving slowly over a floodplain. If flooding does not occur, or is reduced in extent, then one could expect a gradual loss of these fine particles in the top 30cm as this material is mixed in by cattle, soil organisms, or blown away by wind in the dry season.
Flow related location: The fine sand that comprises most of the River's solid load moves by the process of saltation and is not truly suspended in the water column. On the other hand, the finer clay and silt-sized particles are easily suspended in the water column. For them to be

deposited requires a substantial reduction in flow velocity. This does not occur in the main channel except where eddies occur in pockets or reedbeds along the channel margins. However, as the water spreads out over the floodplains, its flow velocity drops and vegetation such as grasses help to trap the clay particles.

Known water needs: It is assumed that the percentage of silts and clays in the top 30cm of soil on the floodplains will decrease during the dry season as it is mixed downwards by soil organisms or blown away by wind. They would only be replenished during subsequent overbank flooding onto the floodplains.

(Geomorphology) Indicator 8

Name: **Extent of the floodplain inundated during each wet season**

At Kapako there are extensive floodplain areas, which can be divided into two zones. The active floodplains display distinct scroll bars and are understood to have been flooded every year for which flow records exist. There are also extensive floodplains at a level of 0.5m -1m higher than the active floodplains. These higher relict floodplains do not display scroll bars, which suggests that they are no longer flooded, with the possible exception of the highest floods on record. Higher floodplains are also common elsewhere along the River in Namibia.

They could represent the result of tectonic processes, or reduced sediment yield in the catchment for a period that resulted in downcutting of the river by 0.5m – 1m.
The following discussion relates to the active floodplains. The most extensive one lies to the south of the oxbow loop. Here the floodplain drops away from the present channel by approximately 2m over about 1.3km to an older channel. The river is contained by levees along its banks. As the flood rises and overtops those levees, the water flows over almost the entire floodplain, with the exception of a few higher localities.

On the floodplains at Kapako, it is assumed that most of the active floodplain will be inundated once the levees overtop. More accurate contour maps would be needed to determine the exact extent of inundation for any given flow scenario.

There are no significant floodplain areas at Popa Falls, only a few small areas covered by reeds or papyrus.

(Geomorphology) Indicator 9

Name: **Extent of inundated pools / pans on floodplains**

Description: An increase or decrease in the extent of inundated pools on the floodplain – at the end of the dry season.

Flow related location: Perennial pools occur mainly on the active floodplain, where they are understood as remnants of old river channels. Small pools may be found between scroll bars, or large pools found in old channels that have been abandoned by the river. In the case of the latter, the width of the old river channel is reflected in the width of the pool. On active floodplains, these pools fill with water as a result of river level rising and spilling over onto the floodplains. It is assumed that the pools contain some water throughout the dry season due to the permeability of the fine sand, allowing ingress of groundwater from the river channel into the floodplain throughout the year. This would need to be confirmed by accurately surveying

the surface levels of pools in relation to the river stage at any time in the low flow season, and doing groundwater surveys.
In the case of pools on higher and older relic floodplains filling is more likely to be from rainfall, but it is not known whether these pools persist throughout the dry season. Even if infiltration is impeded by a clay or calcrete horizon, the pools are likely to dry out due to high evaporation rates.

Such pools do not occur at Popa Falls due to the absence of significant floodplain areas.

Known water needs: If the assumption is correct that the perennial pools on the active floodplain are maintained by seepage, then their levels will be related to the level of the river (probably lower than the river level due to evaporation). However, it may be that the pools need to be filled during overbank flooding, and that they then retain water due to an impermeable lining of fine material.

To prevent stagnation, annual flushing of pools by flooding is probably desirable. However, flooding also means that sediment is deposited in these pools, gradually reducing their depth. In time all pools will be in-filled, but others will have formed where the river has meandered. The filling in of pools and creation of new ox-bows and cut-off meanders is likely to occur over a longer timescale than is considered for this study.

(Geomorphology) Indicator 10

Name: **Extent of cut banks along the active channel**

Description: Active erosion of banks produces steep (near-vertical) banks, which gradually retreat. The horizontal length of such cut banks is the proposed indicator of increased erosion.

Flow related location: Bank erosion occurs on the outside of bends, where the flow velocity is higher. Tighter bends are more prone to bank erosion. Cut banks occur where there is no rock control present. There are cut banks in several places at Kapako. However, at Popa Falls, the banks are well protected by vegetation – reeds, papyrus or trees, so that bank cutting is rare.

Known water needs: Bank erosion is primarily a function of high flow periods. Bank collapse may also occur during the Transition stage 2, if the water level drops rapidly. This is because the sandy banks are infiltrated with water, and as the water level drops rapidly, the water flowing out at the base of the bank combined with the saturated weight of the bank soil causes bank failure and slumping.

3.2 Flow categories – river sites

One of the main assumptions underlying the EF process to be used in the TDA is that it is possible to identify parts of the flow regime that are ecologically relevant in different ways and to describe their nature using the historical hydrological record. Thus, one of the first steps in the EFA process, for any river, is to consult with local river ecologists to identify these ecologically most important flow categories. This process was followed at the Preparation Workshop in September 2008 and four flow categories were agreed on for the Okavango Basin river sites:

Dry season Transitional Season 1 Flood Season Transitional Season 2.

Tentative seasonal divisions for river Sites 4 and 5 are shown in Figure 3.1 and 3.2. These seasonal divisions were formalised by the project hydrological team in the form of hydrological rules in the hydrological model. In the interim they provide useful insights into the flow regime of the river system. Figure 3.1 shows the flow of the Cubango / Okavango River at Rundu (just downstream from Kapako). Figure 3.2 shows the flow of the Okavango River downstream from the confluence with its major tributary the Cuito River.

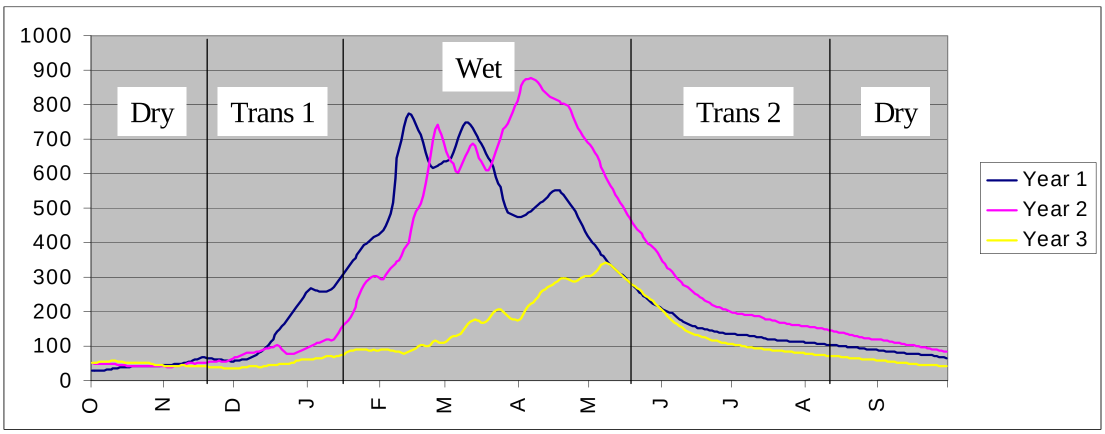


Figure 3. 1:Three representative years for Site 4: Okavango River at Kapako (hydrological data from Rundu), illustrating the approximate division of the flow regime into four flow seasons

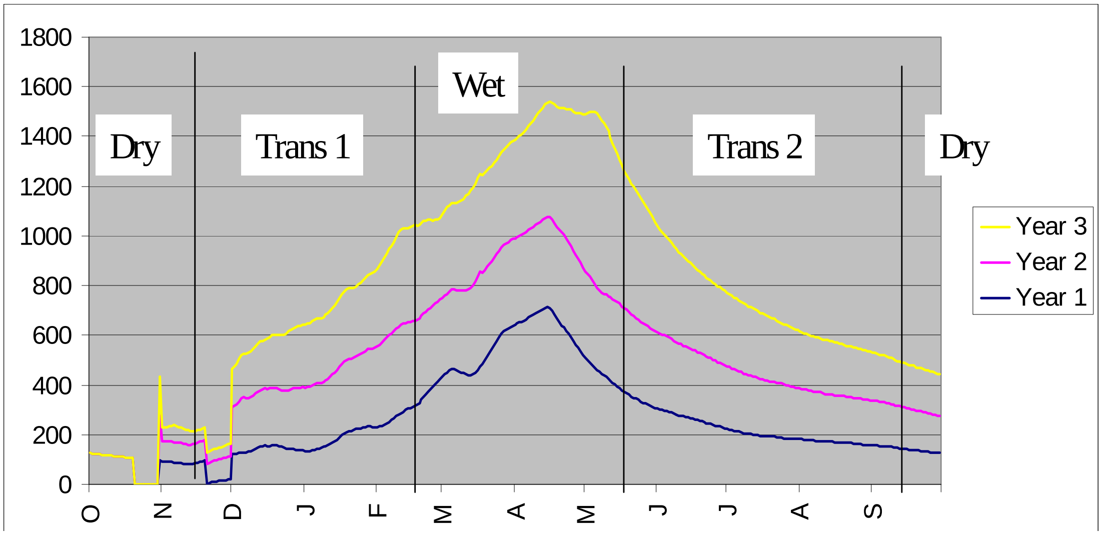


Figure 3. 2:Three representative years for Site 5: Okavango River at Popa (hydrological data from Mukwe), illustrating the approximate division of the flow regime into four flow seasons

Table 3.2 poses the **nine main questions that are** initially expected to be related to these flow seasons. These questions were considered in the Knowledge Capture Workshop in Windhoek in March/April 2009 and where relevant, the answers were provided in the form of completed response curves (not included in this report).
This exercise was carried out for each indicator, first at Kapako (Site 4) and then at Popa Falls (Site 5).

Question number	Season	Response of Indicator 1… if:
1	Dry Season	Onset is earlier or later than natural mode/average.
2		Water levels are higher or lower than natural mode/average.
3		Extends longer than natural mode/average
4	Transition 1	Duration is longer or shorter than natural mode/average i.e. hydrograph is steeper or shallower.
5		Flows are more or less variable than natural mode/average and range.
6	Flood season	Onset is earlier or later than natural mode/average synchronisation with rain may be changed.
7		Natural proportion of different types of flood year changed.
8	Transition 2	Onset is earlier or later than natural mode/average.
9		Duration is longer or shorter than natural mode/average –i.e. hydrograph is steeper or shallower.

Table 3. 2: Questions addressed at the Knowledge Capture Workshop, per indicator per site. In all cases, 'natural' embraces the full range of natural variability

4 LITERATURE REVIEW

4.1 Introduction

The literature review for this report was intended to concentrate mainly on the identified indicators – and relate mainly to the Namibian section of the River. In fact, none of the literature found relates directly to the indicators. General references were found that relate to the nature of sediments, and sediment transport rates – but only for the river below the confluence with the Cuito River.
The literature search for this report was conducted by various means:

a. Discussions with an expert in geomorphology and sedimentology relating to the Okavango Basin -Prof T. McCarthy of WITS University,
b. Review of books on the Okavango River by Mendelsohn and el Obeid (2004) and Mendelsohn (2006),
c. Review of papers of the Okavango Research Group, WITS University,
d. Searches in Libraries in Windhoek, especially the DRFN library,
e. Internet web search,
f. Review of original field data relating to soils.

The results turned up very little of direct relevance to this component report. No detailed studies were found on the subject of geomorphology on the Namibian portion of Okavango River.

4.2 Literature on Geomorphology and Sedimentology

Mendelsohn et al (2002), Mendelsohn & el Obeid (2004) provide very useful general data on the flows of the various river tributaries, climatic information (e.g. regarding evaporation relative to rainfall), maps, diagrams and photographs. However there is no specific information available on geomorphology or the processes that give rise to the landforms observed along the river.

There is a great deal of literature available on the geomorphology of the Okavango Delta and panhandle, some of which is applicable to the lower reaches of the river in Namibia. The work of the Okavango Research Group at the University of Witwatersrand (WITS) is particularly valuable in this regard. Their research papers have been published by WITS in seven volumes (ORG, 1986 to 2005). It is expected that the Botswana team for the TDA and EFS will cover this literature, so only that which is of specific relevance to the Namibian reaches of the river will be covered here.

McCarthy, Green and Franey (1993), McCarthy et al (1997), Gumbricht, McCarthy and Merry (2001), and McCarthy et al (2002) have described the tectonic processes and faulting affecting the Delta and Panhandle, which explains the existence of the inland Okavango Delta.

McCarthy, Ellery & Dangerfield (1998) have described the role of trees on islands in removing dissolved load from the waters of the Delta, concentrating this load in islands as a result of transpiration processes, and the resulting growth in small islands. This may be of some relevance in the margins of the floodplains in Namibia – at the foot of the dry banks, where calcrete is formed, but there is no research available on this. Islands in the river, for instance near Andara, and above and below Popa Falls, appear to be built of sand on a base of bedrock, but no studies have been found that investigate the possible concentration of salts here.

The author's experience in the field has found a hint of such processes in the form of slightly white accretions of salts on floodplains. The most striking example is below Rundu, where a plantation of Eucalyptus trees exists (Eco.plan, 2001). The trees are some 20 years old but are not growing as well as this species normally does. A clue to the reason for this is found around the bases of these trees. Here white accretions of salts are found – evidence of strong transpirative action that concentrates carbonates and silicates in the soil around the trees. Eucalyptus trees are known for high rates of transpiration. Whether trees and transpiration may play a role on some of the islands near Andara and Popa Falls is unknown.

The likely effects of climate change in the Kavango Region and near regions in neighbouring countries has been modeled and reported in BBC News / Science-Nature / African sands 'set for upheaval' (30 June 2005).

The most recent research on the Namibian portion of the river was carried out for the Popa Falls Hydro Power Project Environmental Assessment. (Eco.plan, 2003). The appendices include three specialist reports that relate to geomorphology and sediment transport. McCarthy (2003) gave an account of the measurement and estimation of sediment transport at Divundu, about 4km upstream from Popa Falls. McCarthy (2003) provided a very useful, concise account of the ecological importance of sediment transport for the Delta. This report drew on work done by the McCarthy, Ellery and others in the Okavango Research Group, WITS University (ORG, 1986 to 2005).

McCarthy & Ellery (1998) measured sediment transport at Mohembo and estimated that on average 170,000 tonnes of bedload sediment (fine sand in the range 0.25 – 0.4mm) was transported into the Delta each year. The study also estimated that about 39,000 tonnes of suspended sediment (e.g. clay, mud and organic material) and about 380,000 tonnes of dissolved load entered the Delta each year.

McCarthy (2003), on the basis of work done for the Popa Falls Hydro Power EIA, revised this estimate of bedload transport down to 117,000 tonnes (or about 70,000 m^3).

No other literature was found that has particular relevance to the geomorphology on the Namibian portion of the Okavango River.

Some general references were found on the Internet, which may help to provide some understanding of the subject, but applicability may be limited.

4.3 Information on Soils

4.3.1 Soils in relation to geomorphological units and vegetation

A brief description of soils is given by CCA (2007) for the Kavango Biofuel project proposal.

The soils along the Namibian section of the River are very weakly developed and consist mainly of fine sand. They are all derived from Kalahari sands, which were aeolian deposits during a much drier palaeo-climate. This sand is comprised mainly of quartz and is very low in nutrients. In the current wetter era, some of that material was re-worked by the River, while vegetation colonized the sand dunes and stabilized them.

Outside of the dry banks of the River, the Kalahari dunes are/were covered dry Kalahari Woodland. This woodland receives its water by rainfall only and is drought-deciduous. The fine sand here is often reddish in colour due to coating of the sand grains with a little iron oxide (refer **Photos 16 & 17**).

Photo 16: Kalahari palaeo-dunes are colonised by Kalahari woodlands until cleared for cultivation. Note the reddish coloured soils.

Photo 17: Soils outside the dry bank are reddish, compared to floodplain soils, which are whitish because the iron oxide coating on the quartz sand grains has been reduced by contact with water.

Photo 18: Soil in woodlands may also be whitish, but it also originates from Kalahari dunes.

Photos 6: 16-18

Photo 19: Floodplains support hygrophilous grasses, reeds and sedges where trees cannot grow due to long periods of inundation. On floodplains clay particles in the soil are replenished during flooding. Deposition is encouraged by the vegetation.

Photo 20: Omurambas may be inundated for weeks or months during the wet season. Only grasses (in this case) or wetland vegetation can grow in these conditions.

Photo 21: Cultivation exposes soils to wind erosion. Especially during the hot dry months in spring, dust storms result as the fine particles are removed from the soils.

Photos by C.Christian, October 2006

Photos 7: 19-21

On a narrow margin along the river banks and islands, evergreen Riverine Forest was dominant, but has been largely cleared by people. The most intact section of this habitat lies in the Mukwe-Andara-Popa Falls section of the River. This type of forest derives much of its water from the river and seepage so that evergreen species are able to survive. Close to the river and on the floodplains, the soil is whitish – the iron oxide having been reduced as a result of contact with water (Photo 17).

Soil in woodlands may also be whitish in colour. Here the loss of iron oxides is assumed to be the result of organic acids produced by plants and detritus in the soil (Photo 18).

On floodplains and omurambas, where trees were not able to grow due to flooding, various grasses and hygrophilous grasses dominate (Photo 19). Omurambas, where water stands for up to a few weeks during the wet season, also do not permit the growth of trees (Photo 20).

Mixed with the fine Kalahari Sand are small amounts of clay that were contributed by wind or, close to the River, by over-bank flooding. Within the dry woodlands and riverine forests the nutrients in the soil are continually being recycled by plants and animals. Nutrients are returned to the soil by leaf litter, droppings of animals, birds and insects, and fires (in dry woodland). Organic content also helps to maintain the fertility of the soil.

Where indigenous vegetation has been cleared for agriculture, the fertility rapidly declines. Nutrients are leached out of the soil or taken up by crops, and clay particles are blown away so that fields are abandoned after a few years of cultivation (Photo 21). In the case of the limited irrigation projects, artificial fertilizers are essential to maintaining the fertility of the irrigated soils.

Mendelsohn & el Obeid (2004, p.74) stated that all the water in the Namibian reaches of the River comes from Angola. The rainfall in Namibia contributes virtually no runoff to the river. This is true also for the "fossil tributary" – the Omatako, which barely reaches the mainstem river. Mendelsohn (2006, p.27) stated that "There is also little surface run-off or erosion of these porous soils. Sand, or more correctly grains of quartz, makes up the bulk of the soil, which contains limited humus or organic matter...". It therefore follows that sediment yield to the river from the Namibian side will be almost negligible, under any development scenario. Wind erosion of finer particles from cleared lands may contribute slightly to a decline in water quality and clarity, but not to a significantly increased solid load. Fine sand comprises the bulk of the river's solid load. Thus under present climatic conditions, changes in land use in Namibia are not expected to significantly alter the sediment loading in the river.

However, regional modelling of the effects of climate change has predicted that the Kalahari dunes that are now vegetated could become re-mobilised within several decades (BBC News / Science-Nature / African sands 'set for upheaval' (30 June 2005)). In a scenario where the Okavango Basin gets warmer and drier, woodlands may die off leaving the dunes exposed to winds. Concurrent increases in wind speeds would accompany such change – resulting in mobilization of Kalahari dunes that would surely encroach on the river's course. Climate change therefore represents a "wild card" that will have serious impacts but the exact nature, extent and timing of those impacts are not yet sufficiently understood.

Excerpts from the soil and vegetation study (Simmonds & Burke, 2001) which contributed to the Kavango Region Environmental Profile provide the following insights on the soils, landforms and vegetation of the Okavango floodplain and terrace system.

Genetic Inheritance

The majority of soils in Kavango have formed on either sandy or loamy substrates. The older Tertiary parent materials are completely recycled – eroded and re-deposited. As a result the soils developed on these substrates have not inherited the end-products of in situ weathering and individual soil particles are therefore not commonly coated by oxidized iron. The only soils in which oxidized iron coatings would give the soils a red colour are the younger red aeolian sands blown in on top of the older Tertiary aeolian deposits, and the soils developed on top of the alluvial deposits of the Okavango river terraces.

Between these two soil settings the genetic chemical conditions favouring iron coatings are very different. In the case of the younger red aeolian sands, it is possible that previous weathering conditions did not completely remove the iron pigment which consequently remains coated on quartz grains giving a pale pink to red colouration. In the case of soils on alluvial terraces, the immature sediments forming the parent material would have originated in humid paleo-environmental conditions of central Angola and provide the source of iron. Furthermore, the mixture of materials comprising the alluvial deposits of the Okavango river terraces derive their bases from the same weathered origins in central Angola.

Fluvisols: Soils of Alluvial Lowlands

FL FLUVISOLS
FLd Dystric Fluvisols

FAO Soil Classification:

FL FLUVISOLS Soils showing fluvic properties and having no diagnostic horizons other than an ochric, a mollic or an umbric A horizon, or sulphidic material within 125cm of the surface.

FLd Dystric Fluvisols Fluvisols having a base saturation rate of less than 50% at least between 20 and 50cm below the surface; lacking a sulphidic horizon and sulphidic material within 125cm of the surface.

Fluvisols have developed in recent fluviatile deposits on the floodplain of the Okavango River. On the banks and active floodplain of the Okavango River these soils are periodically wet in all or part of the profile due to the presence of seasonal flood water.

The floodplain area, two to six kilometres wide, can be divided into two zones in terms of soil development and modification. A broad area adjacent to the present course of the river actively receives fresh sediments during regular seasonal periods of inundation and hence the soils are regularly rejuvenated. The soils of this zone, although used for wet season cropping and dry season grazing, are not profoundly modified by agricultural activities and can therefore be classified by their fluvic properties.

Soil profiles and auger holes show stratified layers of coarse and fine materials with a predominance of fine to very fine sands and silts in shallower horizons and an increase in clay content with depth. Significantly, the deposition of clay layers is uncommon and clay contents even at depth are consequently lower than would be expected in these alluvial soils. This attribute can be linked to the scarcity of clays in the provenance areas (Minader, 1996). Surface clay contents are lower than subsurface horizons with an average of 6%, increasing irregularly to 14% in lower horizons. Low clay contents combined with low and irregular levels of organic matter are also linked to relatively low nutrient concentrations and CEC (total) levels. Whereas these soils are not infertile, they are also not highly productive.

Anthrosols: Soils Conditioned by Human Influence

AT ANTHROSOLS
ATd Dystric Anthrosols

FAO Soil Classification:

AT ANTHROSOLS Soils in which human activities have resulted in profound modification or burial of the original soil horizons through removal or disturbance of surface horizons, cuts and fills, secular additions of organic materials, long-continued irrigation, etc.

ATd Dystric Anthrosols Anthrosols which have a base saturation of less than 50% at least from 20 to 50cm below the surface. Moderately deep to deep; moderately well to well drained; dark brown fine sands to sandy loams. This unit of classification does not appear in the FAO Revised Legend. Based on field experience, however, it best describes the soil characteristics modified by man on the old and now drying (no longer periodically inundated) Okavango floodplain. It is suggested as a refinement to the Legend.

Away from the main Okavango River channel in a broad zone of variable width, the floodplain is no longer seasonally inundated. In this area soils resembling buried Fluvisols at depth and Arenosols nearer to the surface have developed on colluvial sands lying over older dry fluviatile deposits.

Intensively used for both dryland and irrigated cultivation, these soils have been significantly modified. Evidence from borehole records and sample analyses (Weirenga, 1999) indicate that the original morphology of these soils would have included buried accumulation horizons of stratified coarse and fine materials under moderately deep fine sands of colluvial and aeolian origin. Analytical and profile records from Mashere Agricultural College indicate that the surface horizons have been physically mixed by ploughing, chemically altered by the addition of organic materials, leached by irrigation water and generally deficient in potassium.

These soils therefore have been classified as Anthrosols to indicate the degree to which modification by agricultural use has altered a number of their diagnostic properties. Judging by the inherently low CEC status of the Arenosol group, by the relatively low nutrient concentrations of the underlying Fluvisols, and by the fact that organic additives are needed to increase the concentration of base cations, these soils have been categorized as Dystric Anthrosols.

Soils, Landforms and Vegetation Sequences on Okavango Floodplains and Terraces

LAND REGION	LAND SYSTEM	VEGETATION MAPPING UNIT	VEGETATION TYPES	SOIL ASSOCIATIONS
Northern Sandplain	Okavango floodplain and terraces	Okavango river valley -fields and shrublands	Acacia nigrescens – *Peltophorum africanum riverine forest*	Dystric Fluvisols
			Combretum imberbe – *Acacia erioloba shrubland*	Dystric Anthrosols
			Terminalia sericea – *Bauhinia petersiana shrubland*	Haplic Arenosols
			Catophractes alexandri shrubland	Ferralic Arenosols
			Floodplain grassland	Dystric Fluvisols

Table 4. 1: Vegetation Types and Soil Associations Aggregated by Land Syatem

Floodplain, river bank, old flood plain (terrace) and terrace slope comprise the main sequences of landforms bordering the Kavango River. Grasslands with species such as Vossia cuspidata, Cynodon dactylon and Setaria sphacelata dominate the floodplain, while riverbanks originally supported riverine forests with Acacia nigrescens, Peltophorum africanum and Diospyros mespiliformis as dominant tress and a dense shrub undergrowth of various species. However, due to intense clearing and cultivation along the river, riverine forest has disappeared almost entirely and only few, localised patches remain. Today's river banks and terrace present an open parkland with few trees, cultivated land and many villages in between. Remnants of shrubland with Combretum imberbe, Acacia erioloba, Terminalia sericea and Bauhinia petersiana indicate the potential vegetation types of former terraces. However, human impact has also resulted in an increase in shrubs, often on old farmland and may thus give a false indication of what may have occurred naturally on these old floodplain terraces.

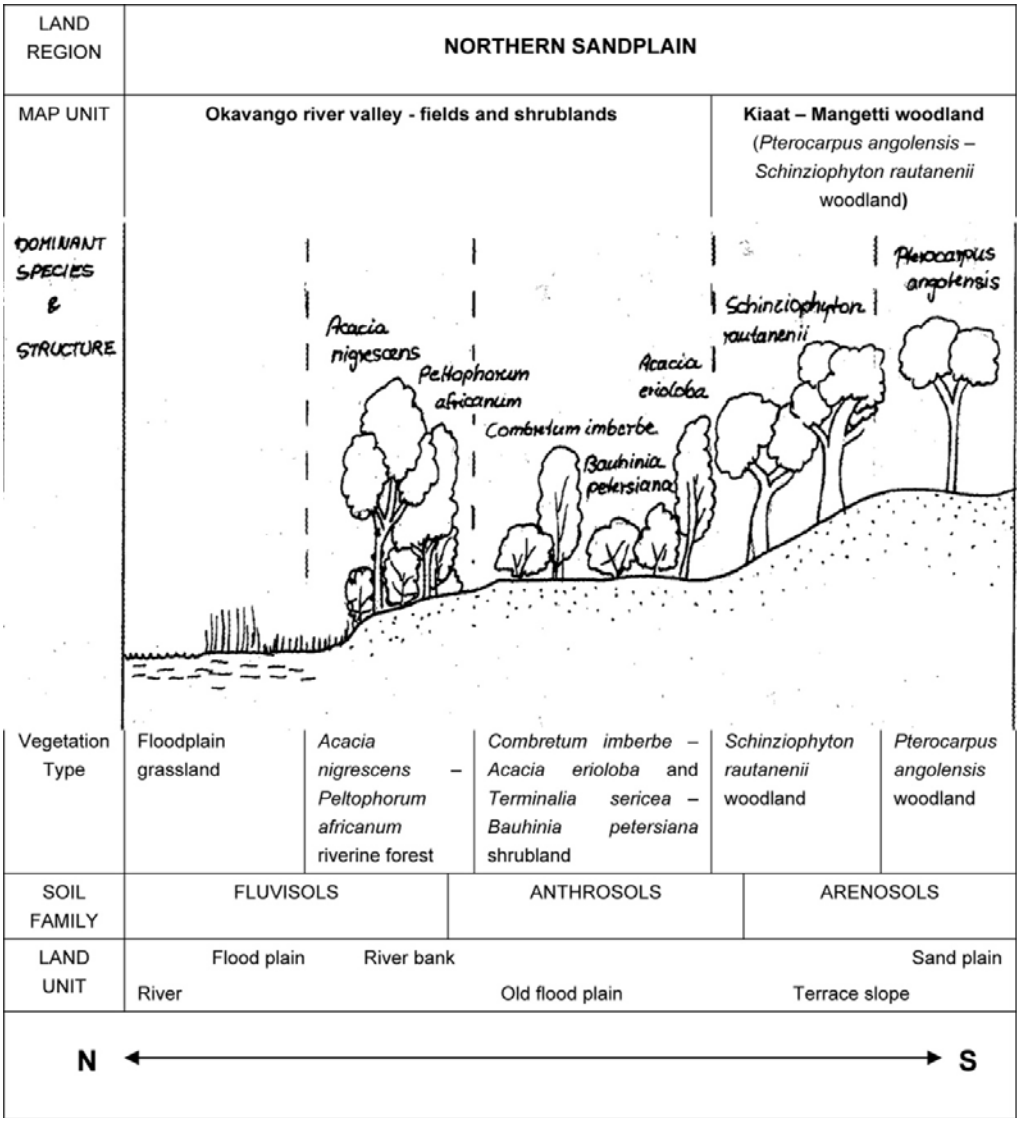


Figure 4. 1: Schematic diagram (not to scale) of Pterocarpus angolensis – Schinziophyton Rautanenii woodland and associated soil families on the floodplain and terrace system of the Okavango River.

The terrace slopes support open stands of *Schinziophyton rautanenii,* possibly still prevalent despite human impact because of their value as fruit trees.

The northern sandplain forms a sheet of several meters of sand cover with very few pans. Although *Pterocarpus angolensis* and *Schinziophyton rautanenii* woodlands are prominent, localised patches of *Baikiaea plurijuga* and *Burkea africana* woodlands occur throughout this map unit. *Combretum collinum* forms another important tree component, *while Combretum zeyheri, Combretum psidioides, Bauhinia petersiana* and *Baphia massaiensis* are prominent in the shrub layer. Common grasses associated with these woodlands *comprise Digitaria seriata, Schmidtia pappophoroides* and *Urochloa brachyura.*

4.3.2 Soils and agriculture

Mendelsohn (2006, p.24-29) provides a useful description of soils in Namibia including the Kavango Region. He points out that the dry climate is not only a problem for agriculture due to low rainfall, but also because – over millions of years -it has provided little opportunity for soil formation and nutrient retention.

The Kalahari sands are wind blown deposits that cover most of Kavango. They are called arenosols and they are extremely poor in nutrients. Being highly permeable, they are also poor in water retention. Quartz grains make up the bulk of the soil and there is little humus or nutrients. These soils are particularly low in phosphorous, which results in deficiencies of nitrogen.

Along the river and omuramba, Kalahari sand has been reworked and deposited by water. Here small and patchy areas of better soils occur, with slightly higher clay and nutrient content. But even these are rated has having "low" agricultural potential (p.29). The fertility of these soils has to be maintained by the regular application of suitable fertilisers.

Mendelsohn and el Obeid (2007) provided a specialist socio-economic report for the Kavango Biofuel EIA. Farming near the river consists largely of a mix of small-scale dryland crop production and livestock farming. Most households practise this type of subsistence farming. The dominant crop planted (95%) is mahangu because it is the only cereal that grows relatively well on sandy, nutrient poor soils. Mahangu is also a bit more reliable in conditions of unreliable rainfalls.

Yields are usually too low to support households. Average yields of mahangu amount to between 100 and 300 kg/hectare. At a market value of N$3.00 – N$4.00/kg, one hectare of mahangu has a value of only N$300 to N$1,200 per year. Most fields cover less than 2ha. The estimated maximum daily rate of return on labour devoted to mahangu amounts to only about N$13.60 (Mendelsohn, 2006). Therefore 80% of households rely on cash incomes from other sources to meet some or all of their cereal needs. Most rural Kavango households are **not** self-sufficient in food production. There is also no need for them to be self-sufficient because their food security comes largely from off-farm cash incomes.

Mendelsohn and el Obeid (2007) used satellite or aerial images to identify land within 10km of the river to identify available land for the proposed Kavango Biofuel project. They found 65,000 ha of land that had been cleared for cultivation before 1990. They also found that only 75% of cleared fields were actually utilised for crops. This fact is testimony to the poor yields, low value of crops produced, and rapid decline of soil fertility under cultivation.

Most of the cultivation occurs outside the dry banks of the river, while some small fields are made on the old, higher floodplains.

Apart from dry-land cultivation, a number of irrigation projects exist or are being planned. Figures supplied by the Directorate of Agriculture, indicated that 770 ha were already under irrigation along the Namibian reach of the River, while a further 7,793 were being planned. Thus a total of some 8,563 hectares may ultimately be irrigated. This would require a water consumption of 128 million m^3/year, or an abstraction rate from the River of 15.45 m^3/second (Eco.plan 2003).

The soils thus targeted are not good soils, by international standards, but Namibia is short of arable lands. The Green Scheme, as this irrigation initiative is known is fairly contentious critics of the scheme argue that:

a. The existing irrigation schemes are of dubious economic viability, requiring subsidies,
b. A considerable input of artificial fertilisers is required,
c. Maize can be imported from South Africa more cheaply than it can be produced in Kavango, and
d. The Green Scheme is being driven by a misguided government policy that aims for food self-sufficiency, instead of aiming for food security through developing cash economies, e.g. based on tourism and commerce.

Simmonds (1998) prepared an overview of soils for OKACOM which provided the following exerpt.

Soils of the Okavango River floodplain and terraces

Soils of the Namibian and Botswana segments of the Okavango River floodplain and terraces are composed predominantly of infertile aeolian sands of the Kalahari Formation with a low organic matter content (Bethune, 1991; OCC, 1995).

Along the Okavango River channel on the Namibian side, the sandy soils of the floodplain and river terraces are enriched with interspersed clay and silt layers deposited by seasonal flood waters (FAO, 1984). Vegetated slacks between scroll bars on the floodplain trap deposits of clay and fine silt, whilst layers of calcrete are exposed on many river terraces. Away from the main river channel the soils are predominantly grey to yellow-orange sands (Schneider, 1987). According to Bethune (1991) floods seldom deposit alluvial silt on the higher river terraces.

Both the floodplains, and the river terraces are cultivated by subsistence farmers (Bethune, 1991). Formal (irrigation) agriculture is confined to the higher river terraces, and is restricted to a few locations with suitable soils, along the Okavango River between Rundu and Bagani (Cashman *et al.,* 1986).

Soil erosion is evident over much of the southern bank of the Okavango River between Rundu and Bagani. Extensive soil erosion is particularly evident for a distance of some 50 kilometres downstream of Rundu and between Andara and Popa Falls. Elsewhere along the Okavango River, soil erosion occurs in scattered areas which mark the sites of existing and former mahangu gardens, livestock kraals and villages. Most of this "scattered" erosion pattern is due to trampling by livestock, indiscriminate clearing of riparian vegetation for agriculture and collection of construction materials and fuel-wood.

Further notes on Okavango River terrace soils

Along the south and west banks of the Okavango River the terrace system constitutes a distinct but discontinuous physiographic unit, lying some 7m above the river and separated from it by a floodplain which varies in width between 2-6 km. The terrace itself is flat to even and gently sloping, and incised by minor drainage lines.

Clovelly, Oakleaf and Hutton soil forms pre-dominate on the terrace system exhibiting classic catenery associations with slope position (Schneider, 1987).

The three soils exhibit physical, chemical and mineralogical properties typical of semi-arid soils whereby moderate to high base saturation due to slow leaching of the basic cations results in pH values between 6.8 and 7.6 (slightly acid to slightly alkaline). The cation exchange capacity is low to moderate and in all three soil forms kaolinite is the most abundant clay mineral.

Soil Series identified are mostly sandy and differ little in colour. Particle size analysis indicated that the sand fraction dominates in all series by more than 50%. The clay content of all identified series varies from 0-15%; locally more clay was recorded, as for example in the case of an Oakleaf Limpopo.

All three soils have a relatively thin surface layers of non-calcareous loamy sand, overlying thicker non-calcareous to loamy and clayey sand in B1 and B2 horizons. Calcareous subsoils are found in the lower parts, as in the C-horizon of the Hutton Zwartfontein. The calcic C-horizon (which has more carbonate than the parent material) appears to have formed by the upward movement of carbonate-rich capillary water from the shallow groundwater table.

Landuse and soil quality on the Okavango river terraces

Soil formation processes on the river terrace system have ultimately been controlled by topography and semi-arid climatic processes. These factors, together with sandy parent materials and the accumulation of carbonates, soluble salts and silica, combine to yield soils unfavourable for agricultural purposes. Even so, the terraces of the Okavango River and its tributaries are cultivated by traditional subsistence farmers, and during the past 25 years, by centre-pivot irrigation schemes.

Subsistence farming on the river terraces downstream from Rundu is dominated by dryland cropping of maize and mahango along the silt-enriched river banks. Stock (primarily cattle) are grazed on the floodplains.

A marked degree of environmental degradation is evident along the entire length of the riparian environment. Landslip features, slope failures and moderate gully formations can be observed on the discontinuous terrace slopes east of Rundu. In the area 0-4 km east of Rundu, these appear to be associated with excavations and earth diggings. Both incipient and extensively developed gully systems, observed from Rundu to Mukwe, radiate from numerous footpaths and animal tracks linking villages situated on terrace ridges to the floodplain and river banks. Accelerated and extensive riverbank erosion was observed on the northern (Angolan) river banks and floodplain where land has recently been cleared for village and garden development .

Parastatal irrigation schemes have been developed on the river terraces. No comment can be made on the environmental status of these areas without further research, although detailed soil studies (Schneider, 1987; Engels, pers.comm) indicate that the quality of the terrace soils is expected to deteriorate rapidly under irrigation, given their high potential to allow upward movement of carbonate-rich capillary water.

Production levels of the schemes appear to be lower than the development opportunity suggests, as volumes of water abstracted from the Okavango River for irrigation have recently been measured at levels substantially lower than the maximum permissible abstraction limit of 13.223 Mm3/annum, set by the Agreed Commitment for irrigation permits in Namibian territory (Crerar,1997). It is possible that the reasons for under-utilization of available abstraction water for irrigation purposes are rooted in decreased production levels under conditions of declining soil fertility and the inability to fund increased production costs.

4.4 Summary & Information Gaps

There is almost no literature available that is applicable to geomorphology on the Namibian section of the river. Hence nothing has been found of relevance to the Indicators here.

Several major gaps in knowledge have been identified for further research:

1. Sediment transport studies on the Cuito and Kavango/Cubango Rivers - separately. All the studies that have estimated sediment transport/discharge have been done in the Delta (e.g.
2. by McCarthy et al – see reference list) and for the Popa Falls Hydro Power EIA (Eco.plan, 2003). No studies were found on sediment dynamics upstream of the confluence with the Cuito.

Geomorphological rates of change within the natural flow regime are not known. For example at Kapako, we have no idea of the rates of meander migration / scroll bar formation. We need to identify methodologies for dating parts of the floodplain and therefore estimating the natural rates of change of various geomorphological features.

A detailed ground survey is needed for Kapako. I suggest using (a) digital laser aerial survey in conjunction with (b) digital full colour images:

(a)

The laser survey has the advantage of penetrating vegetation and thatched roofs. It is capable of generating 0.5m contours (or better). This was done by Water Transfer Consultants for NamPower, for the Popa Falls Hydro Power project. It covers the area from just below Popa Falls up to Andara (or Mukwe, somewhere). It should be possible to get this from NamPower.

(b)

Full colour digital overlay is necessary to see vegetation, which gives a lot of information about geomorphological processes – e.g. tree lines.

Accurate mapping would help to better understanding of floodplain processes, areas inundated at specific flow levels etc.

The river section between Divundu and Andara/Mukwe is fundamentally different from the rest of the Namibian reach of the Okavango River. It should be included if the EFA is extended in future. Some of the key differences are:

(a)

It is almost the only Riverine Forest left on the Namibian reach of the river,

(b)

The channel is largely rock controlled, with a lot of extensive islands made of sand on top of a base of bedrock. The islands are forested. The islands would be particularly vulnerable to rapid changes in water level (Eco.plan 2003), they would also be vulnerable to people if the water levels are low enough to allow people easy access to the islands.

(c)

There are many small backwaters, rock pools, riffles and rapids – which are surely of ecological importance being scarce habitats.

5 PREDICTED RESPONSES OF INDICATORS TO CHANGE IN FLOW REGIME

This chapter provides a summary of present understanding of the predicted responses of all geomorphological indicators to potential changes in the flow regime. This is done first for Kapako (Section 5.1) and then for Popa Falls (Section 5.2). In those two sections a table is presented for each indicator that is relevant to that site. In each of those tables, an attempt is made to answer the questions posed in Table 3.2. That is, to predict the response of the indicator in question to potential changes in the flow regime.

The tables present the background understanding that was entered into the model at the Knowledge Capture Workshop in Windhoek. However, one important parameter could not be taken into account in the model, namely the effects of sediment-trapping dams or weirs that may be built in future. This represents an important limitation on the Response Curves in the model.

5.1 Site 4: Kapako – Indicator responses to changes in flow regime

Six indicators are applicable to Kapako and its floodplains:

a. Cross sectional area of channel,
b. Extent of backwaters,
c. Percentage silts and clays in top 30cm on floodplain,
d. Extent of inundated floodplain,
e. Inundated pools and pans,
f. Extent of cut banks.

5.1.1 Cross Sectional Area of the Channel

Table 5. 1: Predicted response to possible changes in the flow regime of cross sectional area of the channel

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Nil	High
3		Extends longer than natural	Extended dry seasons without intervening floods would result in the channel slowly narrowing as vegetation (reeds etc) encroaches	Low
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	
6	Flood	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	If floods are regularly larger than normal, one would expect channel cross section to increase. If floods are repeatedly lower than normal, a very slow decrease in channel cross section may occur because stabilising vegetation on the sides of the channel would be taken out less easily.	Med
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or shallower	Steeper than normal falling hydrograph would tend to cause bank collapse.	Medium

5.1.2 Extent of Backwaters

Table 5. 2: Predicted response to possible changes in the flow regime of slow/no flow backwaters

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Because backwaters are, buy our definition, connected to the main channel, water level will be the same as in the main channel. The backwaters are steep sided, therefore area does not change very much in response to changes in river stage.	High
3		Extends longer than natural	Nil	Nil
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	High
6	Flood	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	Nil	High
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or	Nil	High

		shallower		

5.1.3 Percentage Silt and Clay on Floodplain

Table 5. 3: Predicted response to possible changes in the flow regime of percentage silt and clay in the top 30cm on floodplains

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Nil	High
3		Extends longer than natural	Nil	High
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	High
6	Flood	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	If substantial flooding does not occur, clays will not be added. Since clays that are present will be eroded by wind or mixed down by soil organisms, failure of overbank flooding will result in silt and clay levels declining over time.	Med
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e.	Nil	High

		hydrograph is steeper or shallower		

5.1.4 Extent of Inundated Floodplain

Table 5. 4: Predicted response to possible changes in the flow regime of the extent of inundated floodplains

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Nil	High
3		Extends longer than natural	Nil	High
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	High
6	Flood	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	The river is contained by levees along its banks in most places. Once the levees are overtopped, most of the floodplain will be inundated quickly. However, as the flood continues to rise, it increases water depth on the floodplain but the area inundated probably increases relatively little in proportion to discharge.	Medium
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or	Nil	High

		shorter than natural –i.e. hydrograph is steeper or shallower		

5.1.5 Extent of Inundated Pools and Pans on Floodplains

Table 5. 5: Predicted response to possible changes in the flow regime of inundated pools and pans

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Assuming that pools are connected to the river channel by groundwater and that the floodplain is permeable, then higher flows in the dry season would increase the likelihood that pools will retain water to the end of the dry season.	Med (assumption not tested)
3		Extends longer than natural	Assuming that pools are connected to the river channel by groundwater and that the floodplain is permeable, then higher flows in the dry season would increase the likelihood that pools will retain water to the end of the dry season.	Med (assumption not tested)
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	High
6	Flood	Onset is earlier or later than natural –synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	Greater floods would increase the likelihood of pools filling and remaining full because the groundwater in the floodplains would be recharged.	Medium
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or shallower	Nil	High

5.1.6 Extent of Cut Banks

Table 5. 6: Predicted response to possible changes in the flow regime of cut banks

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Nil	Med
3		Extends longer than natural	Nil	Med
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	High
6	Flood	Onset is earlier or later than natural –synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	Increased flood levels would result in greater erosion of banks (assuming no change in sediment supply)	High
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or shallower	If the falling hydrograph is steepened, water seeping out of the saturated banks will tend to cause collapse – i.e. the likelihood of bank collapse will be increased	High

Site 5: Popa Falls – Indicator Responses to Changes in Flow Regime

Four indicators are applicable to Popa Falls:

a) Extent of exposed rocky habitat,
b) Cross sectional area of channel,
c) Sand bars at low flow,
d) Extent of vegetated islands.

5.2.1 Extent of exposed rocky habitat

Table 5. 7: Predicted response to possible changes in the flow regime of exposed rocky habitat

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Increased water levels in the dry season would reduce the area of rocky habitat for Rock Pratincoles. These birds breed on the rocks in the rapids during the low flow season.	Medium
3		Extends longer than natural	Nil	High
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	High
5		Flows are more or less variable than natural	Nil	High
6	Flood	Onset is earlier or later than natural –synchronisation with rain may be changed	During a low flood season there is still enough rocky habitat for Rock Pratincoles to feed upon, but at above-average flood levels this habitat becomes drowned out.	High
7	season	Natural proportion of different types of flood year changed	Nil	High
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or shallower	Nil	High

5.2.2 Cross Sectional Area of the Channels

Table 5. 8: Predicted response to possible changes in the flow regime of cross sectional area of the channels

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	If low flow levels are consistently lower than normal without intervening floods, then encroachment by plants (reeds etc) would reduce the cross sectional area of the channel. Scouring of the bed would also be decreased.	High
3		Extends longer than natural	Ditto – as above	Ditto – as above
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Prolonged high floods would tend to enlarge the channel a little, even though at Popa Falls the banks are well stabilised by vegetation.	Medium
5		Flows are more or less variable than natural	Higher flood peaks would tend to enlarge the channel a little, even though at Popa Falls the banks are well stabilised by vegetation. However, reduced flood peaks would result in a much slower reduction in channel cross section.	Medium
6	Flood	Onset is earlier or later than natural –synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	Nil	High
8		Onset is earlier or later than natural	Nil	High
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or shallower	A rapid decline in the hydrograph (greater than natural) would tend to destabilise the banks as water seeps out of the saturated banks. This may result in bank collapse, even though at Popa Falls the banks are quite well stabilised by vegetation.	Medium

5.2.3 Extent of sandbars at low flow

Table 5. 9: Predicted response to possible changes in the flow regime of sandbars at low flow

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Higher flow levels in the dry season would tend to cover sand bars, which are used for breeding by African skimmers.	High
3		Extends longer than natural	Nil	High
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	Medium
5		Flows are more or less variable than natural	Nil	Medium
6	Flood	Onset is earlier or later than natural –synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	Nil	High
8		Onset is earlier or later than natural	Nil	Medium
9	Transition 2	Duration is longer or shorter than natural –i.e. hydrograph is steeper or shallower	Nil	Medium

5.2.4 Extent of vegetated islands

Table 5. 10: Predicted response to possible changes in the flow regime of vegetated islands

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1		Onset is earlier or later than natural	Nil	High
2	Dry Season	Water levels are higher or lower than natural	Nil	High
3		Extends longer than natural	Prolonged dry seasons without intervening floods would allow papyrus and reeds to encroach on the channel, so increasing the area of islands in the main channels	High
4	Transition 1	Duration is longer or shorter than natural i.e. hydrograph is steeper or shallower	Nil	Medium
5		Flows are more or less variable than natural	Nil	Medium
6	Flood	Onset is earlier or later than natural –synchronisation with rain may be changed	Nil	High
7	season	Natural proportion of different types of flood year changed	Higher flood peaks would tend to erode the margins of islands where they are not made of bedrock. Flood peaks of longer duration would also tend to increase erosion. Consistently low peaks may allow islands to grow as vegetation encroaches on the channels.	High
8		Onset is earlier or later than natural	Nil	Medium
9	Transition 2	Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	Nil	Medium

5.3 CONCLUSION

No quantitative data, other than the hydrological data, were available as a basis for predictions about the responses of indicators to changes in potential flow regime. Thus the entries to the EF-DSS model were based on knowledge and experience of a non-quantitative kind. The ages of features in the floodplains were also unknown. Often it was possible to predict, within a reasonable level of confidence, the direction of change but not the rate of change.

Some of the uncertainties could be overcome with further research, including the following:

a. Detailed surveys that can produce contours accurate to 0,2m. This would enable the hydrologists to predict the extent floodplain inundation with for given discharge of the river with greater accuracy.
b. The discharge of sediment at the Kapako site needs to be measured and calculated as it was at Divundu.
c. Groundwater studies on the floodplain would help to understand the degree of permeability, and hence the likelihood of individual pools drying out at any given water level.
d. The percentage of silt and clays in the top 30cm on the floodplains needs to be measured for selected representative locations, on active and older floodplains, as baseline data.
e. It would be useful to find some method by which to date the scroll bars on the active floodplains – to develop an understanding of the time frames involved. That may even lead to the possibility of correlating specific scroll bars with specific flood events in historical flow data.
f. Analysis of old aerial photos that can be geo-referenced in a GIS programme would be very useful to determine the rates of change in extent of islands, backwaters, and floodplains.

Most importantly, any future modelling needs to take into account the interaction of water and sediment. These two components of the system are equally important in the creation or destruction of habitats. The EF-DSS model in its present form does not take into account the effects of sediment trapping dams or weirs, although it is possible that the consequent environmental impacts may reach as far downstream as the Okavango Delta (McCarthy, 2003).

FLOW-RESPONSE RELATIONSHIPS FOR USE IN THE OKAVANGO EF-DSS

Flow-Response Curves showing the relationship between every indicator and every relevant flow category were generated at the Knowledge Capture Workshop in Windhoek in April 2009. These were submitted to the EFA team leaders at that workshop and the instruction was given to the workshop delegates to omit the details from this report as the Response Curves will be made available on CD as part of the final Project reporting.

However, there is one point that must be recorded here. The flow-response model that was used at the workshop was unable to handle the effect of sediment trapping by dams or weirs on the proposed geomorphological indicators that were under discussion. We were therefore told to ignore the effect of sediment-trapping dams in completing the response curves, and consider the response of indicators in relation to water flows alone and in isolation of likely sediment load changes which may occur under the various development scenarios. This represents an important limitation on the EFA study. The importance of this issue is highlighted with reference to the following examples:

a. If sediment was trapped in a weir or dam, the sandy river beds downstream would be scoured for some distance downstream. This would make the channel more efficient in transporting floods and consequently reduce the extent of overbank flooding into the floodplains – with significant ecological consequences.

b. If sediment is trapped, including fine materials (clays and organic particles) then there will be less deposition of fine material and nutrients on the floodplains, with the consequence of deteriorating soil quality there.

It is therefore recommended that the model needs to be amended in some way to take into account the effect of sediment trapping by weirs and dams. It must be stressed that, in determining the flow-response curves for geomorphology, or for the ecological disciplines where physical habitat is an important criterion, the flow of water cannot meaningfully be separated from the flow of sediment.

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APPENDIX A: RAW DATA -SOILS

ENVIRONMENTAL PROFILE, KAVANGO REGION, NAMIBIA

SOILS ANALYSIS Site Summary	Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
	F1	07-Feb-99	17°28.964'S	18°26.814'E	**(3.1)** Okavango river floodplain and terraces	Crest of N-facing terrace bordering sand plain	4	1	NE	straight slope

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B67	F1B (a)	0 - 15	4.1	4.3	91.5	trace to null	6.9	52.8	34.7	5.6	
B68	F1B (b)	15 - 30	4.6	6.1	89.2	trace to null	7.9	47.4	37.0	7.7	1
B69	F1B (c)	30 - 45	4.6	5.5	89.9	trace to null	7.2	50.5	35.8	6.5	

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H_2O)	OrgC % (Walkley-Black)	$CaCO_3$ (quant)
B67	F1B (a)	0 - 15	7.5YR 4/6 brown	sand	Not analysed	Not analysed	< 0.1	32.3	5.0	0.06	low pH
B68	F1B (b)	15 - 30	5YR 4/6 reddish brown	sand	Not analysed	Not analysed	< 0.1	16.5	4.7	<0.01	low pH
B69	F1B (c)	30 - 45	5YR 5/8 bright reddish brown	sand	Not analysed	Not analysed	0.1	11.5	4.7	<0.01	low pH

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO_4 (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B67	F1B (a)	0 - 15	9.1	25	10	8	4	<0.5	<0.2	1.0	1.5
B68	F1B (b)	15 - 30	8.3	8	4	5	4	<0.5	<0.2	1.0	<0.5
B69	F1B (c)	30 - 45	8.0	6	3	5	3	<0.5	<0.2	1.0	<0.5

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B67	F1B (a)	0 - 15	0.26	4.10	6.27	0.244	94.96	3.89	6.616	0.271	0.171
B68	F1B (b)	15 - 30	0.11	4.60	2.44	0.103	91.73	4.22	15.141	0.696	0.288
B69	F1B (c)	30 - 45	0.09	4.60	1.96	0.081	89.72	4.13	14.400	0.662	0.250

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP >15)	Sodicity (Na>1me/100g)	FAO Depth Class
B67	F1B (a)	0 - 15	1.52	0.24	7.78	0.32	No	No	No	
B68	F1B (b)	15 - 30	1.21	0.39	11.58	0.53	No	Yes	No	Deep
B69	F1B (c)	30 - 45	1.20	0.52	14.40	0.66	No	Yes	No	

Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm3)	Porosity (vol %)	FAO Classification			RSA Classification
							Group	Unit	Phase	
U37	F1U (a)	15	0.13	2.6	1.55	41.4				
U38	F1U (b)	30	0.12	2.0	1.57	40.6	Arenosol	Ferralic	Yermic	Gaudam ?
U39	F1U (c)	45	0.09	3.1	1.58	40.2				

Micro-topography	Soil Surface Condition	Surface Drainage	Erosion / Deposition
Uneven; micro-slopes around shrubs	High cover of leaf litter, burnt twigs, tree & shrub branches; no crusting or sealing; no evidence of salt	No visible drainage lines; soil highly permeable	Evidence of water and wind erosion, not severe; sand particle accumulations against surface detritus and hummocks (in prevailing wind direction?) & minor sheet wash effect

Horizon	Depth (cm)	Profile Description
Au1	0-5	Deep, excessively well drained sand; no crusting, sealing or cracks. Thick ochric A horizon, brown (7.5YR 4/6) medium sand; common black organic mottles and fragments in dense band between 5-7cm depth; weakly developed coarse granular structure, very friable, non sticky, non plastic; few fine pores, non calcareous, few fine to very fine roots. Smooth diffuse boundary at 15cm to B horizon with some ferralic properties (texture too coarse to be diagnostic of ferralic horizon). No textural difference although colour change to reddish brown (5YR 4/6); very weak very coarse crumb structure, slightly hard, friable, non calcareous; rare fine roots. Smooth boundary at 30cm to C horizon of bright reddish brown (5YR 5/8) loamy sand; loose, very coarse crumb structure, slightly hard, friable, non calcareous; no roots. No visible lower boundary to >100cm.
Ap	5-7	
Au2	7-15	
Bw	15-30	
BCw	30->100	

ENVIRONMENTAL PROFILE, KAVANGO REGION, NAMIBIA

SOILS ANALYSIS Site Summary	Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
	A9	28-Apr-99	17°54.264'S	20°10.572'E	**(3.1)** Okavango river floodplain and terraces	Crest of oldest north-facing river terrace	9	2	NNE	convex

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2μ clay	% 2 - 53μ silt	% 53 - 2000μ sand	% > 2000μ gravel	% 2000 - 500μ vcs/cs	% 500 - 250μ ms	% 250 - 106μ fs	% 106 - 53μ vfs	FAO Textural Class
B10	A9B (a)	0-30	5.3	6.4	88.3	trace to null	4.6	49.8	38.2	7.5	1
B11	A9B (b)	30-60	5.8	7.5	86.7	trace to null	4.5	45.7	39.8	10.0	

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (μS/cm)	pH (H_2O)	OrgC % (Walkley-Black)	$CaCO_3$ (quant)
B10	A9B (a)	0-30	7.5YR 5/6 bright brown	sand	0.08	0.4	0.2	6.0	6.4	0.14	low pH
B11	A9B (b)	30-60	10YR 6/6 bright yellowish brown	sand	0.07	0.9	< 0.1	30.9	5.0	0.09	low pH

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO_4 (S μg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B10	A9B (a)	0-30	8.8	54	19	6	5	<0.5	<0.2	<0.5	<0.5
B11	A9B (b)	30-60	10.1	22	13	5	5	<0.5	<0.2	<0.5	0.3

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B10	A9B (a)	0-30	0.47	5.30	8.86	0.463	98.61	5.23	4.685	0.248	0.149
B11	A9B (b)	30-60	0.26	5.80	4.45	0.252	97.73	5.67	8.532	0.495	0.209

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP »15)	Sodicity (Na>1me/100g)	FAO Depth Class
B10	A9B (a)	0-30	1.73	0.10	3.19	0.17	No	No	No	Deep
B11	A9B (b)	30-60	1.03	0.12	5.04	0.29	No	No	No	

Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm3)	Porosity (vol %)	FAO Classification			RSA Classification
							Group	Unit	Phase	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Arenosol	Haplic	Yermic	Sandspruit ?
N/A	N/A	N/A	N/A	N/A	N/A	N/A				
N/A	N/A	N/A	N/A	N/A	N/A	N/A				

Micro-topography	Soil Surface Condition	Surface Drainage	Erosion / Deposition
Flat, smooth	50% cover leaf and grass litter; no crust, sealing or cracks; no stones	High permeability; no visible small-scale drainage except for short-lived, small, anastomosing channels by animal tracks	water erosion alongside animal tracks

Horizon	Depth (cm)	Profile Description
Ap Bw	0-49 49->100	Deep, well to somewhat excessively drained medium to coarse aeolian sand; no crust, sealing or cracks. Ochric A horizon modified by ploughing, bright brown (7.5YR 5/6), unconsolidated, friable, no structural development, 1% black organic mottles evenly distributed and fine quartzite fragments, rare fine pores, few fine to very fine and no medium roots, non calcareous. Distinct boundary at 49cm to B horizon where boundary indicated by in situ colour change to bright yellowish brown (10YR 6/6); otherwise no diagnostic features, unconsolidated sand; <1% black organic fragments, no roots, very rare fine pores, non calcareous.

ENVIRONMENTAL PROFILE, KAVANGO REGION, NAMIBIA

SOILS ANALYSIS Site Summary	Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
	A8	28-Apr-99	17°53.511'S	20°15.043'E	(3.1) Okavango river floodplain and terraces	North-facing river bank	0	1	n/a	flat

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B8	A8B (a)	0-30	6.5	12.2	81.3	trace to null	6.4	43.6	42.6	7.4	1
B9	A8B (b)	30-60	14.6	10.8	74.6	trace to null	6.6	39.0	41.1	13.3	

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H_2O)	OrgC % (Walkley-Black)	$CaCO_3$ (quant)
B8	A8B (a)	0-30	10YR 4/2 greyish yellow brown	loamy sand	0.15	1.1	0.9	35.7	8.4	0.24	12.0
B9	A8B (b)	30-60	10YR 2/2 brownish black	sandy loam	0.32	5.2	0.3	125.2	8.1	0.26	<1

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO_4 (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B8	A8B (a)	0-30	7.0	440	53	66	23	<0.5	<0.2	<0.5	<0.5
B9	A8B (b)	30-60	1.5	596	199	92	54	<0.5	<0.2	<0.5	<0.5

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B8	A8B (a)	0-30	2.91	6.50	44.76	2.903	99.78	6.49	3.437	0.223	0.276
B9	A8B (b)	30-60	5.09	14.60	34.84	5.080	99.87	14.58	4.620	0.675	0.489

Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP »15)	Sodicity (Na>1me/100g)	FAO Depth Class
B8	A8B (a)	0-30	5.07	0.39	5.81	0.38	No	No	No	Moderately Deep
B9	A8B (b)	30-60	1.83	0.14	4.62	0.67	No	No	No	

Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm3)	Porosity (vol %)	FAO Classification			RSA Classification
							Group	Unit	Phase	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Fluvisol	Dystric	Inundic/Phreatic	Okavango ?
N/A	N/A	N/A	N/A	N/A	N/A	N/A				
N/A	N/A	N/A	N/A	N/A	N/A	N/A				

Micro-topography	Soil Surface Condition	Surface Drainage	Erosion / Deposition
Uneven; surface disturbed by animal hooves	Surface covered by leaf and grass litter; no crust, sealing or cracks; no stones	Imperfect (slow) drainage although no evidence of ponding	Extensive river bank (water) erosion; small gully development 0.5-4m long

Horizon	Depth (cm)	Profile Description
Ak1 BA Btw Cu	0-25 25-30 30-45 45+	Deep, imperfectly drained alluvial loamy sand to sandy loam; no crust, sealing or cracks. Ochric A horizon greyish yellow brown (10YR 4/2) silty fine sand; unconsolidated to weakly developed very fine platy structure; unstable aggregates; no mottles; surface cover > 70% leaf and grass litter although fine root networks in A horizon are spartan; carbonates detected. Gradual, diffuse transitional AB horizon at 25cm deepening to brownish black (10YR 2/2) at 30cm depth; very fine subangular structure; stable aggregates; medium network of fine roots; no carbonates detected; common fine to very fine pores; tongueing of clay particles. Argic B horizon at 30cm; distinctly higher content of illuvial clay to 45cm. Lower boundary to C at 45cm; material indistinct from lower alluvial sediments.

OKACOM

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 Transboundary Diagnostic Analysis

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

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

			Issues in the Okavango Basin, Botswana
		Magole, Lapologang	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Land Use Planning*
		Magole, Lapologang	*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*
		Masamba, W.R.	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Output 4: Water Supply and Sanitation*
		Masamba,W.R.	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Irrigation Development*
		Mbaiwa.J.E.	*Transboundary Diagnostic Analysis of the Okavango River Basin: the Status of Tourism Development in the Okavango Delta: Botswana*
		Mbaiwa.J.E. & Mmopelwa, G.	*Assessing the Impact of Climate Change on Tourism Activities and their Economic Benefits in the Okavango Delta*
		Mmopelwa, G.	*Okavango River Basin Trans-boundary Diagnostic Assessment: Botswana Component: Output 5: Socio-Economic Profile*
		Ngwenya, B.N.	*Final Report: A Socio-Economic Profile of River Resources and HIV and AIDS in the Okavango Basin: Botswana*
		Vanderpost, C.	*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*
	Namibia	*Barnes, J and Wamunyima, D*	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Socio-economics*
		Collin Christian & Associates CC	*Technical Report on Hydro-electric Power Development in the Namibian Section of the Okavango River Basin*
		Liebenberg, J.P.	*Technical Report on Irrigation Development in the Namibia Section of the Okavango River Basin*
		Ortmann, Cynthia L.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report Country: Namibia: discipline: Water Quality*
		Nashipili, Ndinomwaameni	*Okavango River Basin Technical Diagnostic Analysis: Specialist Report: Country: Namibia: Discipline: Water Supply and Sanitation*
		Paxton, C.	*Transboundary Diagnostic Analysis: Specialist Report: Discipline: Water Quality Requirements For Human Health in the Okavango River Basin: Country: Namibia*

Environmental protection and sustainable management of the Okavango River Basin

EPSMO

Kavango River at Rundu, Namibia

Republic of Botswana

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Tel +267 680 0023 Fax +267 680 0024 Email okasec@okacom.org www.okacom.org
PO Box 35, Airport Industrial, Maun, Botswana