Okavango River Basin Transboundary Diagnostic Analysis Technical Report

OKACOM

The Permanent Okavango River Basin Water Commission

Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module Specialist Report Country: Namibia Discipline: Vegetation

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Environmental protection and sustainable management of the Okavango River Basin

EPSMO

BIOPHYSICAL SERIES

Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module

Specialist Report

Country: Namibia

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EXECUTIVE SUMMARY

As part of a Transboundary Diagnostic Assessment (TDA) of the Okavango River, this preliminary Environmental Flow Assessment (EFA) was undertaken from January until June 2009. The goals were to summarise all relevant information on the Okavango River system and to collect new data within very limited time constraints. This information was then used 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. Within each scenario the major positive and negative ecological, resource-economic and social impacts of the relevant developments have been included. This was undertaken by a team of specialists from the three Basin countries, namely Angola, Namibia and Botswana.

The specific objectives of the EFA were to ascertain the relationships between the flow regime and the ecological nature and functioning of the river ecosystem, as well as the relationships between the river ecosystem and the people's livelihoods. This was then used to predict possible development-driven changes to the flow regime and thus to the river ecosystem.

Eight sampling sites were selected along the length of the river; three each in Angola and Botswana and two in Namibia. These sites were chosen as typical representatives of different reaches of the river. At each site, discipline-specific "indicators" were selected. An indicator is a discipline-specific attribute of the river system that responds to a change in the river flow. Indicators were selected collaboratively by the discipline specialists from the three countries. At each site, no more than ten indicators were assessed.

This report gives details on the vegetation indicators at the two sampling sites along the Namibian section of the river. The indicators selected were based largely on the findings of a reconnaissance fieldtrip to the two Namibian sites in January 2009, when the water was too high to do extensive sampling. Information about the ecology and occurrence of the dominant plants in each indicator was obtained from the literature which the author had at hand, this being mainly field guides. There was insufficient time for extensive literature searches. Very little information was available on the effects of flooding or lack of flooding on the plants concerned, so the predictions are based largely on the intuition and experience of the author, in collaboration with colleagues from the other two countries. Ten indicators were identified for the two sites in Namibia, of which nine were present at site 4 (Kapako) and five were present at site 5 (Popa).

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ABBREVIATIONS

ABBREVIATION	MEANING
EF	Environmental Flow
EFA	Environmental Flow Assessment
DSS	Decision Support System
IUA	Integrated Units of Analysis
NBRI	National Botanical Research Institute (of Namibia)

ACKNOWLEDGEMENTS

Thanks to Frances Crawford and Shirley Bethune for assistance with plant collections and deciding on indicators; to Amândio Gomes (Angola vegetation specialist) and Casper Bonyongo (Botswana vegetation specialist) for discussions on responses of indicators to changes in flow; to Coleen Mannheimer of the NBRI for help with plant identification; to Esmerialda Klaassen of the NBRI for plant species lists; to Ben van der Waal for boat transport during the January fieldtrip; to Shirley Bethune, Namibian team leader, for co-ordination of the project in Namibia, comments on the manuscript and input during the scenario workshop; to Celeste Epach for production of the maps. Special thanks to Prof. William (Fred) Ellery of Rhodes University for commenting on the manuscript.

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.

This preliminary EFA is a joint project of EPSMO and the Biokavango Project. One component of the preliminary EFA is a series of country-specific specialist studies, of which this is the Vegetation Report for Namibia.

1.2 Okavango River Basin EFA Objectives and Workplan

1.2.1 Project objectives

The goals of the preliminary 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
- 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;
- to include in each scenario the major positive and negative ecological, resource-economic and social impacts of the relevant developments;
- 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 at a preliminary level are:

- 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;
- to ascertain the existing relationships between the river ecosystem and peoples' livelihoods;

- to predict possible development-driven changes to the flow regime and thus to the river ecosystem;
- to predict the impacts of such river ecosystem changes on people's livelihoods.
- to use the EFA outputs to enhance biodiversity management of the Delta.
- to develop skills for conducting EFAs in Angola, Botswana, and Namibia.

1.3 Layout of this report

Chapter 1 gives a brief introduction to the background of the project and lists project objectives. Chapter 2 describes the broad study area of the Okavango River Basin and gives more detail on the two specific sites chosen for this preliminary EFA within the Namibian section of the river - Kapako and Popa rapids. In Chapter 3, the nine vegetation indicators are described for the two Namibian sites. Flow categories are also indicated. A short literature review pertinent to vegetation work in the Okavango River is given in Chapter 4, with indicators described in more detail. The field survey work undertaken for the vegetation investigation within Namibia in January 2009 (wet season), including data collection, analysis and results, is outlined in Chapter 5. Chapter 6 is a first attempt to link vegetation to flow and to provide information on the flow-response relationships for use in the Okavango EF-DSS. References are found in Chapter 7. Appendix A shows photographs of the Namibian vegetation indicators, while Appendix B contains some of the raw field data.

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.

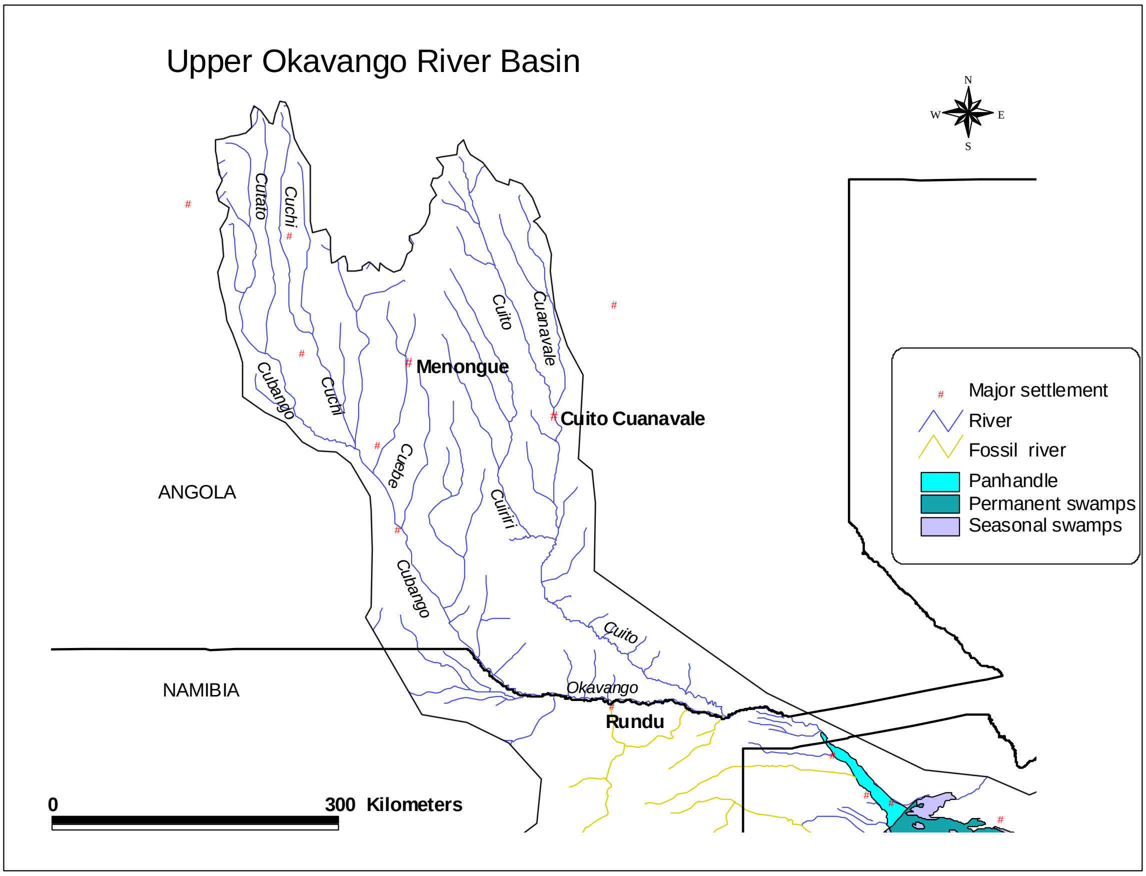


Figure 2. 1: Upper Okavango River Basin from the sources to the northern end of the Delta

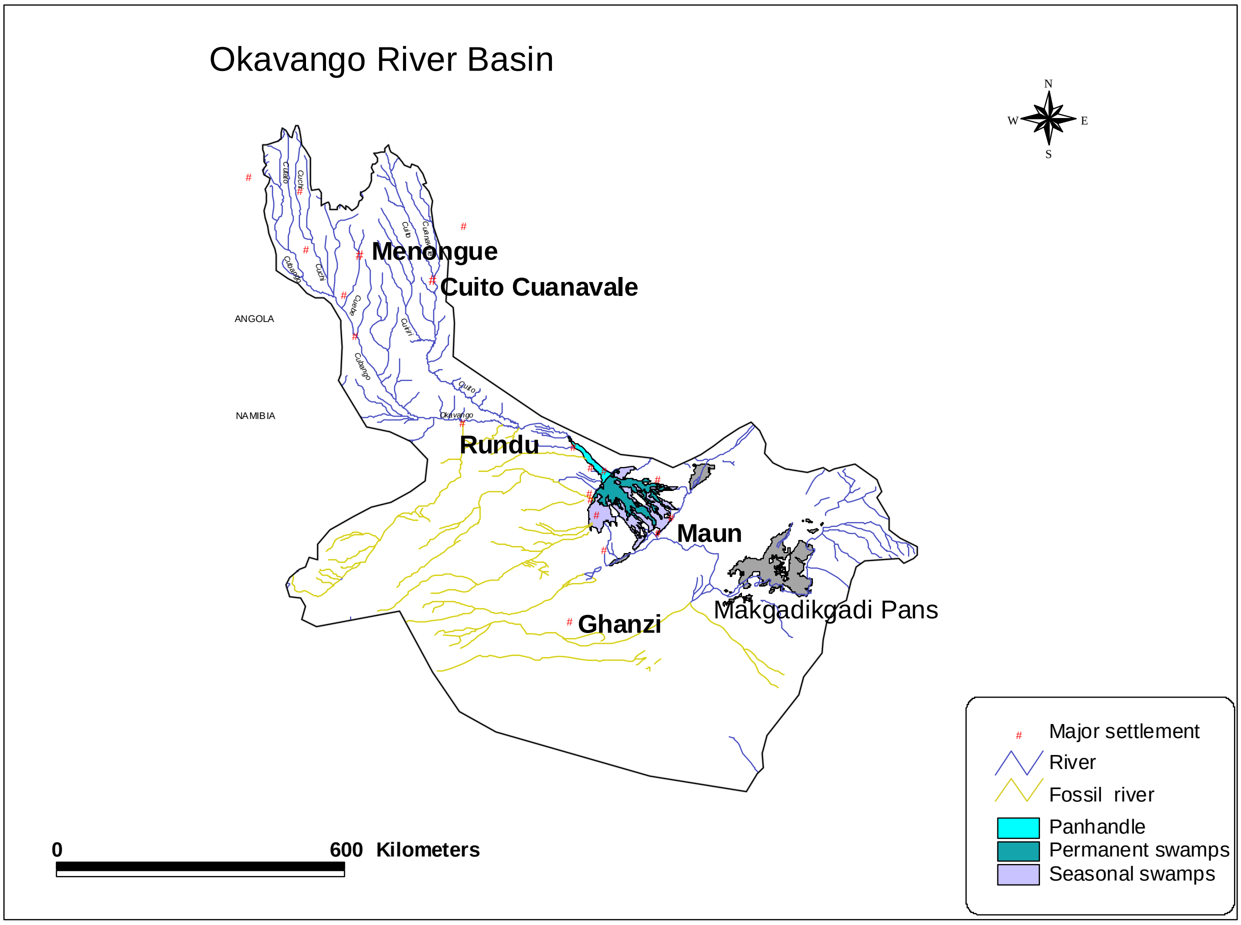


Figure 2. 2: The Okavango River Basin, showing drainage into the Okavango Delta and the Makgadikgadi Pans

2.2 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:
dividing the river into relatively homogeneous longitudinal zones in terms of:

- hydrology;
- geomorphology;
- water chemistry;
- fish;

aquatic macro-invertebrates;
vegetation;
other wildlife
harmonising the results from each discipline into one set of biophysical river zones;
dividing the basin into relatively homogeneous areas in terms of social systems;
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.

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

Table 2. 1: Location of the eight EFA sites

2.3 Overview of 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; the longest section that extends from where the river enters Namibia at Katwitwi to the Cuito confluence that is typified by the meandering mainstream and large seasonally-flooded floodplains on either side to the river (Kapako site 4, was chosen as a typical floodplain and mainstream site within this section); the section immediately downstream of the Cuito confluence that has permanently swamped areas and large islands (not included in the preliminary survey but essential to include in a later more detailed EFA study); the southward flowing rocky, braided section from Mukwe to just below the Popa rapids where the river is largely confined to the mainstream and flows around several sand and rock based islands (Popa rapids Site 5, was chosen as a typical rocky river site within this section) and the protected section of the river downstream of Popa to the border with Botswana at Mohembo that lies within the newly declared Bwabwata National Park which has two of its core conservation areas on either side of the river, the Buffalo core area on the east bank and the Muhango core area on the west bank.

2.3.1 Site 4: Okavango River at Kapako

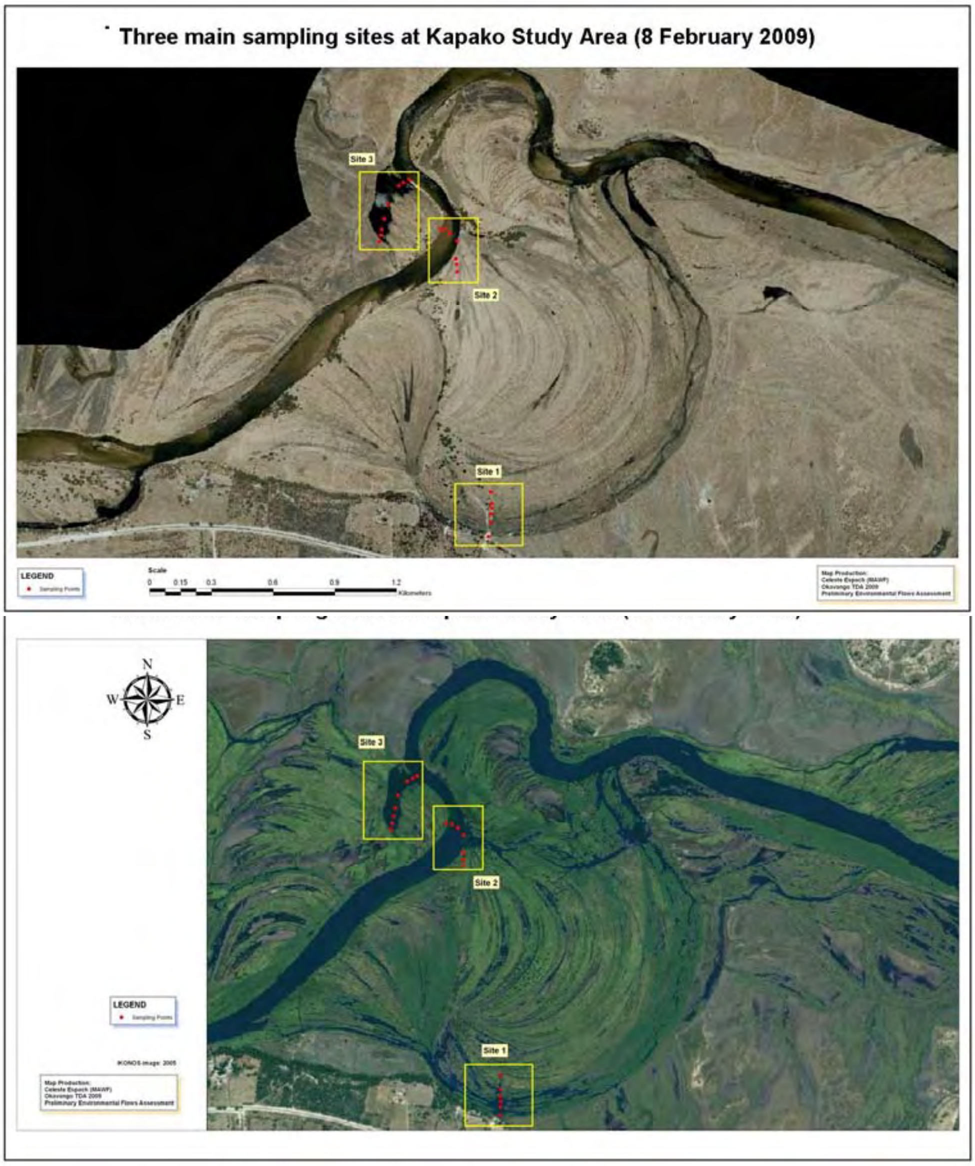


Figure 2. 3: Satellite images of the Kapako floodplain (site 4) in the dry season (top) and wet season (below). The main sampling sites used by all disciplines except vegetation are indicated. Maps by Celeste Espach.

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 metres above the floodplain (this was vegetation indicator 6, Floodplain dry bank)

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 Poplations 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.

During the focus group discussion held at Kapako village, the basin residents mentioned that the flooding starts when the rising river and channel 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.

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 clearing and thus of bare ground and erosion 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.

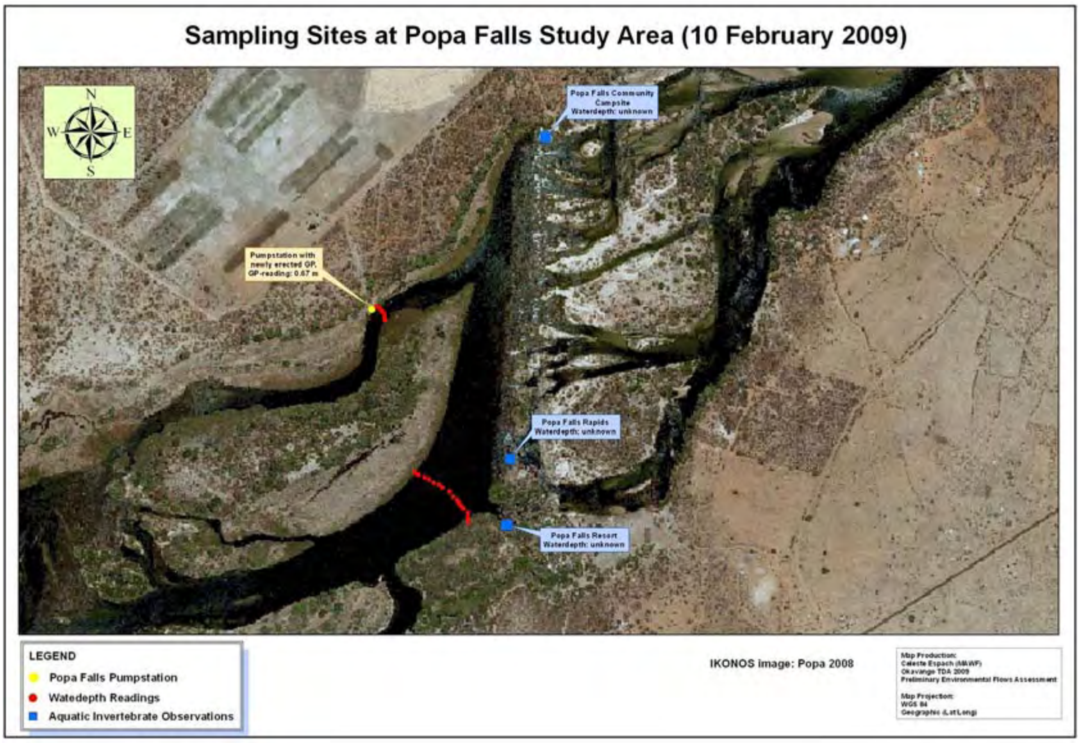
2.3.2 Site 5: Okavango River at Popa Falls

At the Popa rapids, the entire width of the river cascades down several 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).

Papyrus (*Cyperus papyrus*) dominates the deepest water margins alongside the main channels. Water can seep through the walls of papyrus to the reed beds 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 australis*, bulrushes, *Typha* and the grass *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 resident; most of them are employed within the lodges around the Popa area. They value tourism as their major source of income.



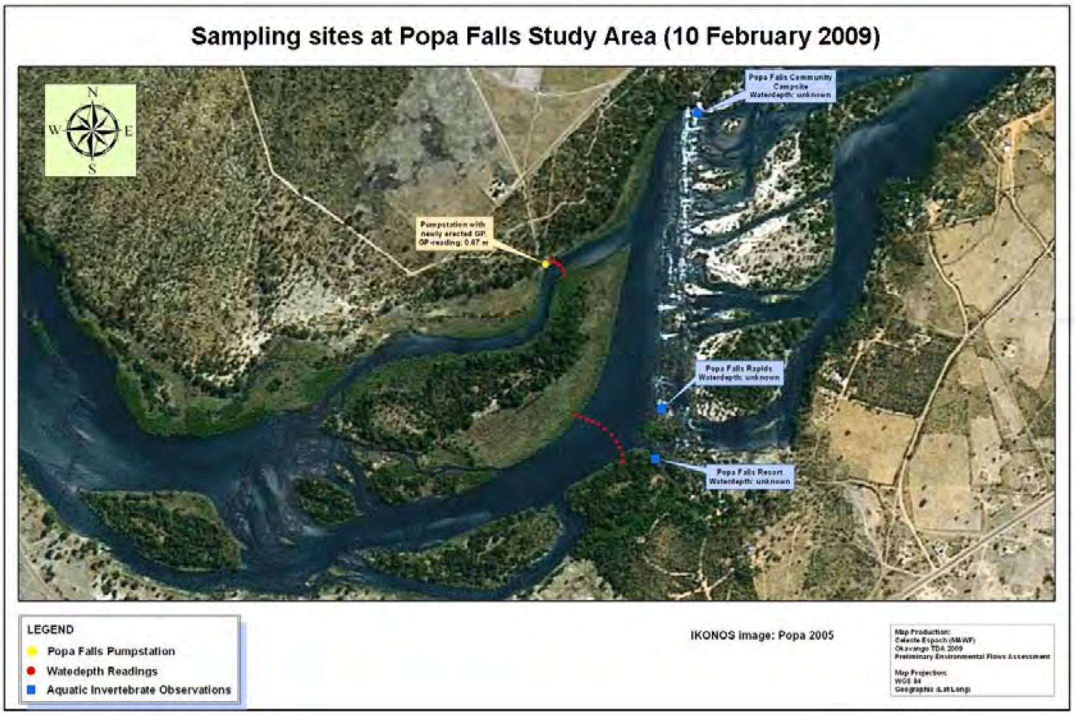


Figure 2. 4: Satellite images of the wet (below) and dry (top) season for Popa rapids (site 5). Transect and main sampling sites for all disciplines other than vegetation are shown. Maps prepared by Celeste Espach.

2.4 Discipline-specific description of Namibian sites

2.4.1 Site 4: Kapako

At Kapako the river curves to the north. On either side of the mainstream, but more so on the southern (Namibian) side, there are extensive floodplains in the form of concentric scroll bars formed as the river channel has changed with time. This means that as the flood comes down, the deeper channel areas fill first, with the water gradually spreading over the whole area. Although the satellite images show clear concentric bands on the floodplain, the differences in vegetation are not as clear cut. There are patches of one species interspersed with individuals of another, and then scattered individuals of the first species among other vegetation again. The highest points of the bars, forming the upper floodplain “islands” that are flooded for the shortest periods of time, are dominated by the shrubby river rhus (*Searsia quartiniana*), with the Chobe candle-pod acacia (*Acacia hebeclada* ssp. *chobiensis*) and a few shrubby umbrella thorns (*Acacia tortilis*). A few islands have striking specimens of the paperbark acacia (*Acacia sieberiana*). Various grass species are found. Slightly lower, on the edges of these “islands” and flooded for longer, are the pygmy fig (*Ficus pygmaea*) and the spindly shrub *Tacazzea apiculata,* along with young reeds and grasses *Setaria sphacelata* var. *sericea* and *Panicum coloratum* var. *coloratum.* In the lower-lying sections of the floodplain are extensive stands of grasses *Setaria sphacelata* var. *sericea* and *Panicum coloratum* var. *coloratum,* and deeper still are beds of hippo grass (*Vossia cuspidata*). There are also some permanent floodplain pools that seem to retain water, even in the dry season.

Along the outer edge of the floodplain (on the Namibian side – we did not look at the Angolan side) is the river bank, which has a moderate to steep slope out of the floodplain (This has been called Floodplain Dry Bank). The upper wet bank, closest to the water and periodically flooded at very high water, is dominated by the river rhus (*Searsia quartiniana*), with buffalo thorn (*Ziziphus mucronata*). Both of these species are often standing in water. Along the banks and playing an important role in stabilising the bank is the large-leaved albizia (*Albizia versicolor*) and an occasional strangler fig (*Ficus burkei*). Dominant shrubs in the under-story include the rough-leaved raisonberry (*Grewia flavescens*) and *G. olukondae.* The outer, dry bank is dominated by lead wood (*Combretum imberbe*) and umbrella thorn (*Acacia tortilis*), with patches of camel thorn (*Acacia erioloba*) and occasional buffalo thorn. Dominant shrubs include the magic guarri (*Euclea divinorum*), bloubos (*Diospyros lycioides*), *Grewia flavescens, G. schinzii* and *G. olukondae.*

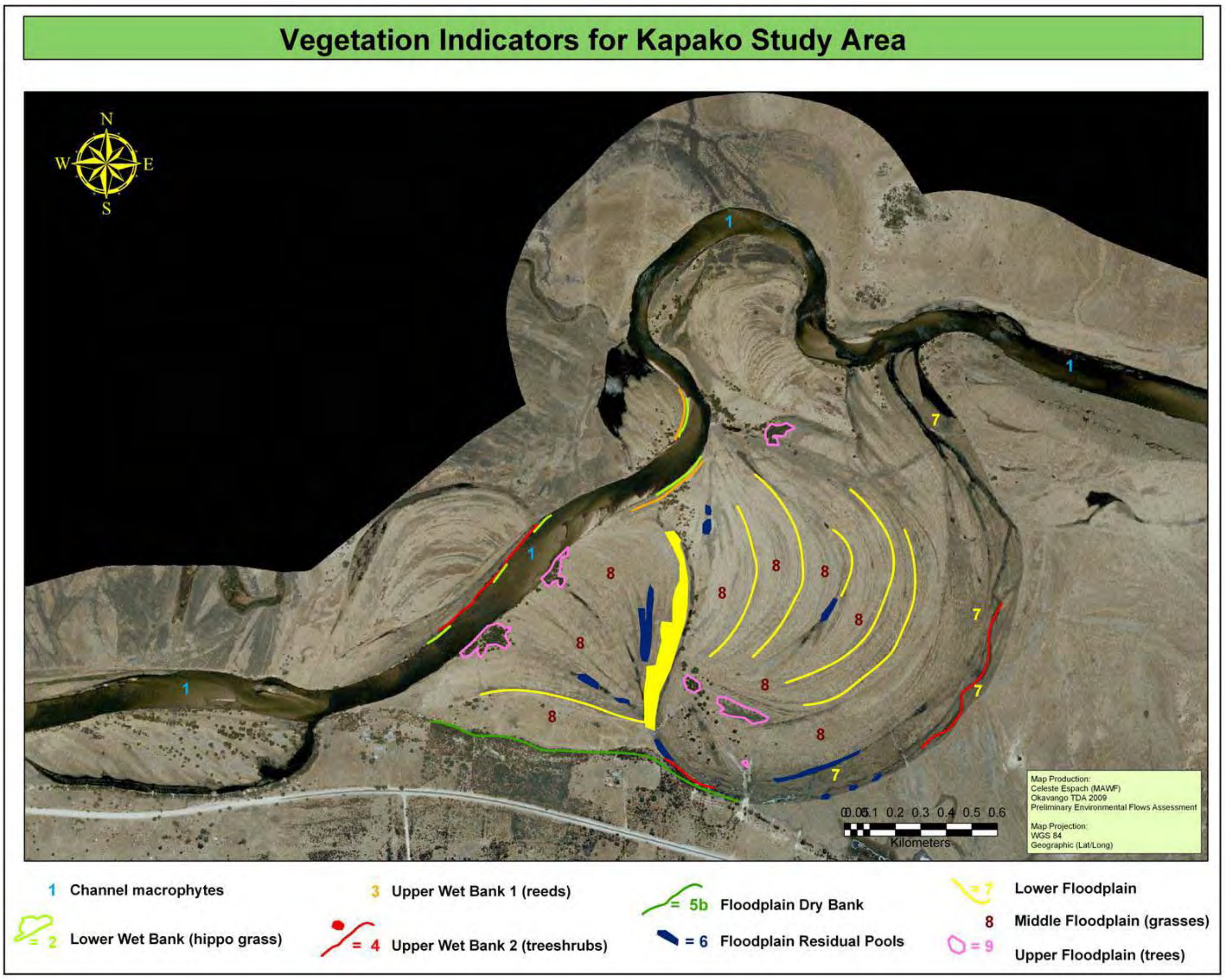


Figure 2. 5: Kapako floodplains showing the location of the nine vegetation indicators

2.4.2 Site 5: Popa Falls

The main river splits and flows around a number of islands. Each main channel is lined by submerged vegetation; then a zone of papyrus (*Cyperus papyrus*) with numerous water daisies (*Aspilia mossambicensis*) and occasional pygmy figs (*Ficus pygmea)* and bog ferns (*Thelypteris interrupta*); then reeds which span the interface between permanently flooded river and the dry bank. The river bank has a dense riparian woodland. The upper wet bank is dominated by the river rhus, with the water pear (*Syzygium guineense* ssp*. barotsense*), the safsaf willow (*Salix mucronata* ssp. *mucronata*), the waterberry (*Syzygium cordatum*), the lance-leaved waxberry (*Morella serrata*), the wild date palm (*Phoenix reclinata*) and buffalo thorn. The species stabilising the banks include the African mangosteen (*Garcinia livingstonei*), the large-leaved albizia (*Albizia versicolor*) and the jackal berry (*Diospyros mespiliformis*). The large tree component of the dry bank vegetation is dominated by the jackal berry and African mangosteen, with sausage tree (*Kigelia africana*). Dominant shrubs include (*Friesodielsia obovata*), *Antidesma venosum*, *Diospyros lycioides*, *Grewia flavescens*, knobbly combretum (*Combretum mossambicense*), *Markhamia obtusifolia,* potato bush (*Phyllanthus reticulates*). The forest well beyond the water line is dominated by *Acacia nigrescens* and *Terminalia sericea* with *Philenoptera violacea* and *Peltophorum africanum.*

The larger islands have a vegetation structure similar to that of the banks of the main channel, but with narrower zones, and sometimes with the vegetation of the zones becoming intermixed. Thus there can be papyrus and reeds growing together, and in places the papyrus/reed zone was part of the upper wet bank zone. Much of the under-story of the island was dominated by the softly woody pioneer shrub *Acalypha ornata.* Due to the dense riparian woodland there is very little grass cover, but grass *Setaria sphacelata* var. *sericea* was found on the gently sloping edges of the islands.

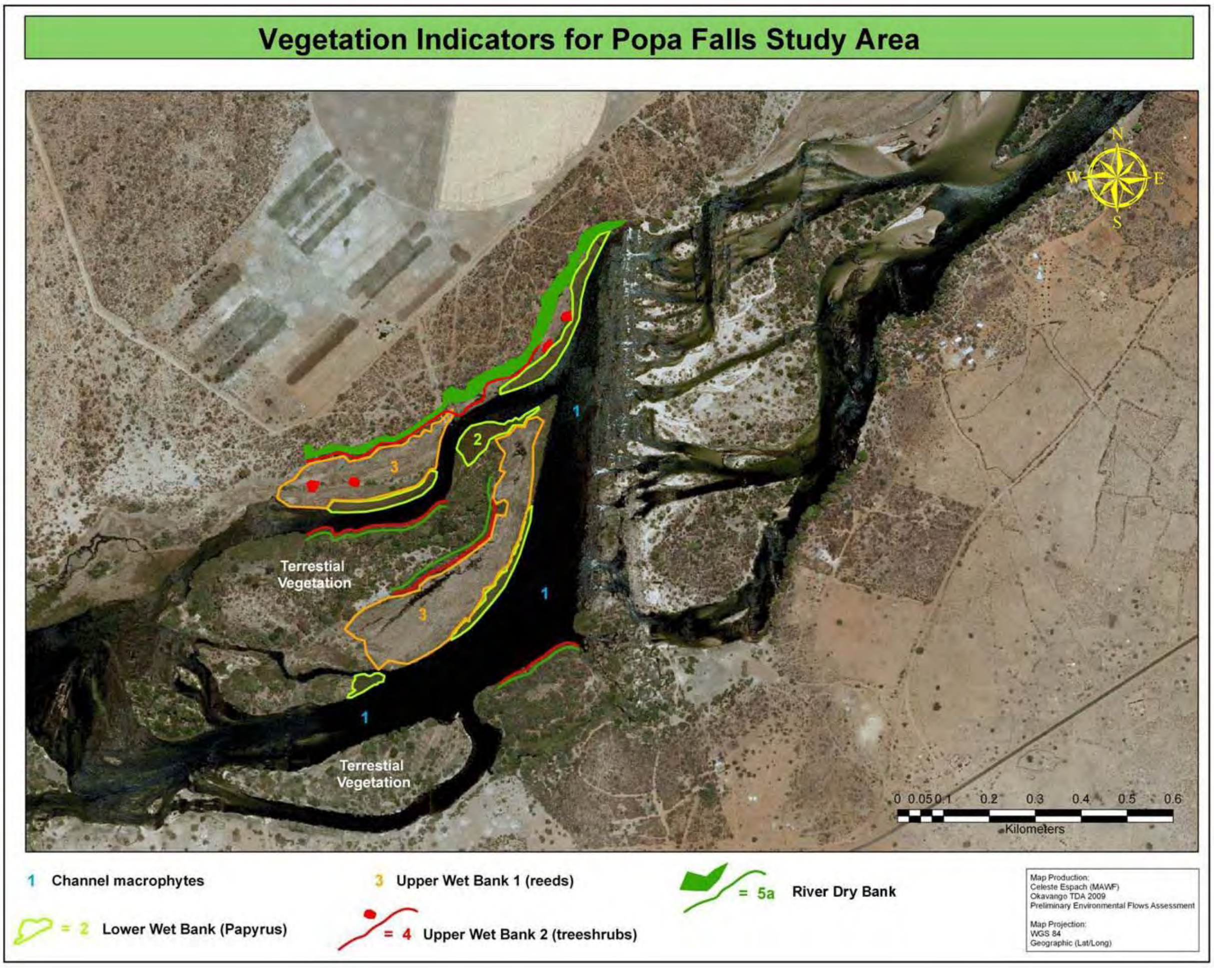


Figure 2. 6: Popa Falls showing the location of the five vegetation indicators

3. IDENTIFICATION OF INDICATORS AND FLOW CATEGORIES

1.1 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 Vegetation

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 – Amândio Gomes, Barbara Curtis and Casper Bonyongo - and is provided in Table 3.1. Further details of each indicator, including the representative species of each biological one, are given below, and are discussed fully in Chapter 4. Photographs are provided in Appendix A.

Indicator Number	Indicator name	Sites represented – no more than ten indicators per site							
		1	2	3	4	5	6	7	8
1	Channel macrophytes				x	x			
2	Lower wet bank (papyrus / hippo grass)				x	x			
3	Upper wet bank 1 (reeds)				x	x			
4	Upper wet bank 2 (trees & shrubs)				x	x			
5	River dry bank				-	x			
6	(River) floodplain residual pools				x	-			
7	(River) lower floodplain				x	-			
8	(River) middle floodplain				x	-			
9	(River) upper floodplain				x	-			
10	Floodplain dry bank				x	-			

Table 3. 1: List of indicators for river vegetation and those chosen to represent each site in Namibia

3.1.3 Description and location of indicators

Vegetation Indicator 1

Name: Channel macrophytes (submerged)

Description: Totally or almost entirely submerged, rooted or floating macrophytes in the main river channel(s).

Representative species: *Potamogeton* spp. (pondweed), *Vallisneria aethiopica* (no common name), *Lagarosiphon ilicifolius* (oxygen weed) (Bethune, 1991).

Other characteristic species: *Myriophyllum seratum* (Bethune, pers. comm.)

Flow-related location: Inner edge or centre of the channel; moving water. Will always be inundated, even at low flow. If the river divides and goes around islands, this indicator is likely to be found in all the channels.

Known water needs: This community is totally dependent on permanent inundation and would die if it dried out, even for short periods. Will be impacted by sediment load and turbidity, which could reduce light penetration. Thus linked to water quality and water level.

Vegetation Indicator 2

Name:	Lower wet bank
Description:	Community of floating macrophytes with stems forming a dense mat and leaves and inflorescences carried well above the water.
Representative species:	*Vossia cuspidata* (hippo grass) (sites 4 and 5); *Cyperus papyrus* (papyrus) (site 5) (pers. obs.)
Other characteristic species:	*Aspilia mossambicensis* (river daisy) (site 5), *Thelypteris interrupta* (bog fern), *Ficus pygmaea* (pygmy fig) (site 5; maybe site 4) (pers. obs.), *Miscanthus junceus* (swamp savanna grass/pampas grass) (Barnes, in litt., 2009; Ellery & Ellery, 1997).
Flow-related location:	Edge of main channel, beyond indicator 1, but always inundated, even at low flow. Moving water.
Known water needs:	Needs permanent inundation. Sine it is floating it can tolerate any high water levels.

Vegetation Indicator 3

Name:	Upper wet bank 1 (reeds)
Description:	Rooted macrophytes at wetted edge during low flow, submerged at high flow.
Representative species:	*Phragmites australis* (pers. obs.)
Other characteristic species:	*Phragmites mauritianus* (NBRI database, 2009)
Flow-related location:	At the location of the wetted edge during dry-season low flow. Moving water.
Known water needs:	Can withstand dry periods for up to several months. Can withstand total inundation for long periods as well. Linked to social.

Vegetation Indicator 4

Name:	Upper wet bank 2 (trees and shrubs)
Description:	Edge of wetted bank of main channel or floodplain at high flow; can be inundated during high flow.
Representative species:	*Searsia (Rhus) quartiniana* (river rhus) (sites 4 & 5); *Syzygium guineense* ssp. *barotsense* (water pear) (site 5) (pers. obs.).
Other characteristic species:	*Ziziphus mucronata* (buffalo thorn) (mainly site 4); *Salix mucronata* ssp. *mucronata* (safsaf willow), *Syzygium cordatum*

	(waterberry), *Morella* (*Myrica*) *serrata* (lance-leaved waxberry), *Phoenix reclinata* (wild date palm) (Site 5) (pers. obs.)
Flow-related location:	Seasonally inundated. Edge of wetted bank at high flow. Moving water or standing water.
Known water needs:	Tolerant of long periods of inundation; generally on edge of river, with some roots in the wet and some on dry land; most will probably not tolerate long period of desiccation. Important for holding the river bank, therefore linked to geomorphology.

Vegetation Indicator 5

Name:	River dry bank
Description:	Upper river bank of river channel or river islands, influenced by the high water table associated with the river, but seldom to never totally inundated. Riparian species that need to be near but not in water.
Representative species:	*Diospyros mespiliformis* (jackal berry) (site 5) (pers. obs.).
Other characteristic species:	*Combretum imberbe (*lead wood), *Acacia tortilis* (umbrella thorn), (site 4), *Grewia flavescens, G. olukondae, G. schinzii,* magic guarri (*Euclea divinorum*), bloubos (*Diospyros lycioides*) (sites 4 & 5); (*Friesodielsia obovata*), *Antidesma venosum*, bloubos, *Grewia flavescens*, knobbly combretum (*Combretum mossambicense*), *Markhamia obtusifolia,* potato bush (*Phyllanthus reticulata*), sausage tree (*Kigelia africana*); *Garcinia livingstonei* (African mangosteen), (site 5) (pers. obs.).
Flow-related location:	Above all but the highest flows; taps water table, which is recharged and thus influenced by river flows.
Known water needs:	Can withstand short periods of inundation in very wet years but cannot withstand long periods of inundation. Would only be influenced by reduced flow if these have an effect on the water table. Representative species dependent on high water table. Some of the associated species are terrestrial species that do not need the high water table. These are also important for stabilising the river banks, and are therefore linked to geomorphology.

Vegetation Indicator 6

Name:	River floodplain residual pools
Description:	Pools on floodplain at site 4 that are deep enough to retain water permanently.
Representative species:	*Nymphaea nouchalii* var. *caerulea, N. lotus* (pers. obs.)

Other characteristic species: *Nymphoides indica* ssp. *occidentalis; Aeschynomene fluitans; Utricularia* cf. *benjaminiana* (pers. obs.)

Flow-related location: Standing water, recharged seasonally by flood waters. Connected to river during high flow but retain water during normal low flow.

Known water needs: Cannot withstand desiccation. Plants will die if they dry out. Can withstand higher inundation, provided inundation does not occur too quickly. These plants are rooted, with leaves on the surface and flowers protruding above the water.

Vegetation Indicator 7

Name: (River) lower floodplain

Description: The deeper sections of channels between scroll bars that flood seasonally, but probably often retain water in the dry season.

Representative species: *Vossia cuspidata* (pers. obs.)

Other characteristic species: *Persicaria attenuata* ssp. *africana; Ludwigia* sp. (pers. obs.)

Flow-related location: Inundated at high water for longer periods

Known water needs: Can withstand some desiccation and long periods of inundation

Vegetation Indicator 8

Name: (River) middle floodplain

Description: The shallower sections of floodplain channels, on the lower edges of the floodplain islands, on clay or sand. This area can be quite extensive in places and supports the floodplain grasses that are important for grazing and maybe thatching grass.

Representative species: Grasses *Setaria sphacelata* var. *sericea* (specimen BC2009/2) and *Panicum coloratum* var. *coloratum* (specimen BC2009/4) (field collection, January 2009 – see chapter 5)

Other characteristic species: young *Phragmites* sp; *Ficus pygmaea; Tacazzea apiculata;* other grasses e.g. *Vetiveria, Eragrostis, Sporobolus* (pers. obs.)

Flow-related location: Seasonally flooded for shorter periods than indicator 7, but longer than indicator 9.

Known water needs: Needs periodic flooding, can withstand periods of total inundation or desiccation. Grazing for cattle in dry season – linked to social.

Vegetation Indicator 9

Name: (River) upper floodplain (islands)

Description: The highest points of the scroll bars on the floodplain, often forming islands. Only inundated during high flow.

Representative species: River rhus (*Searsia quartiniana*); Chobe candle-pod acacia (*Acacia hebeclada* ssp. *chobiensis*).

Other characteristic species: Shrubby umbrella thorns (*Acacia tortilis*) and *Combretum imberbe.* Occasional large *Acacia sieberiana* (pers. obs.). Grasses.

Flow-related location: only inundated at high flow

Known water needs: Can withstand standing in water from long period, and limited periods of desiccation. Linked to water level and social.

Vegetation Indicator 10

Name: Floodplain Dry Bank

Description: Upper bank of river floodplain adjacent to the floodplain, influenced by the high water table associated with the river, but seldom to never totally innundated. Tree and shrub species with a wide tolerance to desiccation and occasional inundation.

Representative species: *Combretum imberbe* (lead wood), *Acacia tortilis* (umbrella thorn).

Other characteristic species: *Albizia versicolor* (large-leafed albizia); *Grewia flavescens, G. olukondae, G. schinzii,* magic guarri (*Euclea divinorum*), bloubos (*Diospyros lycioides*) (sites 4) (pers. obs.).

Flow-related location: Above all but the highest flows; taps water table, which is influenced and recharged by floods.

Known water needs: Essentially terrestrial species that cannot withstand long periods of inundation. Would only be influenced by reduced flow if these have an effect on the water table. *Acacia tortilis* better able to withstand drop in water table than *Combretum imberbe.* These are also important for stabilising the river banks, and are therefore linked to geomorphology.

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 1-5 are shown in Figures 3.1 to 3.5. These seasonal divisions will be 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 suggesting, along with the hydrographs, a higher within-year flow variability of the Cuebe River and a higher year-on-year variability of the Cubango River.

It is planned to use similar flow seasons for the remaining river sites: 6 and 8.

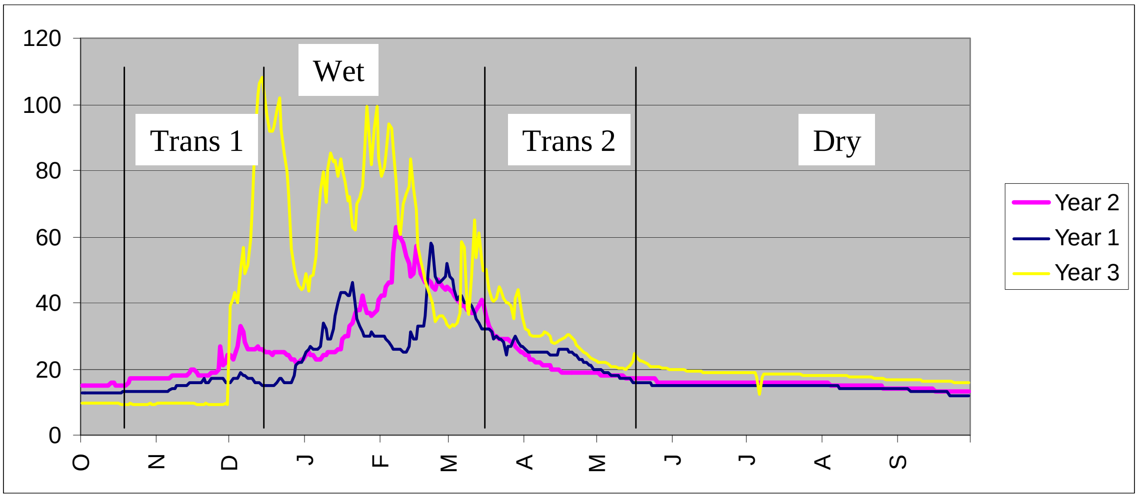


Figure 3. 1: Three representative years for Site 1: Cuebe River @ Capico, illustrating the approximate division of the flow regime into four flow seasons

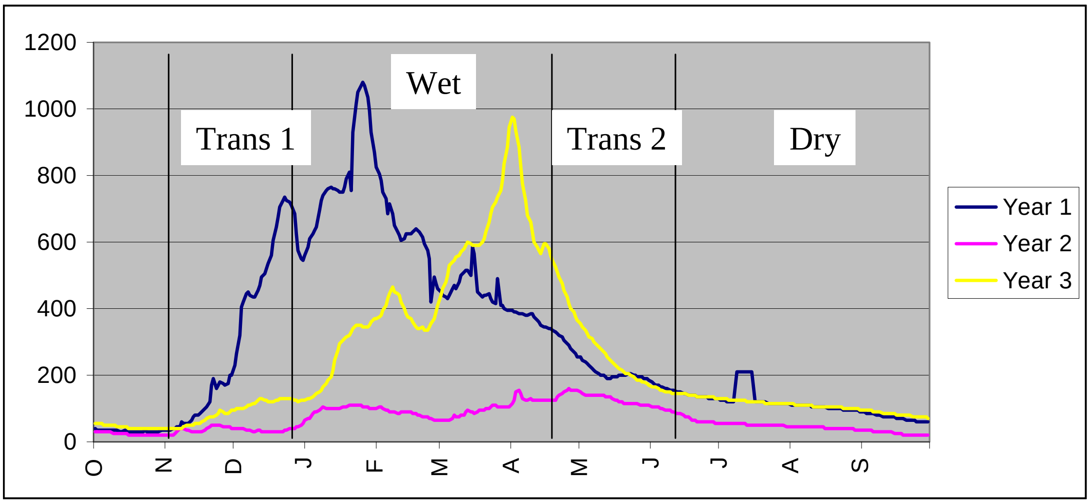


Figure 3. 2: Three representative years for Site 2: Cubango River @ Mucindi, illustrating the approximate division of the flow regime into four flow seasons

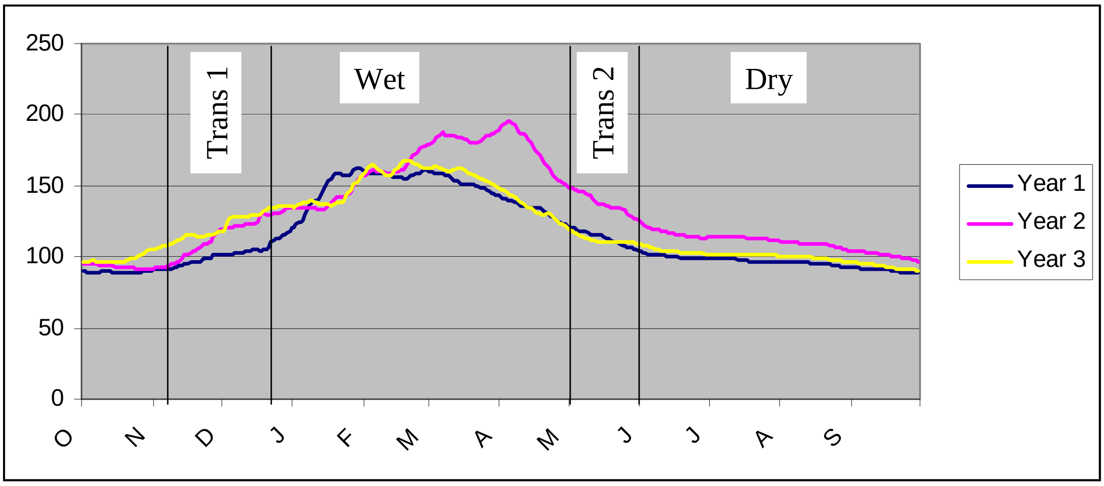


Figure 3. 3: Three representative years for Site 3 Cuito River @ Cuito Cuanavale, illustrating the approximate division of the flow regime into four flow seasons

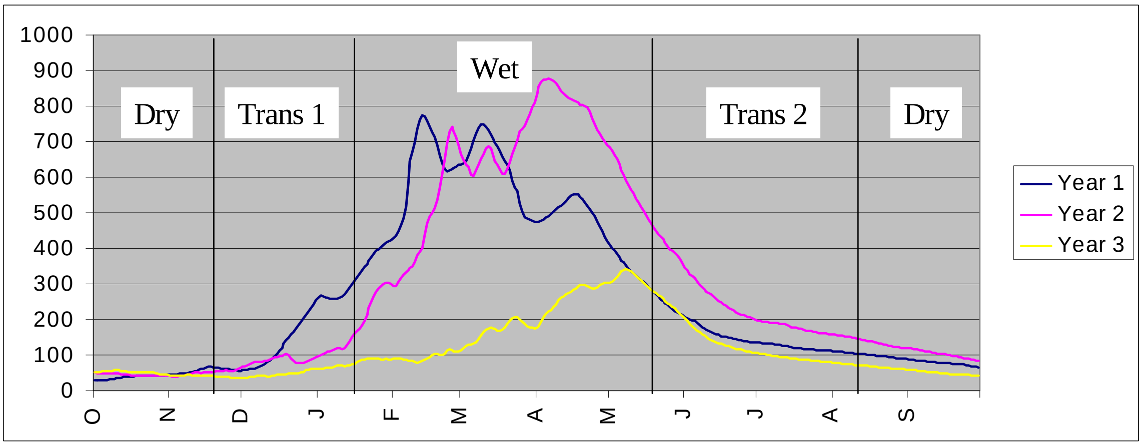


Figure 3. 4: Three representative years for Site 4: Okavango River @ Kapoka (hydrological data from Rundu), illustrating the approximate division of the flow regime into four flow seasons

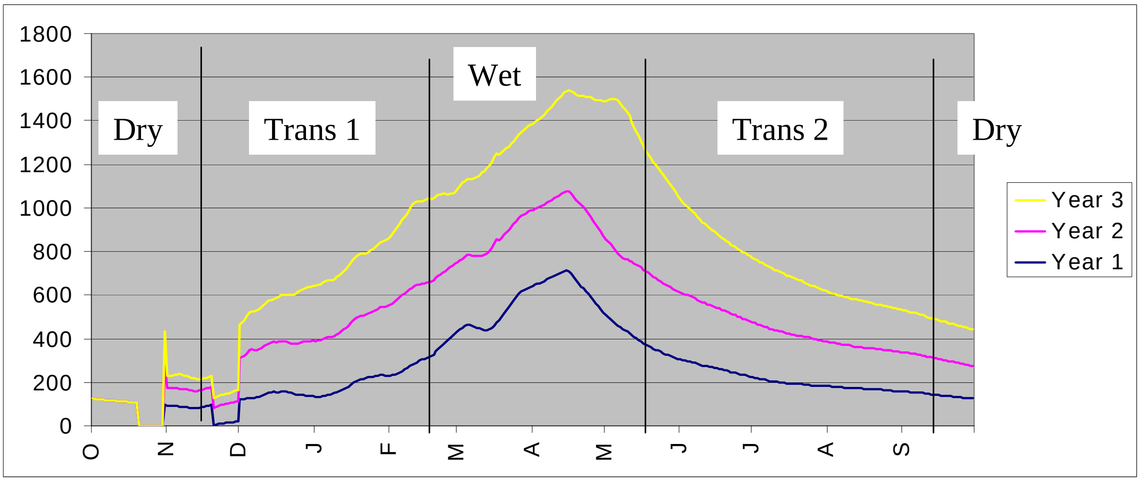


Figure 3. 5: Three representative years for Site 5: Okavango River @ Popa (hydrological data from Mukwe), illustrating the approximate division of the flow regime into four flow seasons

The literature review (Chapter 4) and data collection and analysis exercises (Chapter 5) are focused on addressing what was initially expected to be nine main questions related to these flow seasons (Table 3.2). In the end, owing to time constraints, transition 1 with its two questions was omitted at the workshop, and transition 2 was also omitted from the final scenarios.

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

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

3.3 Inundation categories – delta sites

Although these categories were not relevant to the Namibian sites, this section has been included for completeness. The recognised river flow categories are not relevant in the Delta, where inundation is the major driver of ecosystem form and functioning. The main inundation categories recognised by the inundation model developed by the Harry Oppenheimer Okavango Research Centre (HOORC) are used here (Table 3.3).

Inundation category number	Inundation category name
Delta 1	Channel in permanent swamp
Delta 2	Lagoons in permanent swamp
Delta 3	Backswamp in permanent swamp
Delta 4	Seasonal pools in seasonally flooded zones
Delta 5	Seasonal sedgelands in seasonally flooded zones
Delta 6	Seasonal grasslands

Table 3. 3: Inundation categories for the Okavango Delta as recognised by the HOORC inundation model

4 LITERATURE REVIEW

4.1 Introduction

As far as I am aware, no detailed studies have been undertaken on the vegetation of the Okavango River in Namibia. Mostly the vegetation is described in very broad terms. Correira & Bredenkamp (1987) listed the dominant grasses for swamps and river banks together (Table 4.1). Ellery (1997) identified eight communities on the floodplains and river banks. He did not go into any detail regarding the nature of the communities, nor the species found in them. Hines (2001) described broad plant communities on the floodplains east of Rundu. The National Botanical Research Institute (NBRI 2009) provided a list of species collected from the Okavango River as recorded on their specimen database, but these were only assigned to very broad habitats.

Grass species	Occurrence and life cycle
Vetiveria nigritana	Dense, perennial
Trachypogon spicatus	Dense, perennial
Phragmites mauritianus	Dense, perennial
Setaria sphacelata	Dense, perennial
Hypertelia dissolute	Dense, perennial
Andropogon gayanus	Dense, perennial
Schyzachyrium sanguineum	Dense, perennial
Eragrostis pallens	Dense, perennial
Eragrostis rotifer	Dense, perennial
Themeda triandra	Dense, perennial

Table 4. 1: . Floodplain and river bank grasses as listed by Correira & Bredenkamp (1987)

The indicators described in chapter 3 and presented in Table 3.1 are based on observations made during the field visit in January 2009 (chapter 5). Field guides and checklists were used to obtain information on the ecology of the species recorded during this field visit. Part of the discussion of the indicators in this section therefore also refers to observations made in January since there is nothing in the literature to describe some of these habitats.

Time did not permit an extensive search of the literature or the internet.

4.2 Indicator No 1: Channel macrophytes (submerged)

Main characteristics of Indicator 1

This indicator is in the permanently flowing water of the main river. Bethune (1991) listed *Potamogeton* spp. (pondweed), *Vallisneria aethiopica* (no common name) and *Lagarosiphon ilicifolius* (oxygen weed) as the characteristic species for this habitat. All members are either totally submerged, or the main body of the plant is submerged, with only the reproductive structures extending above the surface of the water. The plants may be rooted or floating. They are important because of their need for permanent, flowing, clear water. Poor water quality or low light penetration due to a high silt load are likely to affect it.

Species	**notes**
Potamogeton octandrus	rooted in main riverbed or in shallow margins (1)
Potamogeton schweinfurthii	running water and floodplain pools (1)
Vallisneria aethiopica	main channel of perennial rivers (1); backswamps of delta (2)
Lagarosiphon ilicifolius	rivers, backswamps (1); still or slow-flowing water (2)

Table 4. 2: Plant species recorded by Bethune (1991) in permanently flowing water.

Life cycle attributes of Indicator 1

Potamogeton spp flower in summer; flowers emergent or floating (Ellery & Ellery, 1997). In both *Vallisneria aethiopica* and *Lagarosiphon ilicifolius,* female flowers float on the water surface, attached to the plant while male flowers are released and free floating (Clarke & Klaassen, 200). Flowers in summer (Ellery & Ellery, 1997).

Links to flow

Entirely dependent on water for whole life cycle. Speed of current may affect these plants, as they may not be able to withstand currents that are too swift. Slower flow would probably not affect them as they all occur in slow flowing water as well as the swifter main channel. Would be expected to expand and contract in response to areas of permanent flooding. Changes in sediment flux as would be experienced by dam and weir construction could impact this indicator (Ellery, pers. com.).

4.3 Indicator No 2: Lower wet bank – papyrus and hippo grass

Main characteristics of Indicator 2

Vossia cuspidata is a “robust, perennial grass with spongy, floating, creeping stems, associated with deep, permanent water; common along the edges of primary channels. Usually dominant and may form floating rafts” (Ellery & Ellery 1997). It is rooted in the channel bed, but the extremely long, floating stems can trail out into the current. It generally occurs on the inner (convex) side of the channel where sediment flux is low (Ellery, pers. com.). *Cyperus papyrus* is a “very robust perennial sedge with stout creeping stems and erect stems in permanent swamps, especially fringing the major rivers where nutrient status of the water is higher than elsewhere. Can form floating rafts. Is very unpalatable and has a low forage quality, therefore supports few herbivores. Sitatunga feed on young shoots” (Ellery & Ellery 1997). It is rooted in the peat bank and grows into the channel from the peat bank on the edges of the channel (Ellery, pers. cm.). This indicator differs from indicator 1 by being on the edges of the main channel. It forms a covering blanket over the water that keeps out sunlight and therefore submerged plant life. It provides a refuge for animals such as fish.

Life cycle attributes of Indicator 2

Vossia cuspidata flowers early spring to autumn; *Cyperus papyrus* in summer (Ellery & Ellery, 1997). Both are perennial.

Links to flow

The plants can rise and fall with the water level since the majority of the plant is floating. *Vossia cuspidata* is able to withstand wide ranges in water level due to its very long stems, as well as a certain amount of desiccation. *Cyperus papyrus* is less tolerant of wide water level fluctuations. It cannot withstand as much deep inundation as *Vossia* can and cannot withstand desiccation as its roots require permanent, flowing water. Papyrus typically occurs where there is permanent water with a fairly small seasonal variation (Ellery, pers. com.). It only occurs at site 5 along the Namibian and Angolan sections of the river due to the deep water immediately upstream of Popa Rapids, which act as a natural spillway, ensuring a reduction in the normally high seasonal variations in water level (Ellery, pers. comm.). Hippo grass will therefore be more adaptable to changes in water level than will papyrus. As long as the water continues to flow, hippo grass should be alright at any water level, whereas papyrus may decline with declining water levels or marked changes to the flood regime.

4.4 Indicator No 3: Upper wet bank 1 - reeds

Main characteristics of Indicator 3

Phragmites australis can grown in damp ground, or standing water up to a metre deep or even as a floating mat (Wikipedia 2009). It can grow tall on the edges of the main channel of the river as it has the best access to nutrients that are brought down with the river water (Mendelsohn & El Obeid, 2004). It can withstand long dry periods in ephemeral rivers, but generally where there is groundwater close to the surface (pers. obs.). It reproduces vegetatively by means of stolons (underground horizontal stems) and rapidly colonises new areas, extending into areas that are further away from water and often becoming the dominant plants. It can occur where sedimentation is active, and will rapidly colonise recently formed depositional features (Ellery, pers. com.).

Life cycle attributes of Indicator 3

It flowers from late summer to early winter (Ellery & Ellery, 1997).

Links to flow

It is very adaptable to variations in water level, being able to withstand long periods of desiccation as well as permanent flooding. It does not need flowing water but it does best where there is at least some soil moisture. With a lowering of the volume and duration of flooding it is likely to expand into areas occupied by the indicators on either side of it.

4.5 Indicator No 4: Upper wet bank 2 – trees and shrubs

Main characteristics of Indicator 4

This indicator possibly corresponds with Ellery's (1997) community number 5 – transitional between floodplain and terrestrial environment, dominated by the grass *Cynodon dactylon* (couch grass).

At site 4 (Kapako), where there is a much greater seasonal fluctuation in water levels than at site 5 (Popa) the representative species of this indicator reflect the variable nature of the indicator. *Searsia (Rhus) quartiniana* is a dense shrub or tree with a wide range of ecological tolerances within the context of perennial rivers (Ellery, pers. com.). It is found along the banks and floodplains of perennial rivers, on islands in permanent swamps, as well as occasionally in ephemeral watercourses (Curtis & Mannheimer, 2005, Ellery, pers. com.). *Ziziphus mucronata* is found in a variety of different habitats; very often close to water, but it can also be found far from water. At Popa, the species associated with this indicator are also always associated with permanent water, and reflect the fact that the water levels are much higher for longer than at site 4.

Life cycle attributes of Indicator 4

Searsia (Rhus) quartiniana flowers from October to June (Curtis & Mannheimer, 2005). *Ziziphus mucronata* flowers from October to April, while *Phoenix reclinata* flowers from August to December (Coates Palgrave, 2002; Curtis & Mannheimer, 2005). The other species flower from late winter to early summer (Curtis & Mannheimer, 2005; Ellery & Ellery, 1997).

Links to flow

Searsia (Rhus) quartiniana occurs where there is permanent water (Ellery & Ellery, 1997), but can withstand some drying out, as long as its roots have access to ground water. The other species associated with this indicator at site 4 are very tolerant of desiccation. A prolongation of the flood season may affect the roots of many of these species due to water-logging of the soil. The associated species at site 5 can withstand longer periods of inundation, but are not tolerant of desiccation.

4.6 Indicator No 5: River dry bank

Main characteristics of Indicator 5

Large trees and a dense shrub layer are important for stabilising the river bank. They grow near water but generally not in the water. This corresponds with Ellery's (1997) community number 6 – broadleaved riparian woodland dominated by broadleaved evergreen trees, with a low cover of the grass *Cynodon dactylon* (couch grass).

Life cycle attributes of Indicator 5

Garcinia livingstonei and *Albizia versicolor* flower in spring and early summer, while *Diospyros mespiliformis* flowers from August to January (Curtis & Mannheimer, 2005). *Combretum imberbe* and *Acacia tortilis* flower in summer (Ellery & Ellery, 1997). Flowering is probably more related to daylength, temperature and rainfall than to river flow.

Links to flow

These trees and shrubs do not get water directly from the river, but from groundwater seepage from the river. *Combretum imberbe* and *Acacia tortilis* are not water dependent and are found in many habitats away from water, although the former is most often associated with rivers. *Albizia versicolor, Garcinia livingstonei* and *Diospyros mespiliformis* are never found far away from permanent water (Curtis & Mannheimer, 2005). The latter three species can presumably tolerate standing in water for longer periods than the former two, but none is adapted to long periods of inundation.

4.7 Indicator No 6: River floodplain residual pools

Main characteristics of Indicator 6

This correlates with Ellery's (1997) aquatic community dominated by *Nymphaea nouchali* var. *caerulea.* The plants of this community are all dependent on standing or slow-flowing, permanent water, which is linked to and recharged by the main river.

Life cycle attributes of Indicator 6

Nymphaea lotus flowers in summer, while *N. nouchali* flowers throughout the year, but most commonly in summer (Ellery & Ellery, 1997).

Links to flow

This community would die if the pools dry out. They would be tolerant of increased water levels or periods of inundation. *Nymphaea* spp have the ability to adapt rapidly to changing water levels as the leaf stalks grow continuously and quickly (Ellery & Ellery, 1997).

4.8 Indicator 7: River lower floodplain

Main characteristics of Indicator 7

These are the deeper parts of the channels on the floodplains that receive water from the river at high flow, and presumably retain water for long periods, based on the water-loving species that are found in them. They link up with the residual pools. They seem to have a mixture of species that prefer permanent water (*Vossia cuspidata*) and species that are found along the waters edge and can also grow on dry land but close to water (*Persicaria, Ludwigia* and some *P. australis*). These species are tolerant of total inundation for long periods and desiccation for varying periods. Their leaves float on the surface of the water, while the flowers are held above the water. This could correspond with Ellery's (1997) lower floodplain community (see indicator 8 below).

Miscanthus junceus (swamp savanna grass/pampas grass) is an important floodplain thatching grass in Namibia (Barnes, in litt. 2009), and would probably also occur in this indicator. According to Ellery & Ellery (1997) it is usually found in permanent water, often in channel fringes. It is an unpalatable climax species. It grows in coarse, sandy soil, and plays an important part in purifying water and stabilising river banks (van Oudtshoorn, 2006).

Life cycle attributes of Indicator 7

Vossia cuspidata flowers early spring to autumn. *Persicaria* spp flower in summer, while *Ludwigia* spp. flower most of the year (Ellery & Ellery, 1997). *Miscanthus junceus* flowers from November to June (van Oudtshoorn, 2006).

Links to flow

Vossia cuspidata and *Miscanthus junceus* prefer permanent water, while the two dicotyledonous plants can probably withstand a short periods of desiccation. None would be able to withstand long totally dry periods.

4.9 Indicator No 8: River middle floodplain

Main characteristics of Indicator 8.

This possibly corresponds with Ellery's (1997) lower floodplain community dominated by *Brachiaria* sp., *Echinochloa pyramidalis* and *Phragmites australis. Brachiaria humidicola* (creeping signal grass) (Klaassen & Craven, 2003) was collected in this habitat during the January fieldtrip (Appedix B). It is a palatable climax grass that is mostly found in damp places along floodplain margins in Botswana (Ellery & Ellery, 1997). *Echinochloa pyramidalis* (antelope grass) is a palatable climax grass that occurs typically in swamps, standing in water or floating (Ellery & Ellery, 1997; Klaassen & Craven, 2003).

Setaria sphacelata var. *sericea* and *Panicum coloratum* var. *coloratum* were the two species found to be the most abundant during the fieldtrip described below (see chapter 5). According to Ellery & Ellery (1997), the former occurs in a wide range of habitats, but prefers seasonally wet areas with heavy textured soils. It is a climax grass that is moderately palatable but unable to withstand continuous grazing. In Namibia, it occurs mainly along the perennial rivers in the north-east, but is also found in vleis and marshes, and occasionally in other habitats (Klaassen & Craven, 2003) and has been described as 'dense' (Correira & Bredenkamp, 1987 - see table 4.9 below) and 'common' (NBRI 2009) along the Okavango. *Panicum coloratum* var. *coloratum* is a very palatable climax grass that is extremely valuable graze for large herbivores (Müller, 2007). It thrives on heavy clay soils as well as damp sandy soils, and is widespread in Namibia.

In Angola *Vetiveria nigritana* is one of the dominant grasses in this indicator (King, in litt. 2009). This is also a common grass in the upper panhandle (Ellery & Ellery, 1997). It normally occurs in seasonally flooded or wet areas on heavy clay, but in the Okavango it is found on organic-rich sand. It is an unpalatable climax grass (Ellery & Ellery, 1997), which is used as thatching grass in Namibia (Klaassen & Craven 2003). It was not listed in the NBRI species list for the river (NBRI 2009).

Life cycle attributes of Indicator 8.

Setaria sphacelata var. *sericea* and *Panicum coloratum* var. *coloratum* are both perennial grasses. Both flower from summer to autumn (Ellery & Ellery, 1997; van Oudtshoorn, 2006).

Links to flow

Both the dominant species are able to grow in areas away from water, but thrive in seasonally wet areas. An increase in the length of inundation may be detrimental, but they would probably survive longer dry periods.

4.10 Indicator No 9: River upper floodplain (islands)

Main characteristics of Indicator 9

This probably corresponds with Ellery's (1997) two upper floodplain communities although those two may correspond with indicator 8. Ellery lists three species of *Eragrostis,* only one of which (*E. porosa*) has been recorded once along the Okavango (Klaassen & Craven 2003; Müller, 2007). *Eragrostis rotifer* was collected in January (Appendix B). This is a widespread species that is sometimes found in damp places (Müller, 2007).
This indicator is somewhat higher than indicator 8, with trees and shrubs that are absent from indicator 8. However, the distinction between the two in terms of grass species present is not clear cut. Some of the woody species that occur here are the same as those found in indicator 4, namely *Searsia quartiniana,* which can withstand being submerged for part of the season. The really water-dependent species

Life cycle attributes of Indicator 9

Searsia (Rhus) quartiniana flowers from October to June; *Acacia hebeclada* in August and *Acacia sieberiana* mainly in Octobe (Curtis & Mannheimer, 2005). Most of the grasses collected are perennials that flower late summer and autumn (Ellery & Ellery, 1997; van Oudtshoorn, 2006).

Links to flow

This indicator will be inundated for short periods during high floods, but will also be exposed during the dry season. It will be better able to tolerant longer dry periods than longer wet periods.

4.11 Indicator No 10: Floodplain dry bank

Main characteristics of Indicator 10

This indicator is similar in composition to indicator 5, but has none of the species that are strongly dependent on a high ground water table, and more terrestrial species that can survive being far from water but do not mind standing in water for short periods.

Life cycle attributes of Indicator 10

Combretum imberbe and *Acacia tortilis* flower in summer (Ellery & Ellery, 1997). Flowering is probably more related to day length, temperature and rainfall than to river flow.

Links to flow

These trees and shrubs do not get water directly from the river, but from groundwater seepage from the floodplain. *Combretum imberbe* and *Acacia tortilis* are not water dependent and are found in many habitats away from water, although the former is most often associated with rivers. *Albizia versicolor* is generally found near water or in areas with a high water table (Curtis & Mannheimer, 2005). None of these species is adapted to long periods of inundation.

4.12 Summary

A far more detailed survey needs to be undertaken during each of the four flow seasons in order to be able to really define the indicators and see which species are associated with each. The boundaries between indicators are fuzzy, with the same species occurring in a few indicators in greater or lesser abundances.

The plants along the river are all probably fairly adaptable. Communities are very fluid and will shift with changes in the flow regime, unless these changes are very drastic.

The major gaps are:

1) the boundaries of the indicators or the component species of the indicators.

2) how these plants will respond to changes in water level and duration of inundation / exposure

3) the extent of flooding of the river and floodplains under various flow regimes

4) the relationship between ground water and surface flow

5 DATA COLLECTION AND ANALYSIS

5.1 Methods for data collection and analysis

Vegetation was samples at sites 4 and 5 from 5 - 9 January 2009. As this was before the main team sampling took place in February, the sites used for vegetation are not the same as those used by the other specialists. The water was much higher than it normally is at this time of the year, and could be regarded as high flood, but not yet maximum flood for the season. It was not possible to get to the main river at site 4, but the floodplain communities were sampled in an area close to the south bank (Sampling site 1 in Map of Kapako). It was assumed that these were representative of the whole floodplain. At site 5 I was able to get onto one of the islands and look at the eastern side of the island. Due to the impenetrable nature of the vegetation on the centre of the island, it was not possible to cross the island and look at the other side, but it is assumed that the vegetation structure would be similar.

Plant specimens were collected of all the dominant grasses, for identification. Notes were made on the presence of woody species. The dominant species were recorded by observing how often they were seen and the extent of their occurrence. No quantitative data were collected.

5.2 Results

The communities described in chapter 3 are mainly based on observations made during this field trip and will not be repeated here.

Setaria sphacelata var. *sericea* and *Panicum coloratum* var. *coloratum* were the two species found to be the most abundant on the shallower margins of the floodplain pools (indicator 8 habit). Other species collected are given in Appendix B.

5.3 A summary of present understanding of the predicted responses of all vegetation indicators to potential changes in the flow regime

The tables that follow summarise the predicted responses for each vegetation indicator to changes in the flow regime.

5.3.1 Indicator 1 – (Submerged) Channel Macrophytes

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	There will be no significant changes. With an increase in water volume, there could be an increase in cover. With a slight decrease in volume, there could be an increase in light penetration and nutrients, leading to more growth and thus more cover. With a larger decrease in volume, there will be less water area for the plants to cover, therefore a decrease in cover. With a stop in flow, only remnant pools will be left in which the plants can survive, thus there will be an overall decrease in the area available to them and thus in cover.	medium
3		Extends longer than natural	An extended dry season means reduced or no flood, therefore less input of nutrients, which could affect the growth of these plants resulting in decreased cover.	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	Seed germination and seedling growth may be affected if the start of the flood season is extended into the winter, or comes too early in the summer before seeds have been produced.	medium
7		Natural proportion of different types of flood year changed	Even with no flood onto the floodplain, there will still be water in the main channel, which will move further into or out of the channel, depending on the depth, thus no change in cover. In a big flood, the rate of increase of the water could be too rapid for the plants to be able to respond. This will result in too little light which will adversely affect them. There will also be a dislodging of the plants with a faster current. This will result in a decrease in cover.	low
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	If the flood drops too quickly the plants will collapse as they are supported by the water, thus a steeper hydrograph will result in reduced plant cover.	medium

Table 5. 1: Predicted response to possible changes in the flow regime of (Submerged) Channel Macrophytes in the Okavango River ecosystem

5.3.2 Indicator 2 - Lower wet bank (papyrus and hippo grass)

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	No effect on *Vossia* at site 4. Could affect papyrus at site 5 if dry season flows are low.	medium
3		Extends longer than natural	An extremely long dry period would exacerbate the effects of desiccation and stress the plant further, resulting in a decrease in cover with increase in dry season length. *Vossia* will be ok, papyrus will be affected.	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	medium
7		Natural proportion of different types of flood year changed	nil	medium
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 2: Predicted response to possible changes in the flow regime of Lower wet bank in the Okavango River ecosystem

5.3.3 Indicator 3 – Upper wet bank 1 (reeds)

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	high
2		Water levels are higher or lower than natural	A stop in flow could result in the reeds being out of water for the dry season, which will stress them a bit and could lead to a slight decrease in cover.	high
3		Extends longer than natural	The longer it is dry, the more the plants will be stressed, thus an extension of the dry season could result in a decrease in cover. A decrease in length of dry season could result in an increase in cover.	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 season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	high
7		Natural proportion of different types of flood year changed	No flood at all will lead to the reduction in extent of this Indicator unless the water table is very close to surface (<0.5m). It doesn't matter how high the flood is, the ground remains as saturated. Extended duration of flood could result in a slight increase in cover.	high
8	Transition 2	Onset is earlier or later than natural	nil	high
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	high

Table 5. 3: Predicted response to possible changes in the flow regime of Upper wet bank 1 in the Okavango River ecosystem

5.3.4 Indicator 4 – Upper wet bank 2 (trees and shrubs)

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	These plants need to have a certain amount of water in the dry season. They cannot withstand a long period of desiccation. No flow in the dry season could lead to a decrease in cover.	low
3		Extends longer than natural	If the dry season lasts a year, this will affect the water level and these water-loving trees may be stressed, with a resultant decrease in cover.	medium
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	low
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	medium
7		Natural proportion of different types of flood year changed	Very little. Too long a flood will cause plants to stand in water for too long, which will have a negative impact.	medium
8	Transition 2	Onset is earlier or later than natural	nil	low
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 4: Predicted response to possible changes in the flow regime of Upper wet bank 2 in the Okavango River ecosystem

5.3.5 Indicator 5 – River Dry Bank

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	Possibly a very slight negative impact if there is no flow in the dry season – could affect the water table.	medium
3		Extends longer than natural	If dry season carries on for too long, i.e. if there is a reduced flood, this would affect the ground water recharge, which would have a negative impact.	medium
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		medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	medium
7		Natural proportion of different types of flood year changed	An exceptionally high flood could cause the dry bank species to be inundated for period that could be detrimental to them. A long duration flood will cause water-logging of the soil, which will have a negative impact on these trees	medium
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 5: Predicted response to possible changes in the flow regime of River Dry Bank in the Okavango River ecosystem

5.3.6 5.3.6 Indicator 6 - River floodplain residual pools

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	little	medium
2		Water levels are higher or lower than natural	nil	high
3		Extends longer than natural	A long dry season will result in increased evaporation, which will affect the pools, leading to a decrease in cover. A short dry season will be good for the plants in the pools, leading to an increase in cover.	high
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	medium
7		Natural proportion of different types of flood year changed	The bigger the flood, the better for the pools, therefore a positive impact. No flood will result in the pools not being replenished and therefore reducing in size or drying up, thus a negative impact. The longer the flood season, the better for the pools. The shorter, the more likely the pools are to dry up.	medium
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 6: Predicted response to possible changes in the flow regime of River floodplain residual pools in the Okavango River ecosystem

5.3.7 Indicator 7 - River lower floodplain

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	nil	medium
3		Extends longer than natural	The longer the dry season, the more these plants will decrease. A short dry season will result in an increase.	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	medium
7		Natural proportion of different types of flood year changed	A higher flood will extend the area in which these plants can grow and thus have a positive impact, and vice versa. The longer the flood, the better for these plants, and vice versa.	medium
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 7: Predicted response to possible changes in the flow regime of River lower floodplain in the Okavango River ecosystem

5.3.8 Indicator 8 - Rivermiddle floodplain (grasses)

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	little effect as dominant plants are also terrestrial	medium
2		Water levels are higher or lower than natural	little	medium
3		Extends longer than natural	When dry season is short, lower floodplain grasses will increase at the expense of these grasses (encroachment). And these grasses will be waterlogged for longer. With longer dry period, these grasses can move into the lower floodplains.	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	low
7		Natural proportion of different types of flood year changed	Middle grasses can move into areas now occupied by lower floodplain grasses at low volume and vice versa in big flood.	low
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 8: Predicted response to possible changes in the flow regime of River middle floodplain in the Okavango River ecosystem

5.3.9 Indicator 9 – River upper floodplain (islands)

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	little	medium
3		Extends longer than natural	If the dry season is too short, the soil may not dry out sufficiently for the roots of these trees and shrubs, thus there will be a slight negative effect. However, if the dry season lasts a year or more, the ground will become too dry for these species, and there will also be a negative effect.	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	low
7		Natural proportion of different types of flood year changed	Too much water will waterlog these species. Too little water can be detrimental. Thus both extremes would have a negative impact. If the flood doesn't reach the floodplain, this will result in the plants becoming a bit stressed due to dry roots. At the other extreme, if the flood lasts too long, the roots could become waterlogged.	low
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 9: Predicted response to possible changes in the flow regime of River upper floodplain in the Okavango River ecosystem

5.3.10 Indicator 6 – Floodplain Dry Bank

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	nil	medium
2		Water levels are higher or lower than natural	nil	medium
3		Extends longer than natural	nil	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	nil	medium
7		Natural proportion of different types of flood year changed	This indicator is dependent on ground water. Big floods would spill further onto the floodplain and there would be more recharge of the ground water, which could result in a positive impact. Small floods that do not get onto the floodplain will not recharge the aquifer, which could result in a negative impact. The longer the water stays on the floodplain, the greater the recharge of the aquifer.	medium
8	Transition 2	Onset is earlier or later than natural	nil	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	nil	medium

Table 5. 10: Predicted response to possible changes in the flow regime of Floodplain Dry Bank in the Okavango River ecosystem

5.4 Conclusion

The combination of extent and duration of inundation, volume and speed of flood, timing of flooding, changes in sediment erosion and deposition, as well as changes in water chemistry all act together to affect the response of the indicators to change. Another very important aspect that should not be overlooked is the cumulative effect of changes over a period of time. While plants may be able to withstand changes for a year or two, prolonged unnatural flow regimes will push the plants beyond their tolerance limits. The whole situation is also compounded by the impact of human and human-induced activities on the plants.

Much more time needs to be spent in the field in the dry and wet seasons in order to determine which species are included in each indicator, and to delineate the indicators, as well as to monitor their response to normal seasonal and non-seasonal changes in flow.

Nevertheless, based on what we currently know of the response of plants to a variable flow regime, we can make informed predictions as to how these indicators will react to unnatural changes in flow regime.

6. Flow-response relationships for use in the Okavango EF_DSS

Flow response curves were built at the Knowledge Capture Workshop, held in Windhoek in March 2009. They are all available on CD. From these response curves, predictions can be made about the response of the various indicators to possible water-related development scenarios. This is discussed fully in a separate report.

7. REFERENCES

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APPENDIX A: PICTORIAL DESCRIPTIONS OF NAMIBIAN VEGETATION INDICATORS

The pictures below show the various indicators at the two Namibian sites, numbered according to table 3.1. In sections of the river and floodplain not all the indicators are present, and one indicator may be immediately adjacent to another that does not follow after it numerically. On the floodplains it is very difficult to delineate the various habitats (indicators) as they merge into each other and plant species do not stick to their demarcated habitats.

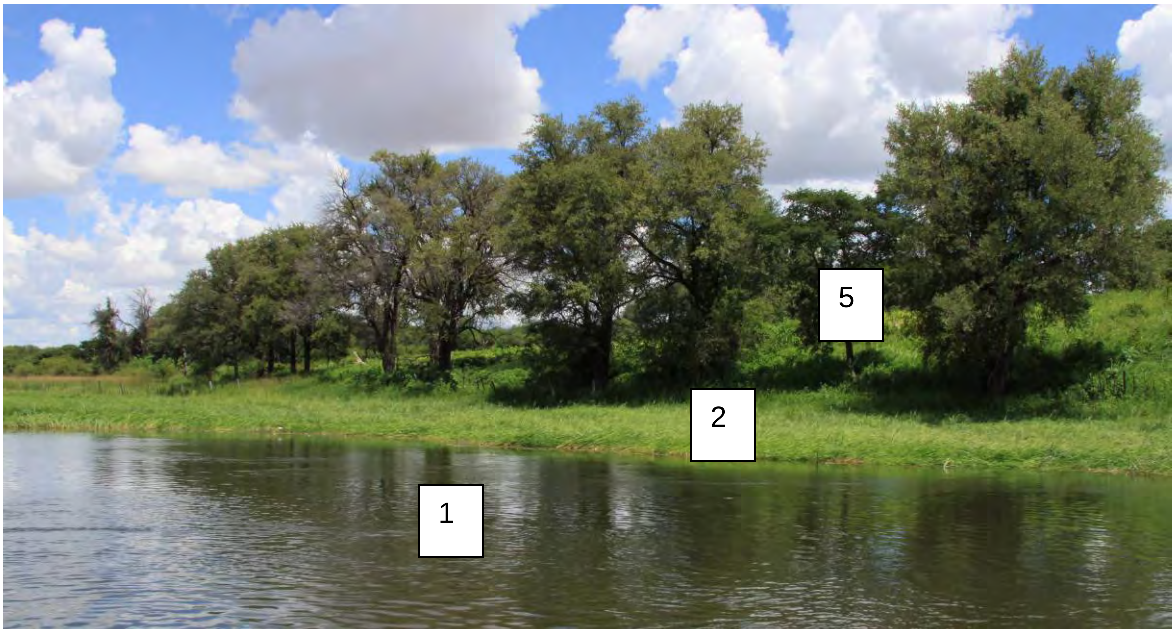

Figure A1: Kapako – River, looking north (Angola) where the river is adjacent to the bank, showing three indicators. Trees in indicator 5a - on left are *Acacia* sp., on right *Combretum imberbe.* (photo: Colin Christian, February 2009)

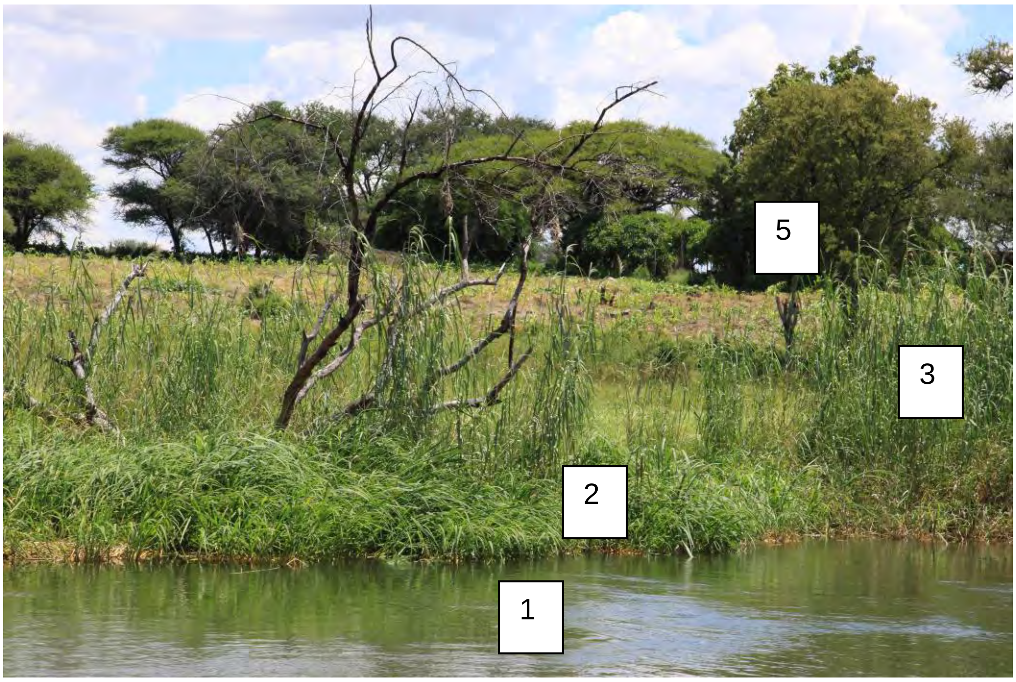

Figure A2: Kapako – River, looking north, where the river is adjacent to the bank, showing four river habitats. Habitat 4 has been removed to make fields. (photo: Colin Christian, February 2009)

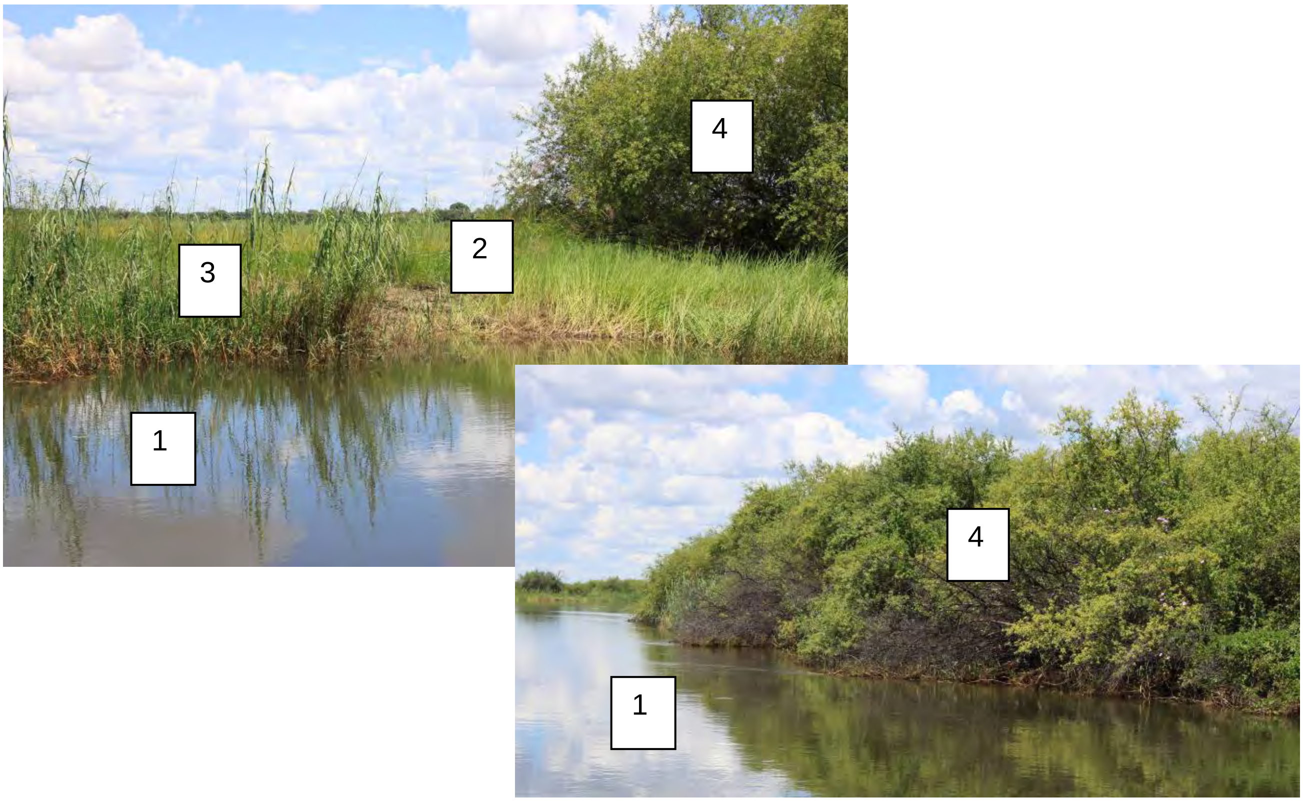

Figure A3: Kapako – River looking north, showing tree indicators. In places (e.g. below) indicator 4 is immediately adjacent to indicator 1. Indicator 4 is represented by *Searsia (Rhus) quartiniana* here. (photos: Colin Christian, Feb 2009).

Figure A4: Kapako – River looking north, showing how the river has eroded the bank, adjacent to indicator 8 on the floodplains. (photo: Colin Christian, February 2009)

Figure A5: Kapako floodplain, looking from an open water channel (indicator 7) lined with hippo grass on the left and right, southwards towards the floodplain dry bank (indicator 5b) with *Albizia versicolor* on the left, *Combretum imberbe* in the centre (with cars and people underneath). On the right are *Searsia quartiniana* and *Ziziphus mucronata* (indicator 4) with reeds just in front (indicator 8) (enlarged below). (photo: Barbara Curtis, January 2009)

Figure A6: Kapako floodplain pool (indicator 6) right up against the upper wet bank 2 (indicator 4) and floodplain dry bank (indicator 5b) on the southern edge of the floodplain. Beyond is hippo grass (indicator 7), with small floodplain islands (indicator 9) interspersed among the hippo grass. (photo: Barbara Curtis, January 2009)

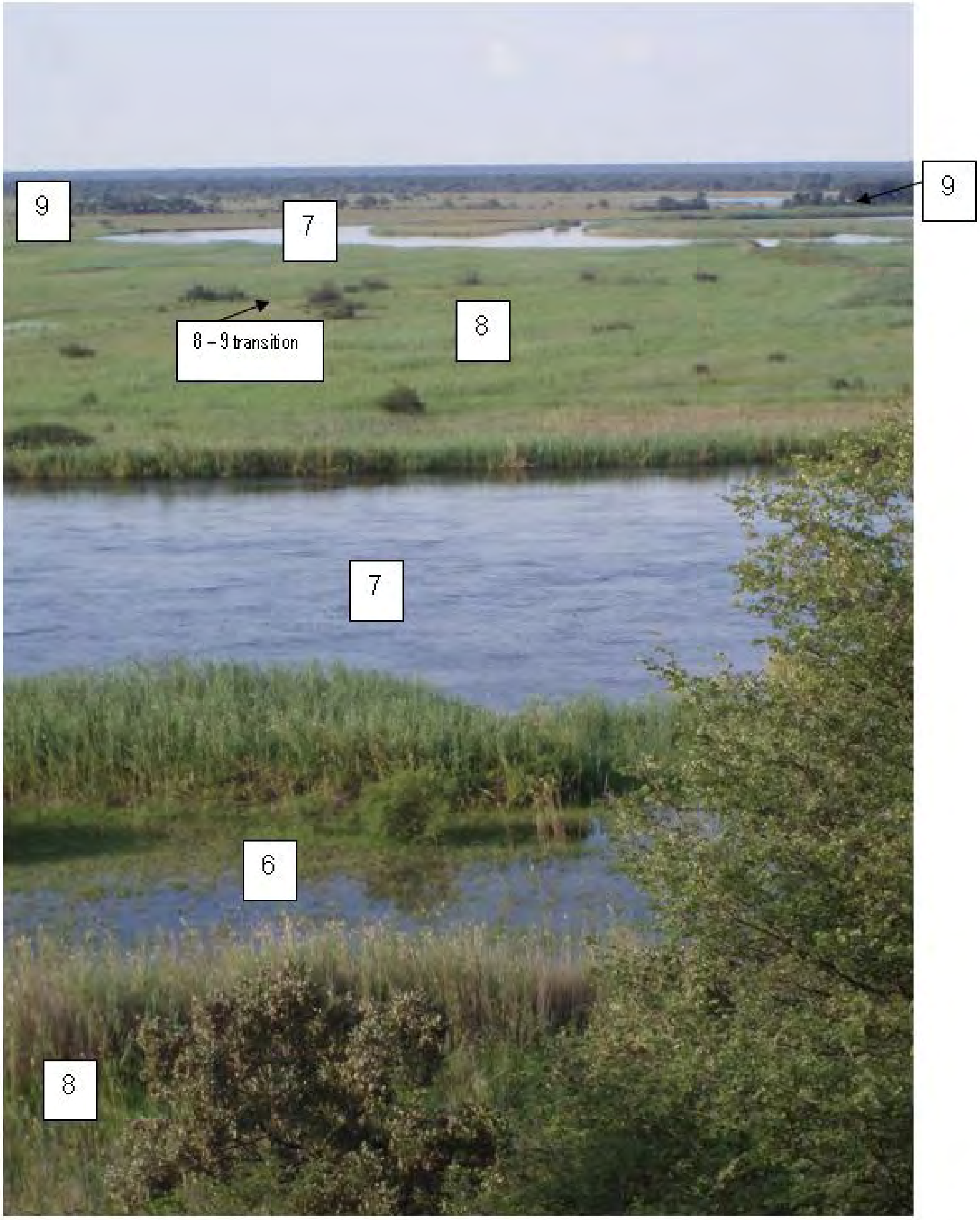

Figure A7: Kapako – looking from the south bank, northwards across the floodplain, toward the river, showing the various floodplain indicators. (photo: Barbara Curtis, January 2009)

Figure A8: Kapako floodplain pool (indicator 6), with hippo grass (indicator 7) on the left, giving way to indicator 8. Indicators 4 &5 in the background. (photo: Barbara Curtis, January 2009). Below are members of the floodplain pool community. Top right: *Aeschynomene fluitans*; left centre *Nymphaea nouchalii* var. *caerulea*; right centre *Nymphaea lotus*; bottom left *Nymphoides indica*; bottom right *N. nouchalii* var. *caerulea* flower with *Trapa natans* leaves. (photos: B. Curtis, Jan 2009, except bottom right, Colin Christian)

Figure A9n(above): Kapako floodplains, indicator 7. Above, extensive area of hippo grass, *Vossia cuspidata*. Below *Persicaria attenuate* ssp. *africana*. (photos: Barbara Curtis, January 2009)

Figure A10 (below): Kapako floodplain, indicator 8.
Top left: Indicator 8 on left, adjacent to indicator 5 with *Acacia tortilis* on right. Top right *Setaria sphacelata* var. *sericea*. Bottom left: *Panicum coloratum*. Bottom right *Ficus pygmaea* – pygmy fig. (Photos: Barbara Curtis, January 2009)

Figure A11: Kapako floodplain island with *Searsia quartiniana* (indicator 9) behind, hippo grass (indicator 7) and open water in front, and young reeds (indicator 8) between the two. (photo: Barbara Curtis, January 2009)

Figure A12: Kapako floodplain islands. Top left: *Combretum imberbe* and *Acacia hebeclada* ssp. *chobiensis*. Centre right *Acacia sieberiana*. Below: Looking from floodplain island with *Acacia hebeclada* on left, over a channel (indicator 7) towards another island with *Searsia quartiniana*, with reeds in front (indicator 8). (photos: Barbara Curtis, January 2009)

Figure A13: Popa showing indicator 1 in the foreground, through to the tall trees of indicator 5 in the background (Photo: Colin Christian, February 2009).

Figure A14: Popa Falls indicator 2, lower wetbank.

Above: A stand of papyrus *(Cyperus papyrus)* with bog fern (*Thelypteris interrupta*) in the foreground. Yelow water daisies (*Aspilia mossambicensis*) can be seen on the right (yellow spots). (Photo: Colin Christian, February 2009).

Right: Pygmy fig (*Ficus pygmea)* and bog ferns among the stems of papyrus. (Photo: Barbara Curtis)

APPENDIX B: RAW DATA FROM FIELDTRIP

Plants collected 5-9 January 2009. G = grass;

Species name	habit	indicator	notes
Setaria sphacelata var. *sericea*	G	8	Abundant at site 4; ca 2 m high.
Panicum coloratum var. *coloratum*	G	8	Abundant at site 4; ca 2 m high.
Chrysopogon nigritanus	G	8	Common at site 4;
Heteropogon melanocarpus ?	G	9	present at site 4 – ID uncertain
Themeda triandra	G	9	present at site 4
Brachiaria humidicola	G	9	present at site 4
Eragrostis rotifer	G	9	present at site 4
Setaria sagittifolia	G	9	present at site 4
Bothriochloa bladhii	G	9	present at site 4

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)*
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		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*
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		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*
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