



OKACOM

The Permanent Okavango River Basin Water Commission

**Okavango River Basin Technical
Diagnostic Analysis:
Environmental Flow Module
Specialist Report
Country: Namibia
Discipline: Water Quality**

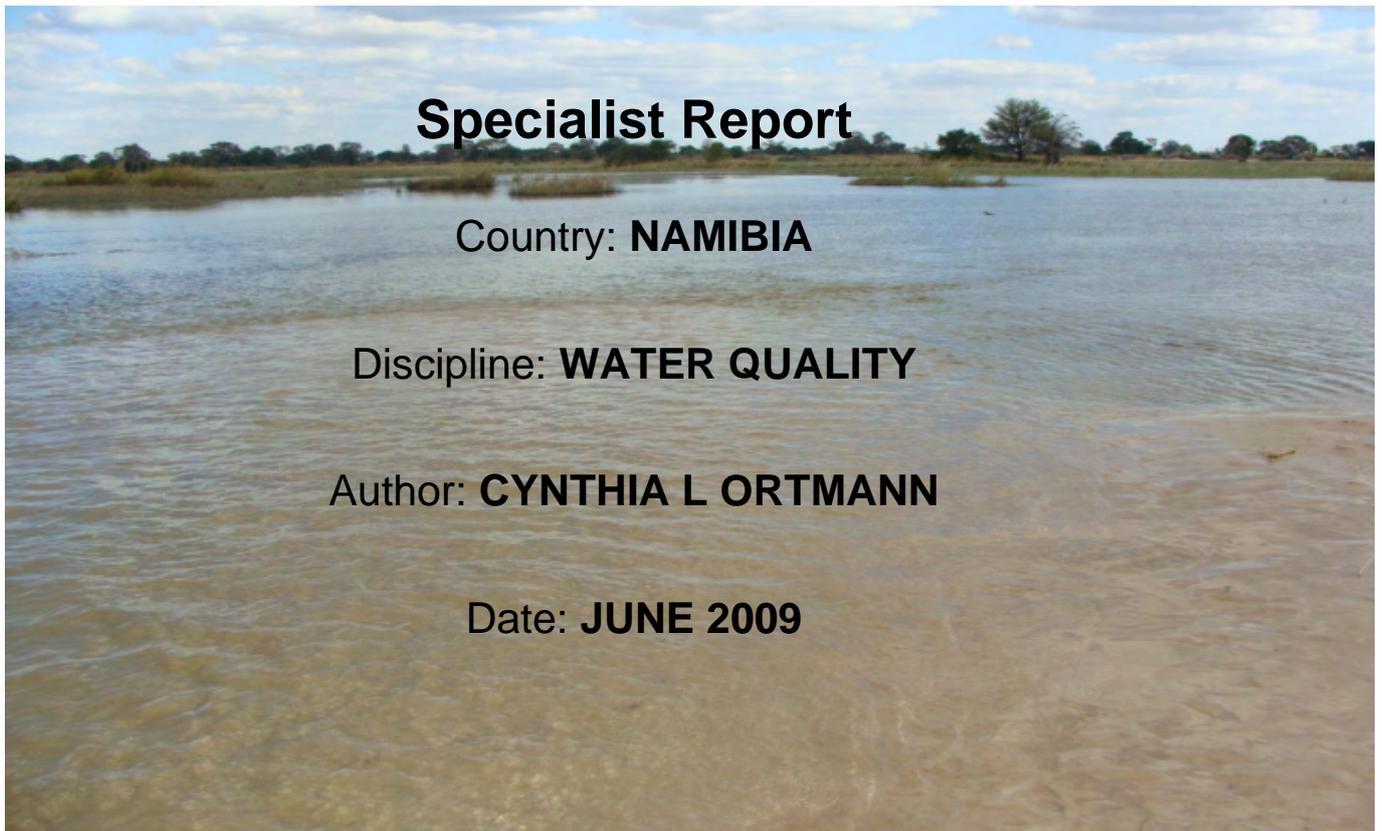
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June 2009

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

EPSMO

Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module



EXECUTIVE SUMMARY

This study dealt with the physiochemical characteristics of the Okavango River on the Namibian side. Two sites were selected as part of an Environmental Flows Assessment exercise and a thorough literature review was conducted prior to the actual monitoring and assessment of findings.

The most outstanding finding of the literature review is that the quality of the Okavango River is generally very good and contains very low concentrations of nutrients, turbidity and suspended solids (Bethune 1986, Bethune 1991, Cronberg et al, 1995, Turton, 1999, Hay *et al* 2000, Trewby 2003 , Anderson 2006) .

The major gaps that were identified are the inability of detecting measurable concentrations of nutrients by the methods that were used in all the studies and the absence of monitoring chlorophyll a concentrations in the Namibian waters.

Seven (7) indicators of water quality were identified and monitored at both the selected EFA sites for the dry season and the wet season. The monitoring was conducted in the mainstream of the river as well as in the isolated floodplain pools and backwaters of the river system. The outcome of the results of this monitoring reflects the findings of the existing studies to a great extent in terms of the seasonal variations of the water quality throughout the river system.

However, as good as the quality of the river water is at this stage, there are human and environmental impacts on riverine environments which can compromise this state of affairs in future. As part of a holistic water management approach, this study aims to investigate the existing relationships between the river ecosystem and the riparian peoples' livelihoods and to predict possible development-driven changes to the flow regime and thus to the water quality of the river.

It is clear from this analysis of linking the different flow regimes and water quality, that most water quality problems are associated with episodes of low flow.

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ABBREVIATIONS

ABBREVIATION	MEANING
DTM	Digital Terrain Model
EFA	Environmental Flows Assessment
DO	Dissolved Oxygen
K-N	Kjeldahl Nitrogen

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- 1.1 The Analytical Laboratory Services for the chemical analyses of my water samples
- 1.2 The NamWater Laboratory for Chlorophyll a analyses
- 1.3 Shishani Nakanwe and Ndina Nashipili for assisting with fieldwork
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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 socio-economic effects of such possible developments. OBSC recommended at this meeting that a preliminary 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 Water Quality 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 this preliminary 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 preliminary EFA, due to time constraints, as input to the TDA and to a future comprehensive EFA.

The specific objectives at this 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 these preliminary 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. Chapter 3, highlighted the agreed water quality indicators and flow categories. Literature review pertinent to water quality work in the Okavango River and other similar systems is given in Chapter 4 and the full indicators are listed. The field survey work undertaken for the water quality investigation within Namibia in both the dry season (October 2008) and wet season (February 2009); together with data collection, analysis and results are outlined in Chapter 5. Chapter 6 is a first attempt to link water quality to flow and provide information on the flow-response relationships for use in the Okavango EF-DSS. References are found in Chapter 7. Appendix A contains the raw field and laboratory 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, Cuelel, Cuelebe, and Cuito rivers in Angola, the Okavango River in Namibia and Botswana, and the Okavango Delta (Figure 2.1). This basin topographically includes the inactive drainage area of the Omatako Omuramba. Although this ephemeral river still regularly floods along its southern portion, it has not contributed any flow to the Okavango River. 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). This study, however, focuses on the active drainage parts of the basin in Angola and Namibia, and the Okavango delta in Botswana. The Omatako Omuramba, Makgadikgadi Pans and Nata River are not included.

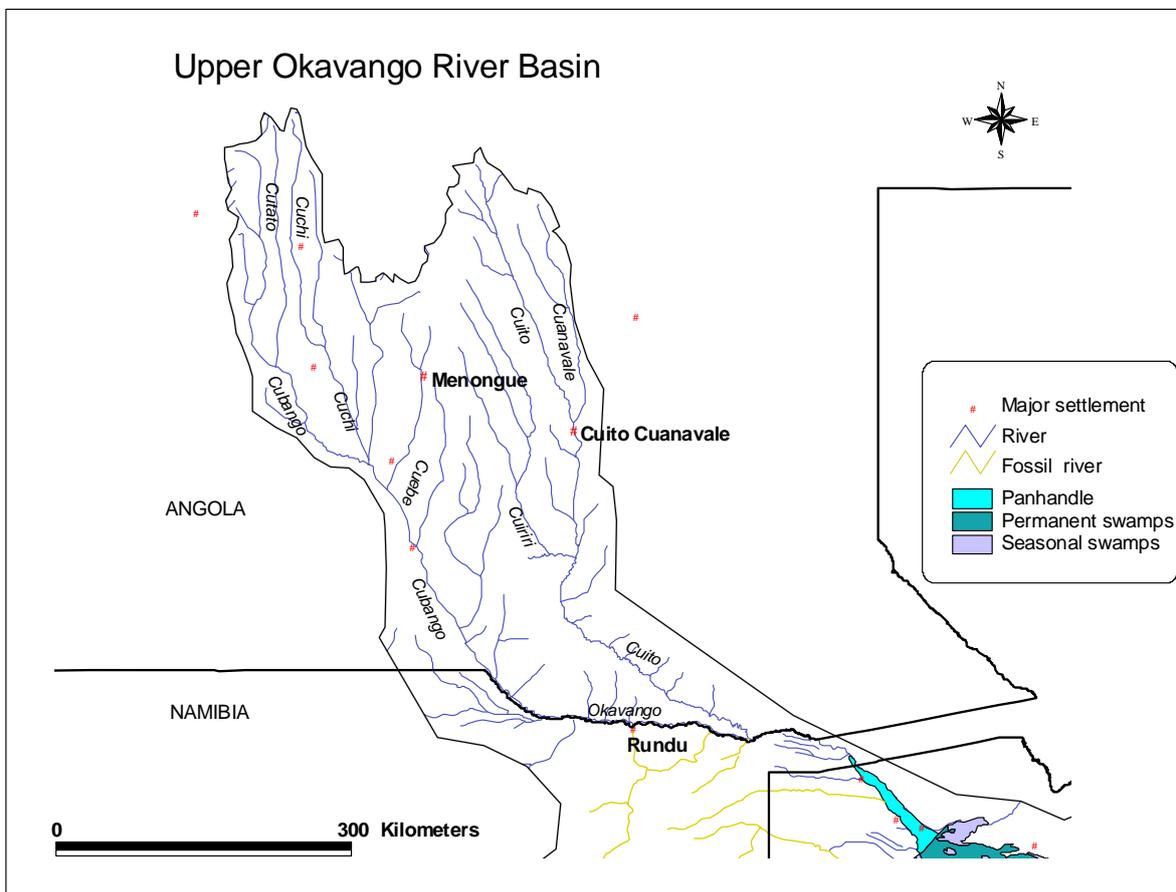


Figure 2.1 Upper Okavango River Basin from sources to the northern end of the Delta

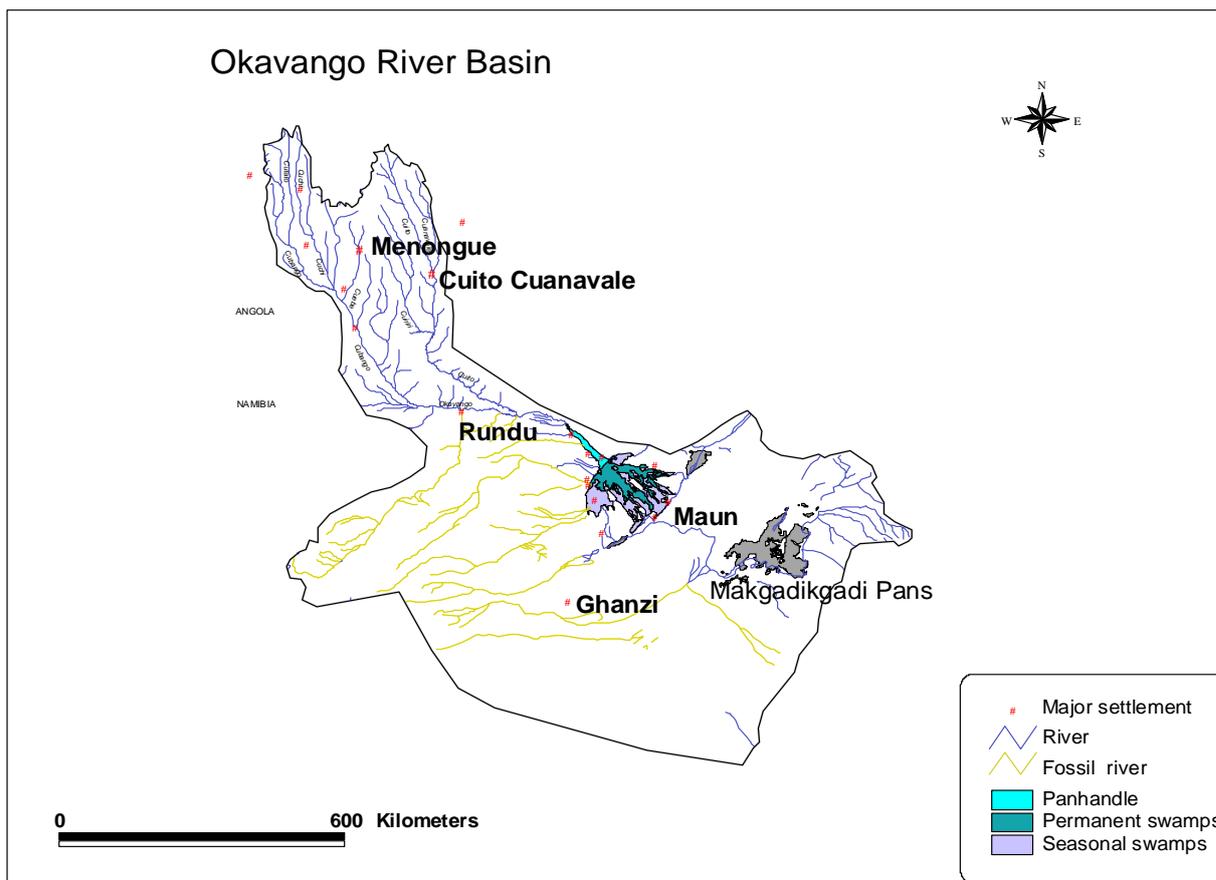


Figure 2.2 The Okavango River Basin, showing drainage into the Okavango Delta and the Makgadikgadi Pans

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. These representative areas, that are reasonably homogeneous in their ecological characteristics and can be delineated, were used to choose several sites in which to focus data-collection and where monitoring can be done. 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 macroinvertebrates, vegetation and 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). (See the delineation report for details).

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	Cuito	Cuito Cuanavale
4	Namibia	Okavango	Kapako
5	Namibia	Okavango	Popa Rapids
6	Botswana	Okavango	Upper Panhandle around Shakawe
7	Botswana	Xakanaka lagoon and Khwai River	Xakanaka in Delta
8	Botswana	Boteti Rivers	Maun and Chanoga

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 hotspots 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 as two of its 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.

2.3.1 Site 4: Okavango River at Kapako

The river is at the heart and core of the Okavango Basin, and a variety of aquatic plants and animals live in and near it and make good use of the river, its water and other wetland resources. In Namibia most of the river often has broad margins of floodplains on either side beyond which there are drier, deciduous woodlands. A variety of organisms are specialised inhabitants of the floodplains.

The fish communities can be divided into two groups based on their food preference and specialization, those that feed on plant material and those that prey on other fish. Secondly they can be divided according to the habitats where the different fish occur, some preferring the mainstream, others the rocky areas and rapids, other groups in the backwaters or

permanent swamps and a distinct community found in the floodplains. The floodplains are of greatest value as places in which most fish breed.

Local people have recognised that the quality of water and fish resources are decreasing in the Okavango River. Fish and fishing remain a significant feature in the lives of people at Kapako, who fish for food or to earn incomes by selling their catches as well as by providing trips for tourists. Fish stocks in the floodplains are estimated to be four times higher than in the main channel.

The riverine landscape comprises the main Okavango River channel and the annually flooded floodplains with braided channels. The higher fluvial terrace with alluvial deposits are flooded less regularly (Mendelsohn and el Obeid 2004).

2.3.2 Site 5: Okavango River at Popa Falls

The southward flowing section from Mukwe to the Popa rapids is rocky without floodplains and has many sand and rock based islands set in the braided rocky channels. The shore is wooded with the exception of settled areas mainly on the western bank that have been largely cleared for settlements and crops. The islands remain well forested and several are used as burial areas for chiefs.

Popa Rapids are where the river cascades down several meters before resuming its normal slow and leisurely flow. The rocks were formed from sediments deposited in rift valleys about 900 million years ago, (el Obeid, S., Mendelsohn date). During the focus group discussion by the socio-economic team, it was mentioned that due to the Popa rapids and rocky areas, it's difficult for the local fishermen to catch fish as desired. Therefore, only a few individuals owning local mukoros, hook and line, and gill fish nets have access to fish catches in the main channel.

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 it exits 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 on the main channel for their water and wetland resources (Mendelsohn and el Obeid 2004).

2.4 Discipline-specific description of Namibian sites – water quality

2.4.1 Site 4: Kapako

This site is characterised by the main channel and floodplain areas with isolated pools and backwaters on the Okavango River. The site is situated about 30 km upstream of Rundu, the biggest town along the Okavango River on the Namibian side. The floodplain is generally characterised by good water quality with very low nutrient concentrations in the mainstream along the stretch from Katwitwi up to Katere at the Cuito river confluence with the Okavango River. The chemical constituents in the backwaters of this stretch of the river are slightly more concentrated especially in the dry season with low flow rates. This is due to gradual drying because of the absence of moving streams in these backwaters.

2.4.2 Site 5: Popa Rapids

The Popa Rapids is a protected area with a resort, a community campsite and small scale local community activities. The river channel here is characterised by shallow, rocky rapids and backwater channels. The site is situated about 103 km downstream from the Cuito River confluence with the Okavango River and in terms of water quality, there is a clear trend of dilution effects of nutrients compared to the sites upstream of the confluence. The confluence of a river is the meeting of two or more bodies of water. The Cuito River is a tributary which joins the Okavango River, which is the high order stream in the drainage basin and is therefore called the mainstream. Dissolved oxygen levels are higher below the Popa Rapids due to the aeration taking place when water flows over the rocks.

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.

3.1.2 Indicator list for Water Quality

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 – Cynthia Ortmann, Namibia; Wellington Masamba, Botswana, Carlos Andrade, Angola, - and is provided in Table 3.1. For water quality 8 indicators were initially agreed and later reduced to 7 by combining total Nitrogen and Phosphorus simply as nutrients. Further details of each indicator are discussed fully in Chapter 4.

Table 3.1 List of indicators for Water Quality and those chosen to represent each site

Indicator Number	Indicator name	Sites represented – no more than ten indicators per site							
		1	2	3	4	5	6	7	8
1	pH				X	x			
2	Temperature				X	x			
3	Dissolved Oxygen				X	x			
4	Electrical Conductivity				X	x			
5	Turbidity				X	x			
6	Total Nitrogen								
	Total Phosphorous								
7	Chlorophyll <i>a</i>				X	x			

3.1.3 Description and location of indicators

Water Quality Indicator 1: pH

Description: The pH value of water refers to its acidity or alkalinity water with a pH of 7 is considered neutral.

Flow-related location: In relatively shallow flowing water systems, the pH remains relatively stable close to 7 in the mainstream and site channels.

Water Quality Indicator 2: Temperature

Description: It is a measure of how cold or warm the water is and is an important indicator as different organisms have different temperature tolerance ranges.

Water Quality Indicator 3: Dissolved Oxygen

Description: Refers to the amount of oxygen dissolved in water and is related to photosynthesis by water plants and aeration as well as decomposition. It is important to organisms living in the water.

Flow-related location: Fast flows over rapids increase aeration and thus the concentration of oxygen in water.

Water Quality Indicator 4: Conductivity

Description: The electrical conductivity of water is directly related to the concentration of the total dissolved minerals in the water.

Flow-related location: Extended dry periods and low flow conditions can contribute to high conductivity readings.

Water Quality Indicator 5: Turbidity

Description: Turbidity refers to how clear the water is. The greater the amount of total suspended solids in the water, the muddier it appears and the higher the measured turbidity.

Flow-related location: During low flow, many rivers have a green color and turbidities are low, usually less than 10 NTU www.jacksonbottom.org/waterqualityconcepts.htm. In most rivers turbidity increases after rainfall and flooding because of soil erosion. Settled particles can accumulate and smother fish eggs, water plants and aquatic insects on the river bottom.

Water Quality Indicators 6: Nutrients

In this report, the total nitrogen and total phosphorous will be addressed as one indicator called nutrients. Total nitrogen consists of NH_4 , NO_3 and NO_2 and total phosphorous includes organic phosphorous and inorganic phosphate. These nutrients are typically low in concentration and are difficult to detect accurately by conventional laboratory methods.

Flow-related location: In slow flowing water, decomposition of organic material takes place faster and the nutrient concentration increases.

Water Quality Indicator 7: Chlorophyll a

Description: Used as a measure of algal productivity

Flow-related location: High concentrations in floodplain pools and backwaters where decomposition takes place and eutrophication is evident.

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. (Later the transitional stages were dropped for the preliminary survey)
 Tentative seasonal divisions for river Sites 4-5 are shown in Figure 3.1 and Figure 3.2.
 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.

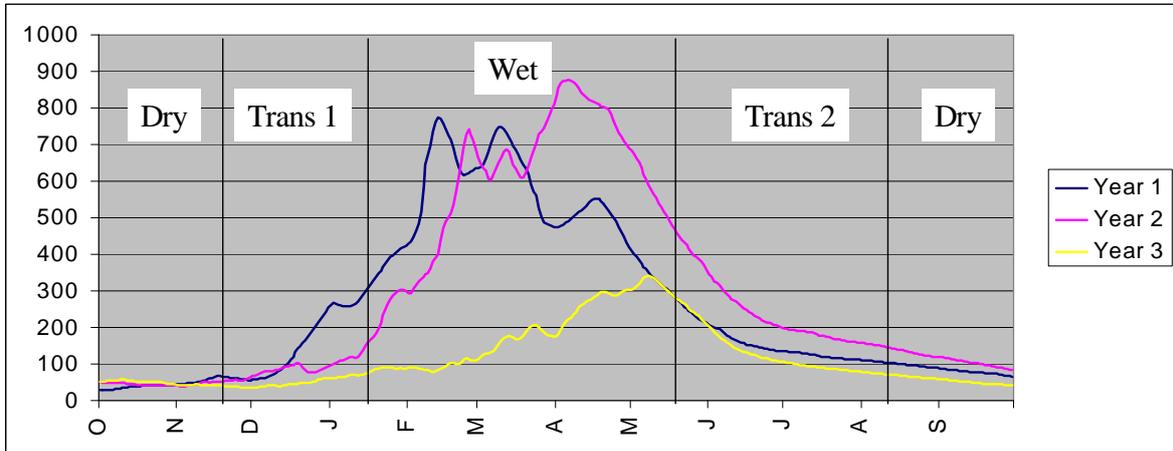


Figure 3.1 Three representative years for Site 4: Okavango River @ Kapoka (hydrological data from Rundu), illustrating the approximate division of the flow regime into four flow seasons

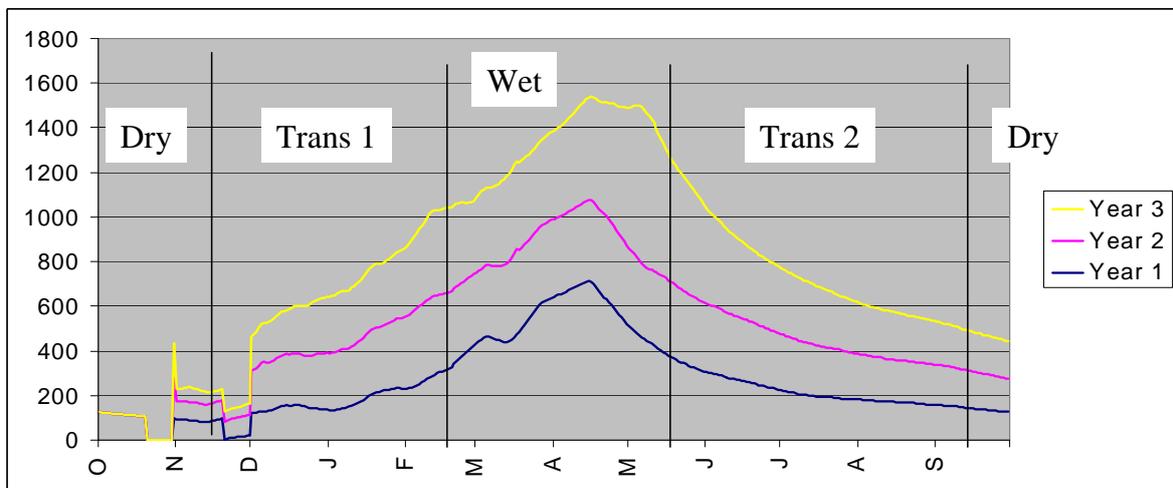


Figure 3.2 Three representative years for Site 5: Okavango River @ Popa (hydrological data from Mukwe), illustrating the approximate division of the flow regime into four flow seasons

The literature review (Chapter 4) and data collection and analysis exercises (Chapter 5) are focused on addressing what is initially expected to be nine main questions related flow seasons (

Table 3.2).

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

Question number	Season	Response of indicator 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

4 LITERATURE REVIEW

4.1 Introduction

This review gives an overview of water quality within the Namibian section of the Okavango River Basin and indicates the response of selected water quality indicators to river flow and water variability as an input to the environmental flow assessment of the river. A few studies have been conducted for investigating the water quality of the Okavango River system. However, there is not as wide a range of detailed water quality studies as there exists for the Okavango Delta in Botswana.

This literature survey looks at data from these studies since 1984 up to currently ongoing studies. Some of the studies carried out by the Department of Water Affairs are available as Country Reports in the Library of the Ministry of Agriculture, Water and Forestry. Books were written as a result of extensive studies in the Okavango River, and the sections pertaining to the Water Chemistry of the river were studied. There is also a report on the Transboundary Diagnostic Analyses of the Okavango River which was conducted in 1998. This report does not have sufficient information on the water chemistry of the river on the Namibian side, only a summary of chemical concentrations that were measured in some mainstream sites and backwater sites in 1984. However, for the purposes of this study, the review will concentrate mostly on the recognized indicators which are pH, Temperature, Dissolved Oxygen (DO), Turbidity, Conductivity, Nutrients which include Total Nitrogen (TN) and Total Phosphorous (TP) and Chlorophyll *a*.

After reviewing the literature, it was found that the water quality of the Okavango River measured in Namibia remains very good overall. The river has low concentrations of nutrients, turbidity and suspended solids (Bethune 1986, Bethune 1991, Cronberg et al, 1995, Turton, 1999, Hay *et al* 2000, Trewby 2003 , Anderson 2006) .

4.2 Indicator 1 (pH)

The pH value of water, on a scale of 0 -14 measures the concentration of hydrogen ions. The pH represents the balance between hydrogen ions and hydroxide ions in water. Water is basic if the pH is greater than 7 and considered acidic if the pH is less 7. The pH is also a useful indicator of the chemical balance in water. A high or low pH will negatively affect the ability of certain chemicals or nutrients in the water for use by plants. Water with a pH of less than 4.8 or greater than 9.2 can be harmful to aquatic life, for example most freshwater fish prefer water with a pH range between 6.5 and 8.4

National data on this indicator in this river system

The pH in the Okavango River is generally stable around neutral throughout the Namibian stretch of the river in both the mainstream and the backwaters in all seasons and at both sites.

Cronberg *et al.* (1995) indicated the pH of the Okavango River generally varied between 5.9 to 7.6. During the study on fish populations, gill net selectivity and artisanal fisheries in the Okavango River (Hay *et al.* 2000), the highest pH value of 9.5 was recorded at Bunya just upstream of the Mupini floodplain during the winter of 1994.

Trewby (2003) found that although the water quality of the Okavango River showed some temporal and spatial patterns during May to December 2002, the pH did not vary much between the sampling periods at various sites in the mainstream. The monthly mean across the stretch of the river for May was 6.84; for July it was 6.84 and for December it was 6.97.

Similarly, Anderson (2006) found that pH was fairly stable around neutral for most of sites throughout the mainstream and channel sites. The mean pH values recorded for Popa Rapids were in the range of 6.7 – 6.9.

In summary the pH of the Okavango River mainstream water is generally within the values of 5.9 and 9.5 with the greatest frequency of values found between 6.5 and 6.9 and can be compared to most natural waters.

4.3 Indicator 2 (Temperature)

This indicator is significant from the rest of the indicator parameters because many of the physical, biological and chemical characteristics of surface water are dependent on temperature. The optimal health of aquatic organisms depends on temperature – if the temperatures are outside the optimal range for a prolonged time, organisms are stressed and can die. The water temperature also affects the volume of dissolved oxygen it can hold.

National data on this indicator in this river system

Findings of the 1984 – 1986 Limnological Baseline Survey of the Okavango River indicated that water temperature at different mainstream and channel sites along the river measured in the same season was very similar. The temperatures were usually within a degree of the air temperature, being relatively high in March (24 - 30°C), decreasing sharply in winter (17 - 19°C) and again increasing towards October (23 - 29°C). (Bethune 1987)

Temperature in shallow flowing waters like the Okavango is determined mostly by solar radiation and is usually very similar to air temperatures. No stratification occurs in the river nor in any of the pools (Bethune 1991 - Kavango River Wetlands). The water of this river system is well mixed and the water temperature is similar with depth and distance downstream. According to Bethune, the temperatures remained fairly constant with depth and distance along the river, but changed with the time of the day, especially in shallow waters. Similar results were recorded during the Hay *et al* 2000 study on Fish populations, gill net selectivity and artisanal fisheries in the Okavango River. Immediately upstream of the Mupini floodplain, at Bunya, the minimum and maximum temperatures recorded in 1993 was 26.50 – 29.0°C in autumn, in the winter it was 15.1 – 19.7°C and in spring 21 – 30.1°C. Slightly lower temperatures were recorded in the same year and seasons at the Popa Rapids: 25.1 - 27.1°C in autumn, 15.4 – 18.7°C in winter and 24.4 – 28.6°C in spring. Temperatures measured in this river seem to be fairly similar throughout the stretch of the river during the same season, and is usually within one degree of the air temperature.

4.4 Indicator 3 (Dissolved Oxygen)

Dissolved oxygen refers to the amount of oxygen dissolved in water. This indicator is one of the most important water quality parameters, as it is an essential element for the maintenance of healthy rivers and lakes. Most aquatic plants and animals need a certain amount of oxygen dissolved in water for survival. The sources of dissolved oxygen in rivers are the atmosphere, algae and vascular aquatic plants and are usually expressed as a concentration of oxygen in a volume of water (mg/l). Oxygen is also introduced into water when oxygen from the atmosphere is mixed into the water. Where the water is turbulent, for example where it is tumbling over rocks, the oxygen and water mix more easily, more atmospheric oxygen gets dissolved in the water and the result is higher DO concentrations. There are also higher concentrations of oxygen in cold water compared to warm water. A concentration of 5 mg l⁻¹ dissolved oxygen is required to maintain a healthy aquatic life in a river system.

National data on this indicator in this river system

In 2003, a study by Fiona Trewby indicated that the DO concentration in the Mupini floodplain was higher than in the rest of the river system both in the winter (July) and summer (December). The means were recorded as 8.6 and 7.8 mg l⁻¹ respectively.

During the Limnological Baseline Survey of the Okavango River of 1984 – 1986, it was found that the dissolved oxygen concentration measured within a season was more or less the same throughout the length of the river at the mainstream and channel sites, with the exception that below the Popa Rapids, the DO concentration increased slightly due to aeration. The oxygen concentrations increased from March (5.8 - 8.1 mg l⁻¹) to October (7.1 – 9.4 mg l⁻¹). (Bethune 1987).

A UNDP study by Charles Hocutt in 1997 indicated that the dissolved oxygen throughout the flowing waters of the Okavango is generally high and near saturation conditions. In contrast, studies by Cronberg et al 1996 stated that the DO content of the water was substantially below saturation and therefore reflected stagnant conditions throughout the wetland. According to the 1998 report on the Transboundary Diagnostic Analyses of the Okavango River, these variations in results probably reflect the relative stages of flood progression in the specific areas of study. The levels of oxygen in relation to flow, decreased with increasing flow.

In the floodplain pools, the oxygen levels are higher by day than at night due to photosynthesis and decrease with depth in isolated backwaters due to decomposition (Bethune 1991 - Kavango River Wetlands)

The study of Jafet Anderson, 2006, indicated that dissolved oxygen levels were elevated at sampling sites below the Cuito River confluence with the Okavango River. It seems that the Cuito has a diluting effect and carries less dissolved solids and less dissolved oxygen than the mainstream before the confluence. This situation should be verified with the results from the samples taken at Popa Rapids.

4.5 Indicator 4 (Conductivity)

The electrical conductivity of water is directly related to the concentration of dissolved solids in the water. It gives an indication of the dissolved ion concentration which may stem from elevated pollution levels. Temperature also affects conductivity; warm water has a higher conductivity. Conductivity is measured in micro-Siemens per centimeter ($\mu\text{S cm}^{-1}$).

National data on this indicator in this river system

Jafet Andersson 2006 found that concentrations of conductivity and total dissolved solids at sampling points upstream of the Cuito – Okavango confluence are significantly higher than those downstream of the confluence. The Cuito carries less dissolved solids than the mainstream therefore, after mixing, there is a decrease in concentration. It can also be due to the intensive land-use of the Okavango River upstream of the confluence.

Similarly, the data from the Hay *et al* 2000 study on Fish populations, gill net selectivity and artisanal fisheries in the Okavango River indicate mean conductivity values of 52.4 $\mu\text{S cm}^{-1}$ at Bunya and 47.0 $\mu\text{S cm}^{-1}$ at Popa Rapids for the 1993 / 1994 period.

With relation to flow, the conductivity levels seems to be decreasing with increasing flow at sites before the confluence and increase with increasing flow below the confluence.

4.6 Indicator 5 (Turbidity / SS)

Turbidity refers to how clear the water is. The greater the amount of total suspended solids in the water, the muddier it appears and the higher the measured turbidity. In most rivers turbidity increases after rainfall and flooding because of soil erosion. Settled particles can

accumulate and smother fish eggs, submerged macrophytes and aquatic invertebrates on the river bottom.

National data on this indicator in this river system

During the Limnological Baseline Survey of the Okavango River of 1984 – 1986, it was found that the waters of the Okavango River are clear and the river bottom was visible from the surface at all mainstream and channel sites. The turbidity was usually below 1 NTU. The shallow backwater sites were not as clear though. Values of 0 – 10 NTU are an indication of a clear stream. (Bethune 1987).

However, it seems that the turbidity may have increased since this baseline survey. Values measured in December 1991 ranged from 0.5 to 3.5 NTU and were highest below the dry floodplain area at the junction of the Omatoko Omuramba and the Okavango River (Bethune 1992).

Similar results were recorded during the Hay *et al* 2000 study. The recorded values at most of the study sites ranged from 0.4 to 5 NTU during autumn, winter and spring of 1993. However, exceptionally high values were recorded during autumn 1994 during low water. Immediately upstream of the Mupini floodplain, at Bunya, the highest turbidity value recorded was 30 NTU in autumn 1994. The same value of 30 NTU was recorded at the Popa Rapids. These values were measured at sites where fish nets were set along the margin and thus do not directly reflect the turbidity in the mainstream.

4.7 Indicator 6 Nutrients

Nitrogen is an essential nutrient for all aquatic organisms. The forms of nitrogen analysed from a water sample are generally reduced (Kjeldahl) nitrogen which includes ammonium (NH_4) and organic nitrogen (N_{org}); and oxidized nitrogen which is nitrate (NO_3^-) and nitrite (NO_2^-). Total nitrogen (Tot – N) is a measure of all the forms of nitrogen, dissolved or particulate that is found in the sample. The main sources of nitrogen in rivers include human and animal wastes, industrial pollutants and non-point-source runoff from agriculture and aquaculture activities. In excess amounts, nitrates in water can cause an increase in algal growth, which can rob the water of dissolved oxygen and can eventually lead to the death of some forms of aquatic life.

Phosphorous is a key element necessary in water for the growth of plants and animals. Its concentrations in pure waters are generally low. It is introduced in a waterbody as a natural element found in rocks and soils and from human activities. Total phosphorous includes organic phosphorous and inorganic phosphate. Organic phosphorous is a part of living plants and animals, whereas inorganic phosphate consists of the ions bonded to soil particles and phosphate present in laundry detergents.

National data on this indicator in this river system

The purity of the Okavango River indicates that it is extremely deficient in nutrients (Mendelsohn J & Obeid S, 2004).

The oxidized nitrogen, which is the sum of the nitrate and nitrite, was below detection limits in the first half of 1984. The highest concentration was recorded at 0.8 mg/L in May of 2002 (F. Trewby, 2003), but during the latter half of the same year it was again too low to be detected. This was double the highest concentration that was recorded during the Limnological Baseline Survey of the Okavango River of 1984 – 1986, which was 0.43mg/L in May 1985. (Bethune 1987).

In the same survey, it was found that the ammonia (NH_4) concentration ranged from below detection limits to 1.68 mg/L, whereas the organic nitrogen (N_{org}) had a much greater range from below detection limit to 6.72 mg/L

Trewby, 2003 found that the total phosphorous concentration in the Okavango River is an order of a magnitude lower than the total nitrogen, with its maximum for the entire stretch of the Namibian side being 0.37mg/L compared to the total nitrogen being 3.8 mg/L.

In 2006, Andersson J found that the phosphorous concentrations were similarly low or even lower than those quoted by Trewby. This study focused on large scale agricultural farms and it was evident that there were no significant variations with respect to phosphorous concentrations at locations above these large-scale agricultural developments and the locations below these developments.

Bethune, 1986 found that ortho-phosphate concentrations were highest in the mainstream sites. This can be attributed to human and cattle wastes and detergents used for laundry, given the fact that most of the sites in this study are at human access points to the river.

4.8 Indicator 7 (Chlorophyll a)

Chlorophyll is the green pigment in plant cells that carries out the bulk of energy fixation in the process of photosynthesis. It is a very important ecological and environmental parameter of waters mostly used to estimate algal biomass in lakes and streams (<http://dipin.kent.edu/chlorophyll.htm>). Chlorophyll itself is not single molecule but a family of related molecules, designated chlorophyll *a*, *b*, *c* and *d*. Chlorophyll *a* is measured as a unicellular algae. Eutrophication in the system is prominent with increasing concentration of chlorophyll *a* in rivers

National data on this indicator

There appear to be no data available for chlorophyll *a* concentration in the Namibian section of the River. This study will however include these analyses.

4.9 Summary

As was indicated in the introduction of this literature survey, there is not a wide range of existing data pertaining to the water quality of the Okavango River on the Namibian side. However, there are five (5) major and quite detailed water quality studies that were reviewed in the course of this Environmental Flow Assessment. They are as follows:

- The Limnological Baseline Survey of the Okavango River 1984 – 1986 by S Bethune. A detailed survey done at mainstream and backwater sites at ten locations seasonally over a three year period.
- The UNDP study of 1997 by Charles Hocutt of the Maryland University
- The Hay *et al* 2000 study on Fish populations, gill net selectivity and artisanal fisheries in the Okavango River
- The Fiona Trewby, 2003 study on Impact of Land-use on the Okavango River
- The Jafet Andersson, 2006 study on Land Cover Changes in the Okavango River Basin

As a means of strengthening the existing database on Okavango River Water Quality, there is currently a project running in the Department of Water Affairs, called “The impact of Land Use Activities on the Water Quality of the Okavango River”. This project is executed by Ms Cynthia L Ortmann and aims at monitoring the water quality on the Namibian side of the river

from Katwitwi up to Mahango Game Park. The monitoring programme started in July 2008, suveys were continued in October 2008, January 2009, April 2009 and will end in July 2009.

The major gaps identified during this literature survey are the inability of detecting measurable concentrations of nutrients by the methods that were used in all the studies and the absence of monitoring chlorophyll a concentrations in the Namibian waters.

More detailed and intensive monitoring surveys like the 1984 – 1986 Limnological Baseline Survey are needed in order to determine if there are real changes in the water quality of the river system due to industrial and agricultural developments that have taken place since then in order to help make predictions of how future developments could affect the river's chemistry.

5. DATA COLLECTION AND ANALYSIS

5.1 Methods for data collection and analysis

The two Namibian EFA sites Kapako / Mupini Floodplain and Popa Rapids Resort were visited during the period of 20 -24 October 2008, during the dry season for data collection. The Kapako / Mupini Floodplain was visited on 20 October 2008 and the Popa Rapids Resort was visited on 21 October 2008. During the wet season, the Popa Rapids Resort was visited on 06 February 2009 and the Kapako / Mupini Floodplain on 08 and 09 February 2009. A motorboat was used in the wet season to access the actual site that was monitored in the dry season.

Samples were taken and physical measurements recorded from the mainstream of the river as well as from the backwaters at both sites. For the physico-chemical water quality data, on-site measurements were recorded of water temperature, pH, Dissolved Oxygen and Conductivity using a HACH Multimeter, and turbidity using a 2100P HACH Turbidity meter. Samples of water were collected in 50 ml polyethylene plastic bottles for Chlorophyll- *a* analysis and these were refrigerated and transported overnight by Nampost Courier to the Namibia Water Corporation (NamWater) Laboratory for analyses. More water samples were collected in 1000 ml polyethylene plastic bottles for analysing Total Nitrates, Total Phosphates and Total Dissolved Solids. These samples were preserved by keeping them about 4°C in a cool box throughout the duration of the sampling period and upon return in Windhoek, they were submitted to the Analytical Laboratory Services for analyses.

5.2 Results

The full raw data – on site measurements as well as laboratory readings are available in Appendix A. The following is an assessment of the results:

5.2.1 pH

Site: Kapako / Mupini Floodplain and Popa Rapids

Date of visit:

Dry Season – 20,21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako n=1	Popa Rapids n=1
Dry season (Low flows):		
Mainstream	7.99	7.88
Backwaters / Floodplain pools	7.64	7.69
Wet Season (High flows):		
Mainstream	7.1	7.69
Backwaters / Floodplain pools	6.8 , 6.7	7.62

Table 5. 1: Field pH measurements

At Kapako the pH was recorded at 7.99 in the main channel of the river during the dry season. This is slightly higher than the pH values for this area recorded during previous studies. This unusual reading can be due to the fact that it is representative of only one (1)

sample and the probe used for this reading could be erroneously calibrated. In a small isolated floodplain pool, the pH value recorded was 7.64, which is slightly less than in the main channel. The flow recorded during this time was relatively low. The recorded pH values are normal, given the low flow period of the river.

In the wet season, the pH of the main channel of the river was recorded as 7.1, which is, as expected, less than it was in the dry season. This can be attributed to slightly acidic precipitation in the wet season. The introduction of organic matter during high flows can also reduce the pH in a river. During this high water period the pH values showed a similarity for the mainstream and the linked floodplain pools. In a deep pool of 2.5m depth and about 15 m from the river bank, the pH was 6.8 and in a shallow floodplain pool of 0.55 m depth, the pH was recorded 6.7.

The river at Popa Rapids is characterized by shallow, rocky rapids and side channels. In the mainstream, the pH was 7.88 in the dry season. This was slightly higher than historic records, but more realistic than the reading of 7.99 at Kapako. In the backstream waters at the campsite of the resort the pH was recorded 7.69.

In the wet season, the mainstream pH was slightly less at 7.69, compared to the dry season. There was again a similarity with the linked side channel pH which was recorded 7.62.

5.2.2 Temperature

Site: Kapako / Mupini Floodplain and Popa Rapids

Date of visit:

Dry Season – 20, 21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako n=1	Popa Rapids n=1
Dry season (Low flows):		
Mainstream	26.7°C	28.7°C
Backwaters / Floodplain pools	27.9°C	25.4°C
Wet Season (High flows):		
Mainstream	27.1°C	27.4°C
Backwaters / Floodplain pools	27.4°C	27.5°C

Table 5. 2: Field measurements of water temperature

At Kapako, under low flow conditions in the dry season, the temperatures recorded in the mainstream and the floodplain pools showed a slight difference of 1.2°C. The water temperature measured in the mainstream was 26.7°C compared to 27.9°C in a pool in the floodplain. During the wet season, the temperature of the mainstream water was recorded 27.1°C. The temperature in a linked deep pool of 2.5m depth and about 15 m from the river bank, was 27.4°C. This trend confirms the findings of the 1984 – 1986 Limnological Baseline Survey of the Okavango River (Bethune 1987), which indicated that the water temperature at different mainstream and channel sites along the river measured in the same season, were very similar.

At Popa Rapids, the temperatures varied substantially between the mainstream and the backwaters during the low flow season. The temperature variation through the day reflected the time of the day the temperature was measured. In the mainstream of the river, the

sampling was done during the noon of the day at about 14h00 and the temperature recorded was 28.7°C. In the backwaters at the campsite of the resort, the sampling was done in the morning at about 08h30 and the recorded temperature was 25.4°C.

However, there was a similarity of the temperatures in the mainstream and the backwaters during the high flow season: the temperature in the main channel was slightly colder recorded at 27.4°C in the backwater stream it was 27.5°C.

5.2.3 Dissolved Oxygen

Site: Kapako / Mupini Floodplain and Popa Rapids Resort

Date of visit:

Dry Season – 20, 21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako n=1	Popa Rapids n=1
Dry season (Low flows):		
Mainstream	7.06 mg/ℓ	9.76 mg/ ℓ
Backwaters / Floodplain pools	7.01 mg/ ℓ	6.72 mg/ ℓ
Wet Season (High flows):		
Mainstream	4.91 mg/ ℓ	6.63mg/ ℓ
Backwaters / Floodplain pools	2.15 mg/ ℓ	6.50 mg/ ℓ

Table 5. 3: Field Dissolved Oxygen measurements

The table above reflects the Dissolved Oxygen concentrations at the two EFA sites in Namibia during the two seasons. At Kapako, the DO concentrations in both the mainstream and the side channel sites were less than the required 5mg/ ℓ during the wet season, which is necessary for the health of aquatic life. In the dry season the DO concentrations were higher and showed a similarity in the mainstream and floodplain pools due to mixing of water.

During both seasons, the trend from previous studies that DO levels are higher where water is tumbling over rough surfaces was confirmed. The DO in the mainstream and backwater samples at Popa Rapids was higher than at Kapako, with the exception of the floodplain pool which had a higher concentration. The 3.04 mg/ ℓ difference in the DO concentration at Popa Rapids between the mainstream and the backstream can be due to the time of the day that readings were recorded for these samples.

5.2.4 Conductivity

Site: Kapako / Mupini Floodplain and Popa Rapids Resort

Date of visit:

Dry Season – 20, 21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako n=1		Popa Rapids n=1	
Dry season (Low flows):	Field	Laboratory	Field	Laboratory
Mainstream	47.8µS/cm	n/a	28.3 µS/cm	33 µS/cm
Backwaters / Floodplain pools	175.5 µS/cm	n/a	32.7 µS/cm	32.0 µS/cm
Wet Season (High flows):				

Mainstream	35.2 $\mu\text{S/cm}$	38 $\mu\text{S/cm}$	41.4 $\mu\text{S/cm}$	44 $\mu\text{S/cm}$
Backwaters / Floodplain pools	37.5 $\mu\text{S/cm}$	62 $\mu\text{S/cm}$	40.8 $\mu\text{S/cm}$	44 $\mu\text{S/cm}$

Table 5. 4: Field and Laboratory Conductivity measurements

The conductivity concentrations in the mainstream and the backwaters / floodplain pools (33.0 $\mu\text{S/cm}$ - 47.8 $\mu\text{S/cm}$) showed similarity to the study of Jafet Andersson 2006, who found that concentrations of conductivity and total dissolved solids at sampling points upstream of the Cuito–Okavango confluence are significantly higher than those downstream of the confluence due to the input of low conductivity water of the Cuito river. During the low flow period, the conductivity of the mainstream river was recorded at 47.8 $\mu\text{S/cm}$ at Kapako compared to 28.3 $\mu\text{S/cm}$ at Popa Rapids.

The conductivity in the isolated pool of the Kapako floodplain was as expected, exceptionally high at 175.5 $\mu\text{S/cm}$ during the low flow period. This high concentration can be a result of the isolation of pools from the mainstream and the gradual concentration of ions as well as the role of nutrients resulting from eutrophication. During the high flow period, the conductivity in a 2.5m deep floodplain pool at Kapako was recorded at 37.5 $\mu\text{S/cm}$ but in the laboratory it was analysed at 62 $\mu\text{S/cm}$. This difference can be a result of the unavoidable time delay in transporting samples from the date of sampling to the laboratory to the actual day of analysis.

The lower conductivity concentrations at Kapako in both the main channel and the floodplain pools recorded during the wet season are representative of diluting flows of precipitation. At Popa Rapids, the conductivity was higher in the backstream site than the mainstream during the low flow period and was recorded at 32.7 $\mu\text{S/cm}$. In the high flow season the mainstream conductivity was slightly higher than the backstream site which was 40.8 $\mu\text{S/cm}$. The early flash floods and increase in erosion is the explanation for this increase in conductivity measurements in the mainstream.

5.2.5 Turbidity

Site: Kapako / Mupini Floodplain and Popa Rapids Resort

Date of visit:

Dry Season – 20, 21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako n=1		Popa Rapids n=1	
	Field	Laboratory	Field	Laboratory
Dry season (Low flows):				
Mainstream	4.03 NTU	n/a	3.24 NTU	3.6 NTU
Backwaters / Floodplain pools	84.2 NTU	n/a	10.5 NTU	22 NTU
Wet Season (High flows):				
Mainstream	3.89 NTU	3.2 NTU	3.17 NTU	2.0 NTU
Backwaters / Floodplain pools	14.9 NTU	11.4 NTU	3.42 NTU	2.2 NTU

Table 5. 5: Field and Laboratory Turbidity measurements

The highest turbidity value (84 NTU) was as expected recorded in the floodplain pool at Kapako during the low flow season. This can be a result from the decay of vegetation in standing water. Much lower levels of suspended solids were recorded in floodplain pools in the wet season, but values were still higher than in the mainstream.

Lower turbidity readings (less than 10 NTU) were recorded in the mainstream of Kapako and both the mainstream and backwater sites at Popa Rapids during both seasons. This trend confirms the finding of the 1984 -1986 Limnological Baseline Study of the Okavango River, that the waters of the river are generally clear (Bethune 1997).

5.2.6 Nutrients

Total Nitrogen

Site: Kapako / Mupini Floodplain and Popa Rapids Resort

Date of visit:

Dry Season – 20, 21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako	Popa Rapids
Dry season (Low flows):		
Mainstream	Nitrate <0.5 mg / dm ³ NH ₄ 0.02 mg / dm ³ K-N <0.5mg / dm ³	Nitrate <0.5 mg / dm ³ NH ₄ 0.02 mg / dm ³ K-N <0.5mg / dm ³
Backwaters / Floodplain pools	Nitrate <0.5 mg / dm ³ NH ₄ 0.6 mg / dm ³ K-N 1.7 mg / dm ³	Nitrate <0.5 mg / dm ³ NH ₄ 0.04 mg / dm ³ K-N <0.6mg / dm ³
Wet Season (High flows):		
Mainstream	Nitrate <0.02 mg / dm ³ NH ₄ 0.2 mg / dm ³ K-N <0.2mg / dm ³	Nitrate <0.02 mg / dm ³ NH ₄ <0.2 mg / dm ³ K-N <0.2mg / dm
Backwaters / Floodplain pools	Nitrate <0.02 mg / dm ³ NH ₄ <0.2 mg / dm ³ K-N <0.2mg / dm ³	Nitrate <0.02 mg / dm ³ NH ₄ 0.4 mg / dm ³ K-N <0.2mg / dm

Table 5. 6: Laboratory Total Nitrogen measurements

Total Phosphates

	Kapako	Popa Rapids
Dry season (Low flows):		
Mainstream	<0.2 mg/dm ³	<0.2 mg/dm ³
Backwaters / Floodplain pools	0.3 mg/dm ³	0.2 mg/dm ³
Wet Season (High flows):		
Mainstream	<0.2 mg/dm ³	<0.2 mg/dm ³
Backwaters / Floodplain pools	<0.2 mg/dm ³	<0.2 mg/dm ³

Table 5. 7: Laboratory Total Phosphates measurements

The nutrients in the waters of the Okavango River were very low or undetectable, as was expected. Especially during the wet season, there was no difference in the undetectable nutrient concentrations in both the mainstream and the backwater of both sites.

A slightly higher concentration of total nitrogen was recorded in the isolated floodplain pool at Kapako during the dry season. The total phosphates were also mostly undetectable during

the wet season at both sites with a slightly higher concentration in the Kapako floodplain pool during the dry season.

The nutrient richness or trophic level of the Okavango River is therefore classified as oligotrophic in the wet season since all the recorded N03-N values were less than 0.3 mg/dm³ (Massachusetts Water Watch Partnership) in the mainstream and backwater sites. In the dry season a slight increase in nutrient concentration of less than 0.5 mg/dm³ is measured in the mainstream of both sites, suggesting a mesotrophic state. The backstream and floodplain pools indicate a temporary eutrophic state with nutrient levels higher than 1.5 mg/dm³.

5.2.7 Chlorophyll a

Site: Kapako / Mupini Floodplain and Popa Rapids Resort

Date of visit:

Dry Season – 20, 21 October 2008 and Wet Season – 06, 08 and 09 February 2009

	Kapako	Popa Rapids
Dry season (Low flows):		
Mainstream	0.69µg/ ℓ	0.92µg/ ℓ
Backwaters / Floodplain pools	8.60µg/ ℓ	0.69 µg/ ℓ
Wet Season (High flows):		
Mainstream	0.11µg/ ℓ	0.23 µg/ ℓ
Backwaters / Floodplain pools	0.11µg/ ℓ, 0.69µg/ℓ in shallow pool about 8m from riverbank	0.34µg/ ℓ

Table 5. 8:Laboratory Chlorophyll a measurements

The chlorophyll a concentrations recorded in the river during the dry and wet seasons at both study sites were very low, thus showing an oligotrophic system. Oligotrophic systems typically have an average value of 1.7 mg/m³ with the most common values in the range of 0.3 – 4.5 mg/m³ whereas a eutrophic river system often has chlorophyll a concentrations averaging about 14 mg/m³ or higher (Wetzel (1983)). As with the nutrients, a slight peak was observed at the isolated floodplain pool during the dry season.

Slightly higher concentrations were recorded during both seasons, for mainstream samples after Cuito / Okavango confluence – Popa Rapids compared to Kapako

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

The following tables indicate predicted responses, if at all by the indicators to changes in flow

5.3.1 Indicator (pH) Predicted response to possible changes in the flow regime of pH in the Okavango River ecosystem

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	
2		Water levels are higher or lower than natural		
3		Extends longer than natural	Nil	
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower		
5		Flows are more or less variable than natural	Addition of organic matter during high flow periods can reduce pH	Medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil	
7		Natural proportion of different types of flood year changed	Nil	
8	Transition 2	Onset is earlier or later than natural	Nil	
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	Nil	

5.3.2 Indicator (Temperature) Predicted response to possible changes in the flow regime of Temperature in the Okavango River ecosystem

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		
2		Water levels are higher or lower than natural	The waters are well mixed and the pools too shallow to stratify.	medium
3		Extends longer than natural	Extended higher temperatures during dry season lowers oxygen content and can make contaminants more toxic	medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	Nil	low
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	low
7		Natural proportion of different types of flood year changed	Nil	low
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	low

5.3.3 Indicator (*Dissolved Oxygen*) Predicted response to possible changes in the flow regime of Dissolved Oxygen in the Okavango River ecosystem

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	Low
2		Water levels are higher or lower than natural	Nil	Low
3		Extends longer than natural	Decrease in oxygen concentration	medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	Nil	
5		Flows are more or less variable than natural	Nil	
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil	
7		Natural proportion of different types of flood year changed	Nil	
8	Transition 2	Onset is earlier or later than natural	Nil	
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	Nil	

5.3.4 Indicator (Conductivity) Predicted response to possible changes in the flow regime of Conductivity in the Okavango River ecosystem

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	Low
2		Water levels are higher or lower than natural	Nil	Low
3		Extends longer than natural	Conductivity may increase with increasing evaporation and decomposition especially in floodplain pools	medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	Longer period of change may lead to decreases conductivity	Low
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	Low
7		Natural proportion of different types of flood year changed	Nil	Low
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	Low

5.3.5 Indicator (Turbidity) Predicted response to possible changes in the flow regime of Turbidity in the Okavango River ecosystem

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	Higher turbidity as a result of pollution, especially in floodplain pools	Medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	If hydrograph gets steeper, there will be changes in turbidity because of flushing	Medium
5		Flows are more or less variable 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	Considerable addition of sediments can increase turbidity	Medium
8	Transition 2	Onset is earlier or later than natural	Nil	
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	Increased turbidity due to sediment addition may increase acidity and threaten aquatic life	Medium

5.3.6 Indicator (Nutrients) Predicted response to possible changes in the flow regime of Total Nitrogen and Total Phosphorous in the Okavango River ecosystem

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	Low
2		Water levels are higher or lower than natural	Nil	Low
3		Extends longer than natural	Concentrations can reach toxic levels	Medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	Nil	Low
5		Flows are more or less variable than natural	Less flushing can lead to increased nutrient concentration and eutrophication	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

5.3.7 Indicator (Chlorophyll a) Predicted response to possible changes in the flow regime of Chlorophyll a in the Okavango River ecosystem

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

5.4 Conclusion

After reviewing literature and conducting the physiochemical quality survey for the two Environmental Flow Assessment (EFA) sites, it is clear that the water quality of this system remains very good. Although there is not a very wide range of detailed water quality surveys for the Namibian section of the river, the existing data provided a stable baseline and the water quality results obtained for this EFA confirmed the state of affairs for the system. However, there is a gap pertaining to information about chlorophyll a concentrations in this river.

The very low or undetectable nutrient concentrations in the river system or the inadequacy of the methods used to measure these is also a major area that needs future in depth investigations, in order to establish the exact nature and status of nutrient concentrations as well as to predict their responses to the different flow regimes of **the system**.

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

The response curves were developed during a workshop held in Windhoek from 30 March 2009 to 04 April 2009. The final Response Curves from all the disciplines are captured on a CD which is attached to this report.

7. REFERENCES

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APPENDIX A: RAW DATA FOR KAPAKO FLOODPLAIN – DRY SEASON

DRY SEASON**KAPAKO FLOODPLAIN****MAINSTREAM**

Origin	Kavango Region, Mupini/Kapako Floodplain
Description	Water from main channel(EFA site)
S	17°51.954
E	19°34.805
Date of sampling	2008/10/20
Date received	2008/10/28
DWA number	7162
Test item number	08/7162

Parameter	Value	Unit	General standard
Total Dissolved Solids (det.)	79	mg/dm ³	
Nitrate as N	<0.5	mg/dm ³	10
Ammonia Nitrogen as N	0.02	mg/dm ³	
Kjeldahl Nitrogen as N	<0.5	mg/dm ³	
Total Phosphate as P	<0.2	mg/dm ³	

Physical on site measurements:

pH	7.99
Temperature	26.7°C
Dissolved Oxygen	7.06mg/ ℓ
Electrical Conductivity	47.8µS/cm
Turbidity	4.03 NTU

Chlorophyll a concentration:

0.69 µg/ℓ

FLOODPLAIN POOL

Origin Kavango Region,Mupini/Kapako Floodplain
Description Smallpool in Floodplain(EFA site)

S 17°57.055
E 20°28.387
Date of sampling 2008/10/20
Date received 2008/10/28
DWA number 7160
Test item number 08/7160

Parameter	Value	Unit
Total Dissolved Solids (det.)	122	mg/dm³
Nitrate as N	<0.5	mg/dm³
Ammonia Nitrogen as N	0.6	mg/dm³
Kjeldahl Nitrogen as N	1.7	mg/dm³
Total Phosphate as P	0.3	mg/dm³

Physical on site measurements:

pH 7.64
Temperature 27.9°C
Dissolved Oxygen 9.76mg/ ℓ
Electrical Conductivity 175.5µS/cm
Turbidity 84.2 NTU

Chlorophyll a concentration:

8.60 µg/ℓ



APPENDIX B: RAW DATA FOR KAPAKO FLOODPLAIN – WET SEASON

WET SEASON
KAPAKO FLOODPLAIN**MAINSTREAM**

Origin Kavango Region, Kapako Village
Description Mainstream of river

S 17°51,936'
E 19°34,819'
Date of sampling 9/2/2009
Date received 12/2/2009
DWA number 7304
Test item number 7304

Parameter	Value	Unit
Ammonium as N	<0.02	mg/dm ³
Kjeldahl Nitrogen as N	0.2	mg/dm ³
Total Phosphate as P	<0.2	mg/dm ³

Physical on site measurements:

pH 7.1
Temperature 27.1°C
Dissolved Oxygen 4.91 mg/ℓ
Electrical Conductivity 35.2µS/cm
Turbidity 3.89 NTU

Chlorophyll a concentration:

0.11 µg/l

FLOODPLAIN POOL

Origin	Kavango Region, Kapako Floodplain
Description	Floodplain pool - sampled at 15m from riverbank at depth of 2.5m
S	17°52,661'
E	19°34,981'
Date of sampling	8/2/2009
Date received	12/2/2009
DWA number	7303
Test item number	7303

Parameter	Value	Unit
Ammonium as N	<0.02	mg/dm ³
Kjeldahl Nitrogen as N	<0.2	mg/dm ³
Total Phosphate as P	<0.2	mg/dm ³

Physical on site measurements:

pH	6.77
Temperature	27.4°C
Dissolved Oxygen	2.15 mg/L
Electrical Conductivity	37.5µS/cm
Turbidity	14.9 NTU

Chlorophyll a concentration:

0.11 µg/l

APPENDIX C: RAW DATA FOR POPA RAPIDS – DRY SEASON

DRY SEASON**POPA RAPIDS****MAINSTREAM****Full Group II analyses:**

Origin	Kavango Region, Popa Falls Community Camp		
Description	water from rapids behind community camp (past the prison) (EFA site)		
S	18°06.734		
E	21°34.968		
Date of sampling	2008/10/21		
Date received	2008/10/28		
DWA number	7163		Recommended max. limits
Test item number	08/7163		(according to tender specification)

Livestock-

Parameter	Value	me	Unit	Classification	Group A	Group B	Group C	watering
PH	8.0			A	6-9	5.5 - 9.5	4.0-11.0	4.0-11.0
Conductivity	3.3		mS/m	A	150	300	400	
TDS (determined)	58		mg/dm ³					6000
Turbidity	3.6		NTU	B	1	5	10	
Colour	<10		Pt	A	20			
Sulphate as SO ₄	<1	0.02	mg/dm ³	A	200	600	1200	1500
Chloride as Cl	1	0.03	mg/dm ³	A	250	600	1200	3000
Fluoride as F	<0.1	0.01	mg/dm ³	A	1.5	2.0	3.0	6.0
Nitrate as N	<0.5	0.04	mg/dm ³	A	10	20	40	100
Nitrite as N	<0.1	0.01	mg/dm ³					10
Silica as SiO ₂	13		mg/dm ³					
P-Alkalinity as CaCO ₃	0		mg/dm ³					
T-Alkalinity as CaCO ₃	<20	0.3	mg/dm ³					
T-Hardness as CaCO ₃ , cal.	17		mg/dm ³	A	300	650	1300	
Calcium as Ca	5	0.25	mg/dm ³	A	150	200	400	1000
Magnesium as Mg	1	0.08	mg/dm ³	A	70	100	200	500
Sodium as Na	2	0.09	mg/dm ³	A	100	400	800	2000
Potassium as K	1	0.03	mg/dm ³	A	200	400	800	
Iron as Fe	0.1		mg/dm ³	A	0.1	1	2	10
Manganese as Mn	<0.01		mg/dm ³	A	0.05	1	2	10



EFA Namibia Water Quality

Langelier Index	-1.5	corrosive	>0=scaling, <0=corrosive, 0=stable
Ryznar Index	11.0	corrosive	<6.5=scaling, >7.5=corrosive, ≥6.5 and ≤7.5=stable
Corrosivity ratio	0.2	no corrosive properties	Applies to water in the pH range 7-8
Stability pH	9.5		which also contains dissolved oxygen ratios <0.2 no corrosive properties ratios >0.2 increasing corrosive tendency

Remark: Overall classification of water considering only constituents that have been tested for:
Group B, good quality water

Nutrient analyses:

Parameter	Value	Unit
Total Dissolved Solids (det.)	58	mg/dm³
Nitrate as N	<0.5	mg/dm³
Ammonia Nitrogen as N	0.02	mg/dm³
Kjeldahl Nitrogen as N	<0.5	mg/dm³
Total Phosphate as P	<0.2	mg/dm³

Physical on site measurements:

pH	7.88
Temperature	28.7°C
Dissolved Oxygen	7.01mg/L
Electrical Conductivity	28.3µS/cm
Turbidity	3.24 NTU

Chlorophyll a concentration:

0.92_µg/l



BACKSTREAM AT CAMPSITE**Full Group II analyses:**

Origin Kavango Region,
Popa Falls Resort
Description Backstream at
campsite of Lodge

Lat**Long****Date of****sampling** #####**Date received** #####**DWA number** 7301**Test item****number** 7301**Recommended max. limits**

(according to tender specification)

Parameter	Value	me	Unit	Classification	Group A	Group B	Group C	Livestock- watering
p H	7.9			A	6-9	5.5 - 9.5	4.0- 11.0	4.0-11.0
Conductivity	4.4		mS/m	A	150	300	400	
TDS (determined)	80		mg/dm ³					6000
Turbidity	2.2		NTU	B	1	5	10	
Colour	24.0		Pt	B	20			
Sulphate as SO ₄	2.9	0.06	mg/dm ³	A	200	600	1200	1500
Chloride as Cl	1	0.03	mg/dm ³	A	250	600	1200	3000
Fluoride as F	<0.1	0.01	mg/dm ³		1.5	2.0	3.0	6.0
Nitrate as N	<0.5	0.04	mg/dm ³	A	10	20	40	100
Nitrite as N	<0.02	0.00	mg/dm ³					10
Silica as SiO ₂	16		mg/dm ³					
P-Alkalinity as CaCO ₃	0		mg/dm ³					
T-Alkalinity as CaCO ₃	21	0.42	mg/dm ³					
T-Hardness as CaCO ₃ , cal.	0		mg/dm ³		300	650	1300	
Calcium as Ca		0.00	mg/dm ³		150	200	400	1000
Magnesium as Mg		0.00	mg/dm ³		70	100	200	500
Sodium as Na		0.00	mg/dm ³		100	400	800	2000
Potassium as K		0.00	mg/dm ³		200	400	800	
Iron as Fe			mg/dm ³		0.1	1	2	10
Manganese as Mn			mg/dm ³		0.05	1	2	10
Langelier Index	#NUM!	####						>0=scaling, <0=corrosive, 0=stable
Ryznar Index	#NUM!	####						<6.5=scaling, >7.5=corrosive, ≥6.5 and ≤7.5=stable
Corrosivity ratio	0.2		increasing corrosive tendency					Applies to water in the pH range 7-8
Stability pH	#NUM!							which also contains dissolved oxygen ratios <0.2 no corrosive properties ratios >0.2 increasing corrosive tendency



Nutrient analyses:

Parameter	Value	Unit
Total Dissolved Solids (det.)	59	mg/dm³
Nitrate as N	<0.5	mg/dm³
Ammonia Nitrogen as N	0.04	mg/dm³
Kjeldahl Nitrogen as N	0.6	mg/dm³
Total Phosphate as P	0.2	mg/dm³

Physical on site measurements:

pH	7.69
Temperature	25.4°C
Dissolved Oxygen	6.72 mg/L
Electrical Conductivity	32.7µS/cm
Turbidity	10.5 NTU

Chlorophyll a concentration:

0.69_µg/l

APPENDIX D: RAW DATA FOR POPA RAPIDS – WET SEASON

WET SEASONPOPA RAPIDSMAINSTREAMFull Group II Analyses:

Origin	Kavango Region, Popa Falls Mainstream behind Community
Description	Campsite (EFA site)
Lat	18°06.734
Long	21°34.968
Date of sampling	#####
Date received	#####
DWA number	7300
Test item number	7300
	Recommended max. limits (according to tender specification)

Parameter	Value	me	Unit	Classification	Group A	Group B	Group C	Livestock-watering
p H	7.9			A	6-9	5.5 - 9.5	4.0-11.0	4.0-11.0
Conductivity	4.4		mS/m	A	150	300	400	
TDS (determined)	104		mg/dm ³					6000
Turbidity	2.0		NTU	B	1	5	10	
Colour	24.0		Pt	B	20			
Sulphate as SO ₄	2.6	0.05	mg/dm ³	A	200	600	1200	1500
Chloride as Cl	1	0.03	mg/dm ³	A	250	600	1200	3000
Fluoride as F	<0.1	0.01	mg/dm ³		1.5	2.0	3.0	6.0
Nitrate as N	<0.5	0.04	mg/dm ³	A	10	20	40	100
Nitrite as N	<0.02	0.00	mg/dm ³					10
Silica as SiO ₂	16		mg/dm ³					
P-Alkalinity as CaCO ₃	0		mg/dm ³					
T-Alkalinity as CaCO ₃	21	0.42	mg/dm ³					
T-Hardness as CaCO ₃ , cal.	0		mg/dm ³		300	650	1300	
Calcium as Ca		0.00	mg/dm ³		150	200	400	1000
Magnesium as Mg		0.00	mg/dm ³		70	100	200	500
Sodium as Na		0.00	mg/dm ³		100	400	800	2000
Potassium as K		0.00	mg/dm ³		200	400	800	
Iron as Fe			mg/dm ³		0.1	1	2	10
Manganese as Mn			mg/dm ³		0.05	1	2	10
Langelier Index	#NUM!	####						
Ryznar Index	#NUM!	####						

>0=scaling, <0=corrosive, 0=stable
<6.5=scaling, >7,5=corrosive, ≥6.5 and ≤7.5=stable



EFA Namibia Water Quality

Corrosivity ratio **0.2** no corrosive properties
Stability
pH **#NUM!**

Applies to water in the pH range 7-8

which also contains dissolved oxygen
ratios <0.2 no corrosive properties
ratios >0.2 increasing corrosive tendency

Nutrient analyses:

<u>Parameter</u>	<u>Value</u>	<u>Unit</u>
Ammonium as N	<0.02	mg/dm³
Kjeldahl Nitrogen as N	0.2	mg/dm³
Total Phosphate as P	<0.2	mg/dm³

Physical on site measurements:

pH	7.69
Temperature	27.4°C
Dissolved Oxygen	6.63 mg/L
Electrical Conductivity	41.4µS/cm
Turbidity	3.17 NTU

Chlorophyll a concentration:

0.23_µg/l

BACKSTREAM AT CAMPSITEFull Group II analyses:

Origin Kavango Region,
Popa Falls Resort
Description Backstream at
campsite of Lodge

Lat 18°07.310
Long 20°34.970
Date of sampling 06/02/2009
Date received 12/02/2009
DWA number 7301
Test item number 7301

Recommended max. limits

(according to tender specification)

Parameter	Value	me	Unit	Classification	Group A	Group B	Group C	Livestock- watering
p H	7.9			A	6-9	5.5 - 9.5	4.0-11.0	4.0-11.0
Conductivity	4.4		mS/m	A	150	300	400	
TDS (determined)	80		mg/dm ³					6000
Turbidity	2.2		NTU	B	1	5	10	
Colour	24.0		Pt	B	20			
Sulphate as SO ₄	2.9	0.06	mg/dm ³	A	200	600	1200	1500
Chloride as Cl	1	0.03	mg/dm ³	A	250	600	1200	3000
Fluoride as F	<0.1	0.01	mg/dm ³		1.5	2.0	3.0	6.0
Nitrate as N	<0.5	0.04	mg/dm ³	A	10	20	40	100
Nitrite as N	<0.02	0.00	mg/dm ³					10
Silica as SiO ₂	16		mg/dm ³					
P-Alkalinity as CaCO ₃	0		mg/dm ³					
T-Alkalinity as CaCO ₃	21	0.42	mg/dm ³					
T-Hardness as CaCO ₃ , cal.	0		mg/dm ³		300	650	1300	
Calcium as Ca		0.00	mg/dm ³		150	200	400	1000
Magnesium as Mg		0.00	mg/dm ³		70	100	200	500
Sodium as Na		0.00	mg/dm ³		100	400	800	2000
Potassium as K		0.00	mg/dm ³		200	400	800	
Iron as Fe			mg/dm ³		0.1	1	2	10
Manganese as Mn			mg/dm ³		0.05	1	2	10
Langelier Index	#NUM!	####						>0=scaling, <0=corrosive, 0=stable
Ryznar Index	#NUM!	####						<6.5=scaling, >7.5=corrosive, ≥6.5 and ≤7.5=stable
Corrosivity ratio	0.2		increasing corrosive tendency					Applies to water in the pH range 7-8
Stability pH	#NUM!							which also contains dissolved oxygen ratios <0.2 no corrosive properties ratios >0.2 increasing corrosive tendency

Nutrient analyses:

Parameter	Value	Unit
Ammonium as N	<0.02	mg/dm ³
Kjeldahl Nitrogen as N	0.4	mg/dm ³
Total Phosphate as P	<0.2	mg/dm ³

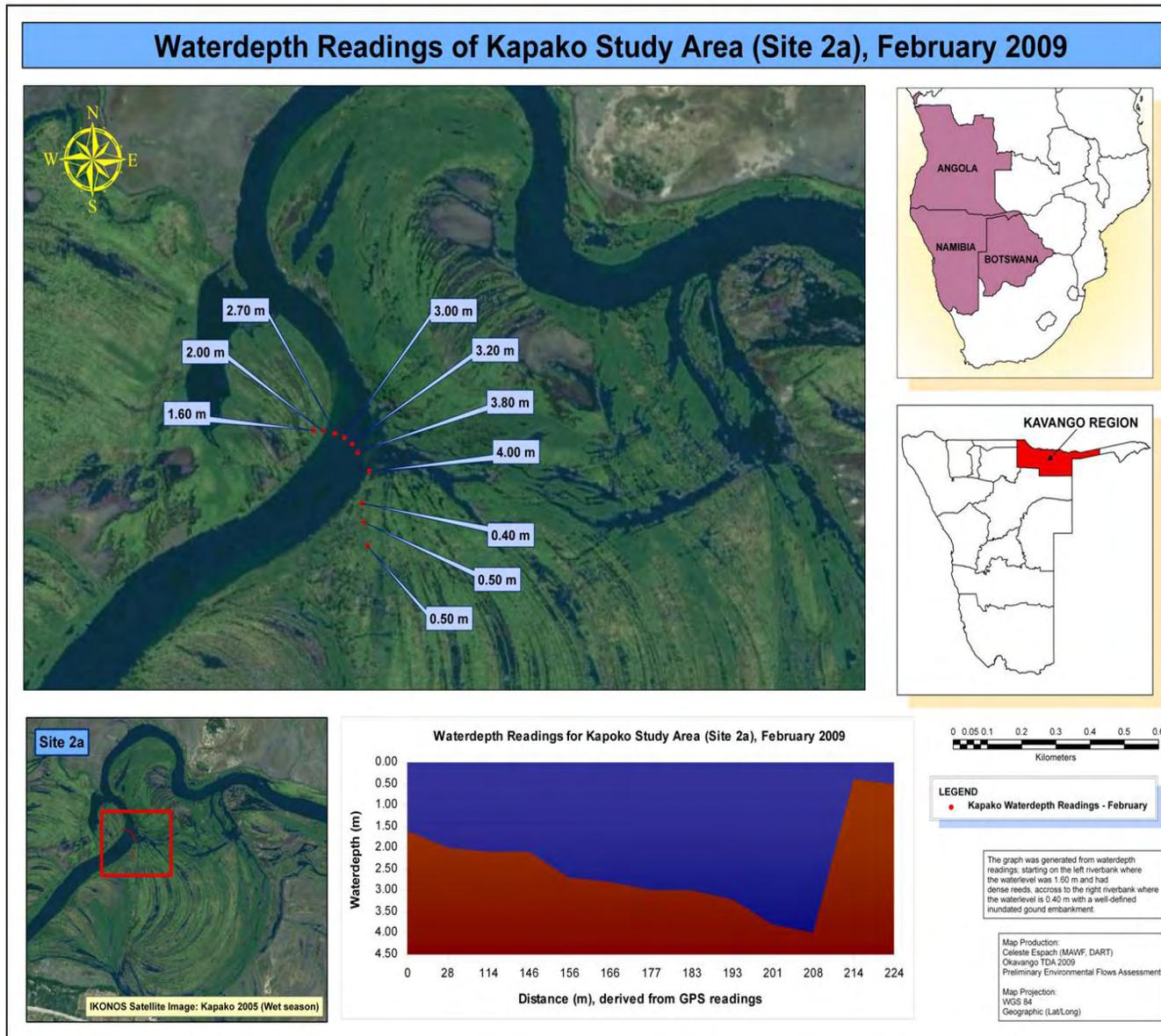
Physical on site measurements:

pH	7.62
Temperature	27.5°C
Dissolved Oxygen	6.50 mg/L
Electrical Conductivity	40.8µS/cm
Turbidity	3.42 NTU

Chlorophyll a concentration:

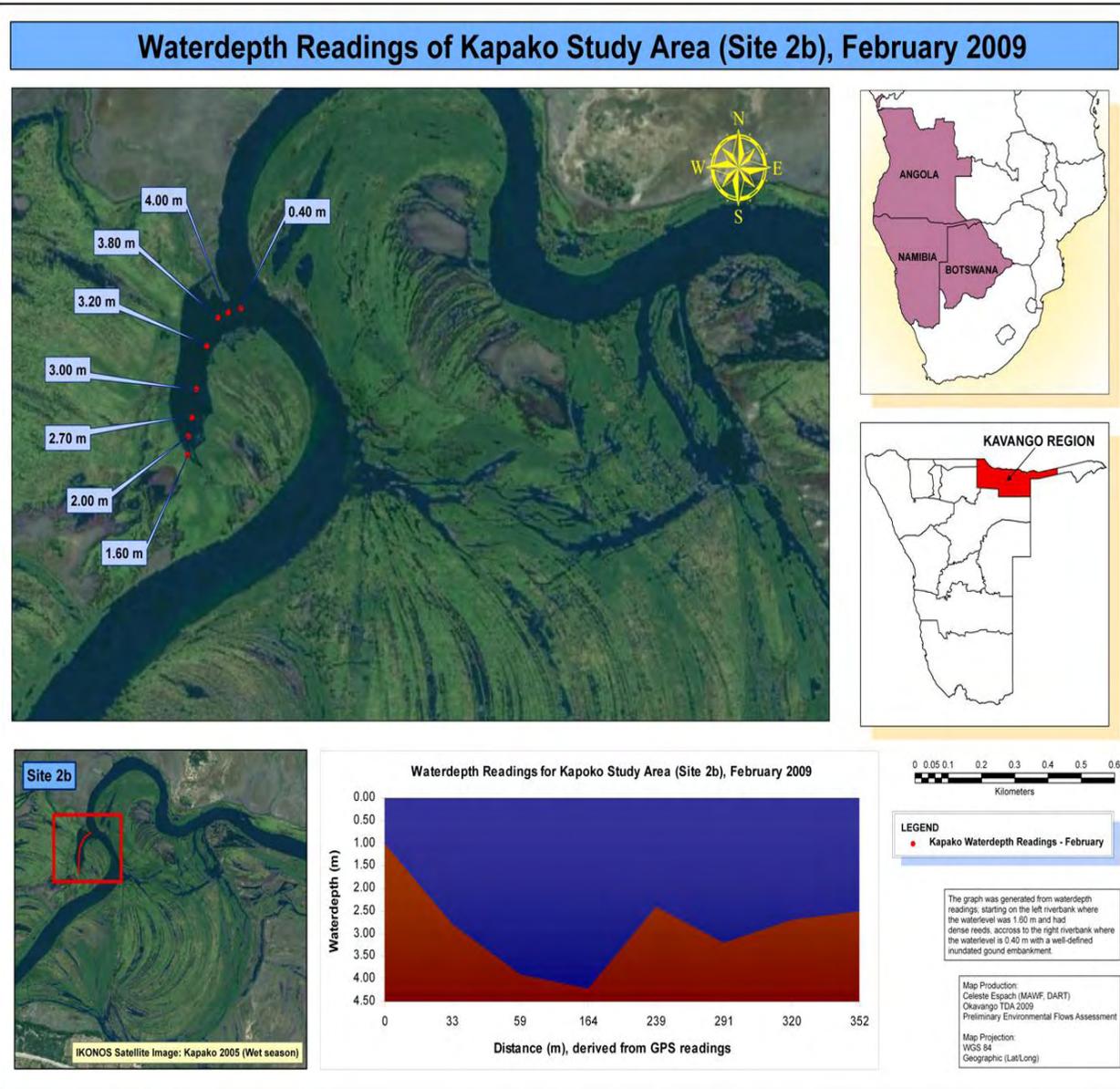
0.34 µg/l

APPENDIX E: KAPAKO SITE A MAP INDICATING WATER DEPTH
READINGS FOR WATER QUALITY SAMPLING IN MAINSTREAM DURING
WET SEASON



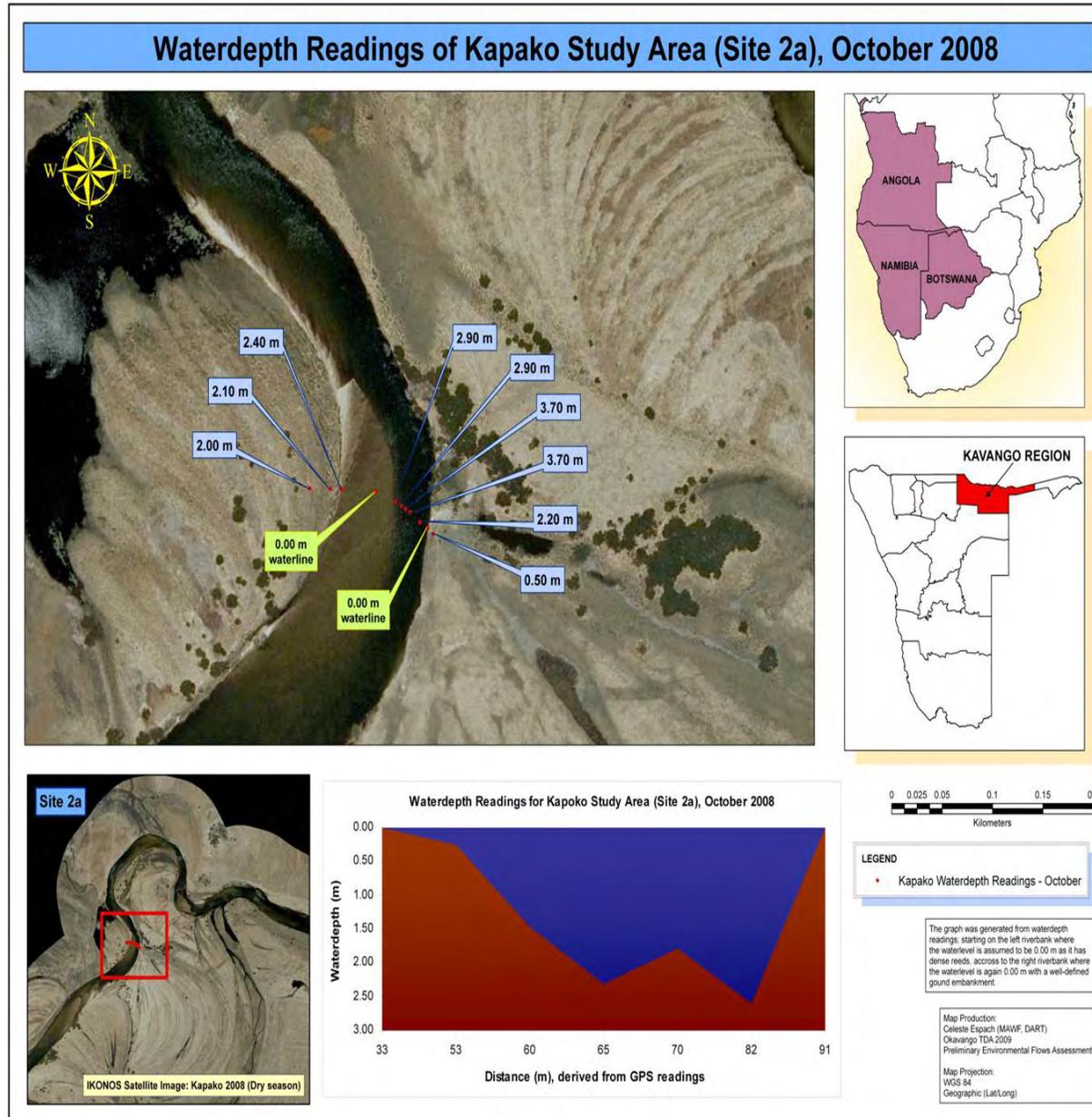
APPENDIX F: KAPAKO SITE B MAP INDICATING WATER DEPTH READINGS
FOR WATER QUALITY SAMPLING IN A POOL DURING WET SEASON



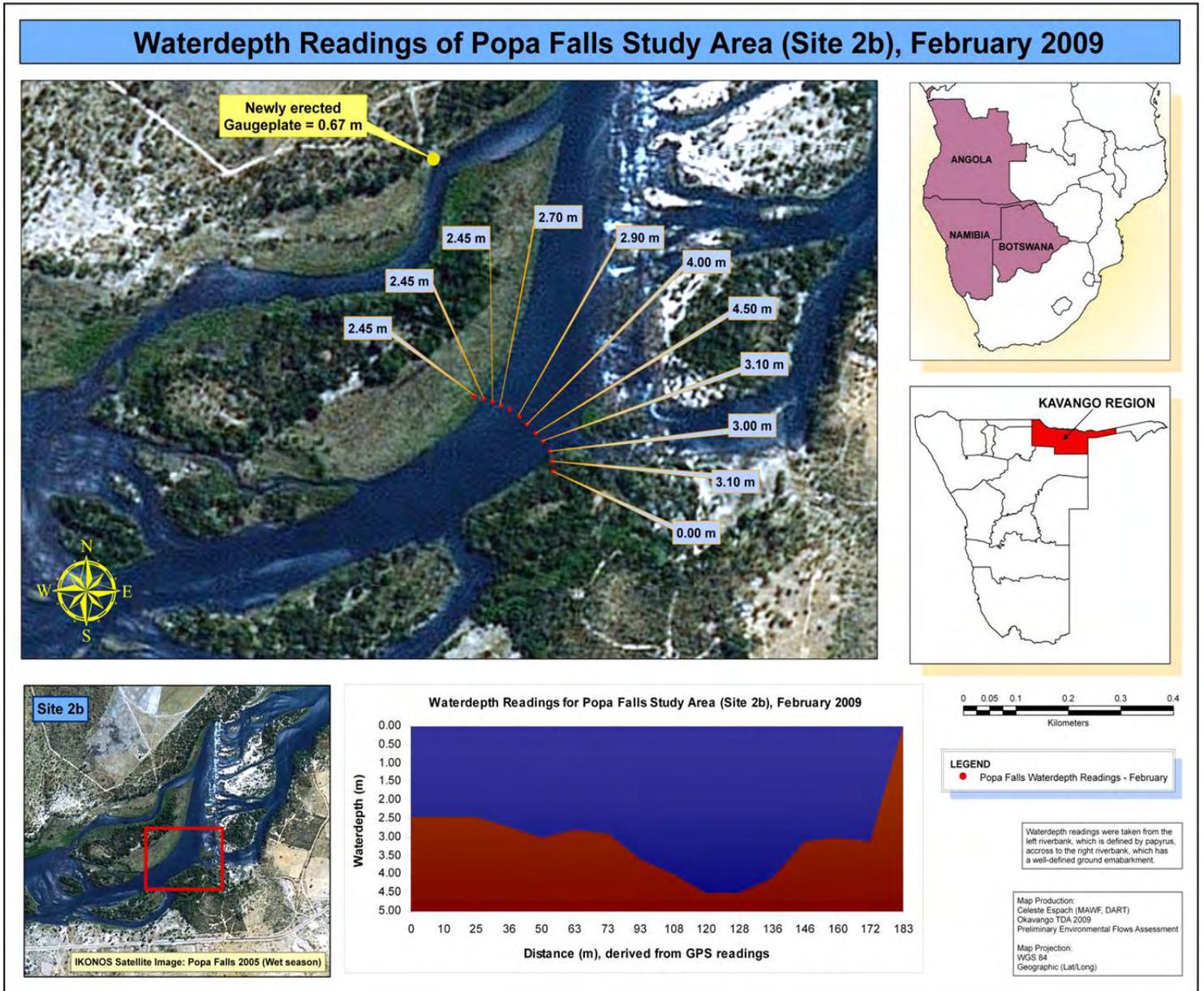


APPENDIX G: KAPAKO SITE A MAP INDICATING WATER DEPTH READINGS
FOR WATER QUALITY SAMPLING IN THE MAINSTREAM DURING DRY SEASON

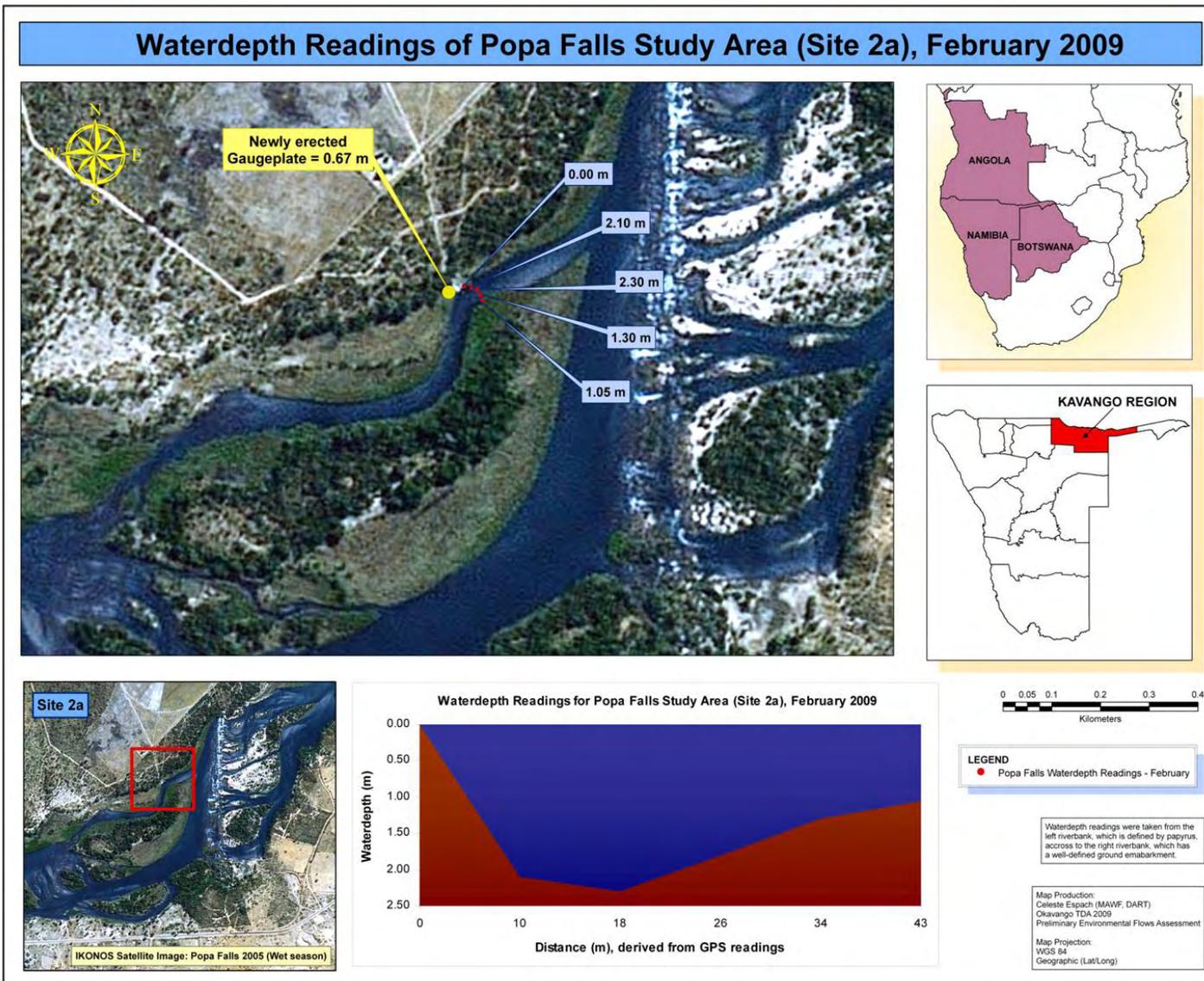




APPENDIX H: POPA RAPIDS SITE B MAP INDICATING WATER DEPTH READINGS FOR WATER QUALITY SAMPLING IN THE MAINSTREAM BEHIND COMMUNITY CAMP IN THE WET SEASON

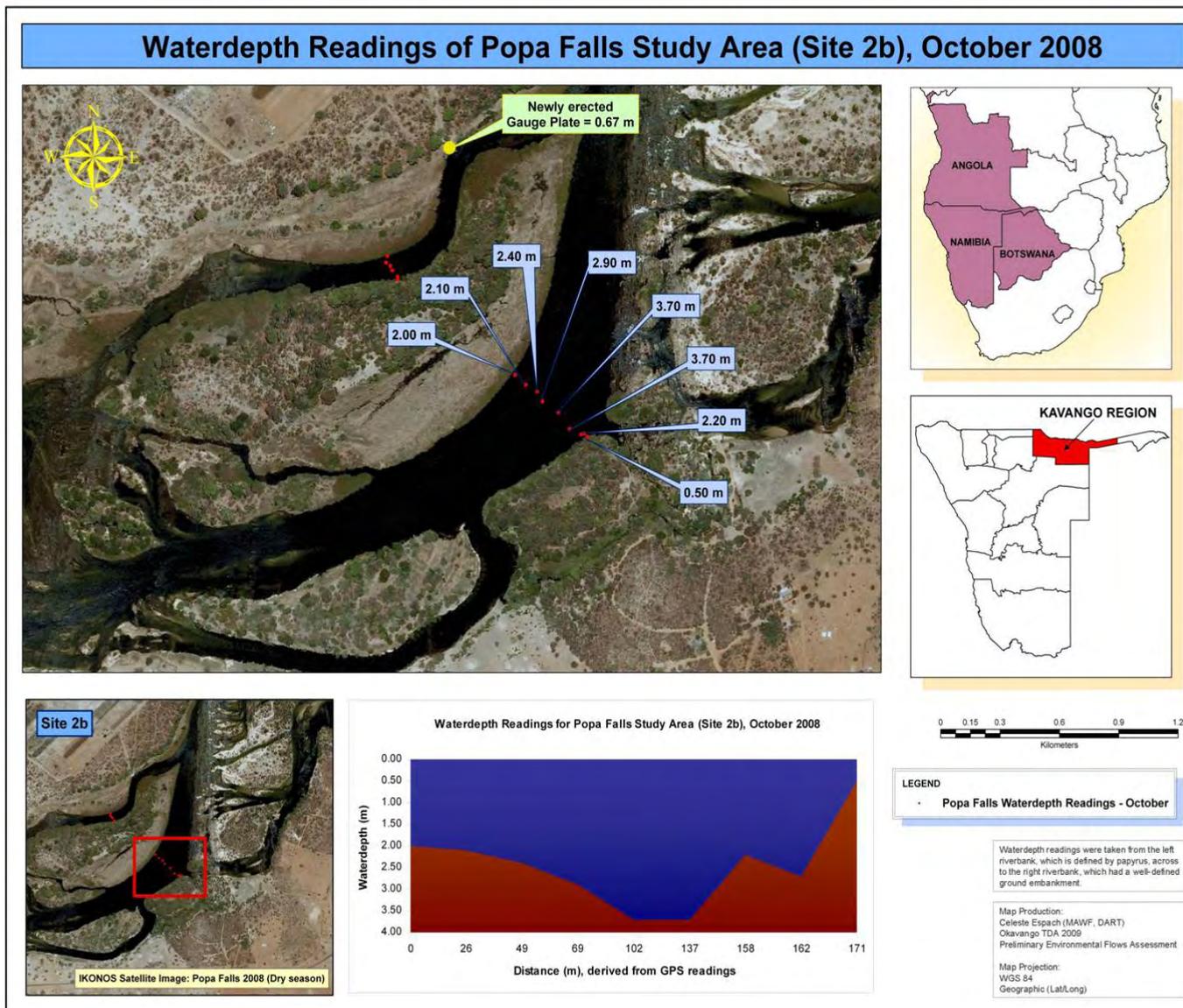


APPENDIX I: POPA RAPIDS SITE A MAP INDICATING WATER DEPTH
READINGS FOR WATER QUALITY SAMPLING IN THE BACKSTREAM AT
CAMPING SITE IN THE WET SEASON

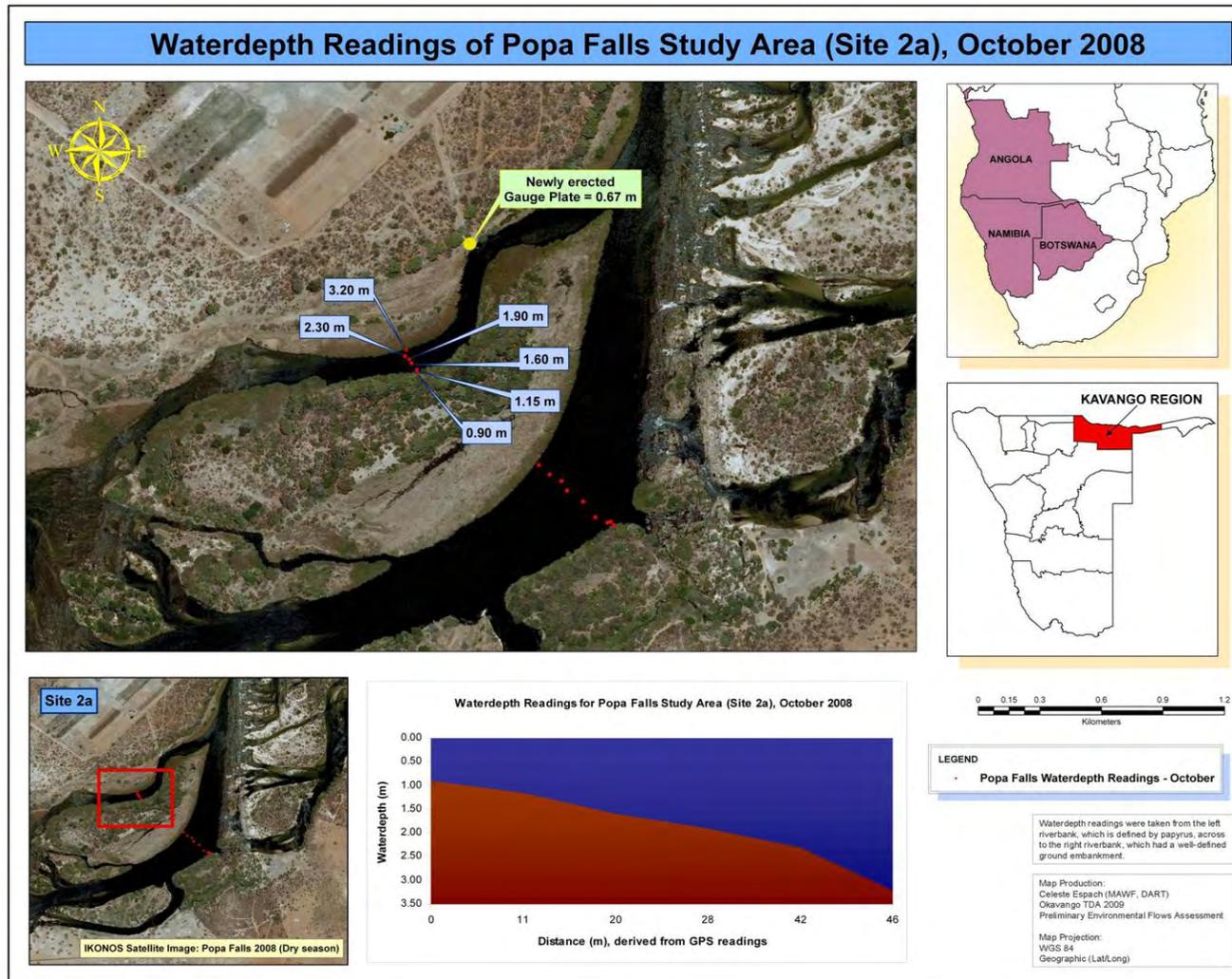


APPENDIX J: POPA RAPIDS SITE B MAP INDICATING WATER DEPTH
READINGS FOR WATER QUALITY SAMPLING IN THE MAINSTREAM BEHIND
THE COMMUNITY CAMP IN THE DRY SEASON





APPENDIX K: POPA RAPIDS SITE A MAP INDICATING WATER DEPTH
READINGS FOR WATER QUALITY SAMPLING IN A BACKSTREAM AT THE
CAMPING SITE IN THE DRY SEASON



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.

<i>Final Study Reports</i>	<i>Reports integrating findings from all country and background reports, and covering the entire basin.</i>		
		Aylward, B.	<i>Economic Valuation of Basin Resources: Final Report to EPSMO Project of the UN Food & Agriculture Organization as an Input to the Okavango River Basin Transboundary Diagnostic Analysis</i>
		Barnes, J. et al.	<i>Okavango River Basin Transboundary Diagnostic Analysis: Socio-Economic Assessment Final Report</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment Project Initiation Report (Report No: 01/2009)</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment EFA Process Report (Report No: 02/2009)</i>
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*Environmental protection and sustainable management
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