Okavango River Basin Transboundary Diagnostic Analysis Technical Report

OKACOM

The Permanent Okavango River Basin Water Commission

EPSMO-BIOKAVANGO
Okavango River Basin
Environmental Flow Assessment
Scenario Report : Hydrology
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EPSMO

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List of reports in report series

Report 01/2009:	Project Initiation Report
Report 02/2009:	Process Report
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Mathews Katjimune

This report is dedicated to Mathews Katjimune, who passed away in October 2009. He contributed immensely to the project and we will miss his energy, enthusiasm, knowledge and outgoing personality.

Executive Summary

E.1. Introduction

The EFA is a joint project of EPSMO and the Biokavango Project. The EFA methodology is based on the evaluation of a reference flow regime ("natural" or "present day") and a range of future flow regimes resulting from water resource developments to make predictions of change for a number of ecological indicators; these usually cover channel geomorphology, water quality, riverine vegetation, fish and aquatic macro-invertebrates. For the EFA, modified future flow regimes are produced with hydrological (and hydraulic) models of the river basin and the delta.

This report (Volume 6) is the second of two reports produced by the EFA hydrological working group. It provides an overview of the hydrological characteristics of the basin and describes the outcomes of the hydrological modeling of present and possible future flow regimes. The report should be read in conjunction with the Hydrology: Data and Models Report (Volume 5), which describes the models, hydrological data and development information that form the basis for the simulation of flow regimes at different points along the Okavango River system, including the Delta.

The hydrological analyses were undertaken to provide summary statistics that are used as inputs to the response curves that are used to predict the biophysical and social outcomes for the flow regime of interest. The response curves, and the predicted ecological and socio-economic implications of the water use scenarios are described in Report 07/2009: Scenario Report: Ecological and social predictions (Volume 1 of 2)

E.2. The Study Area

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 (in Namibia, the river is called the Kavango), and the Okavango Delta. This basin includes the Omatako River catchment in Namibia which is topographically linked to the Okavango River, but due to the low mean annual rainfall (less than 400 mm/year in the headwaters), the river is ephemeral. Due to the sandy nature of the terrain, no surface runoff reaches 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. The Selinda spillway is located in a local depression and provides an occasional link to the Zambezi River. In times of high flow the Okavango overtops a local high point in the Selinda and spills toward the Cuando/Chobe/Linyanti system (2009 Satellite images provided the first recorded evidence of overflow from the Kavango Panhandle reaching the Kwando/Linyanti/Chobe/Zambezi system through the Selinda Channel). On the basis of topography, the Okavango River Basin thus includes the Makgadikgadi Pans and Nata River Basin and has an occasional link to the Zambezi Basin. 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.

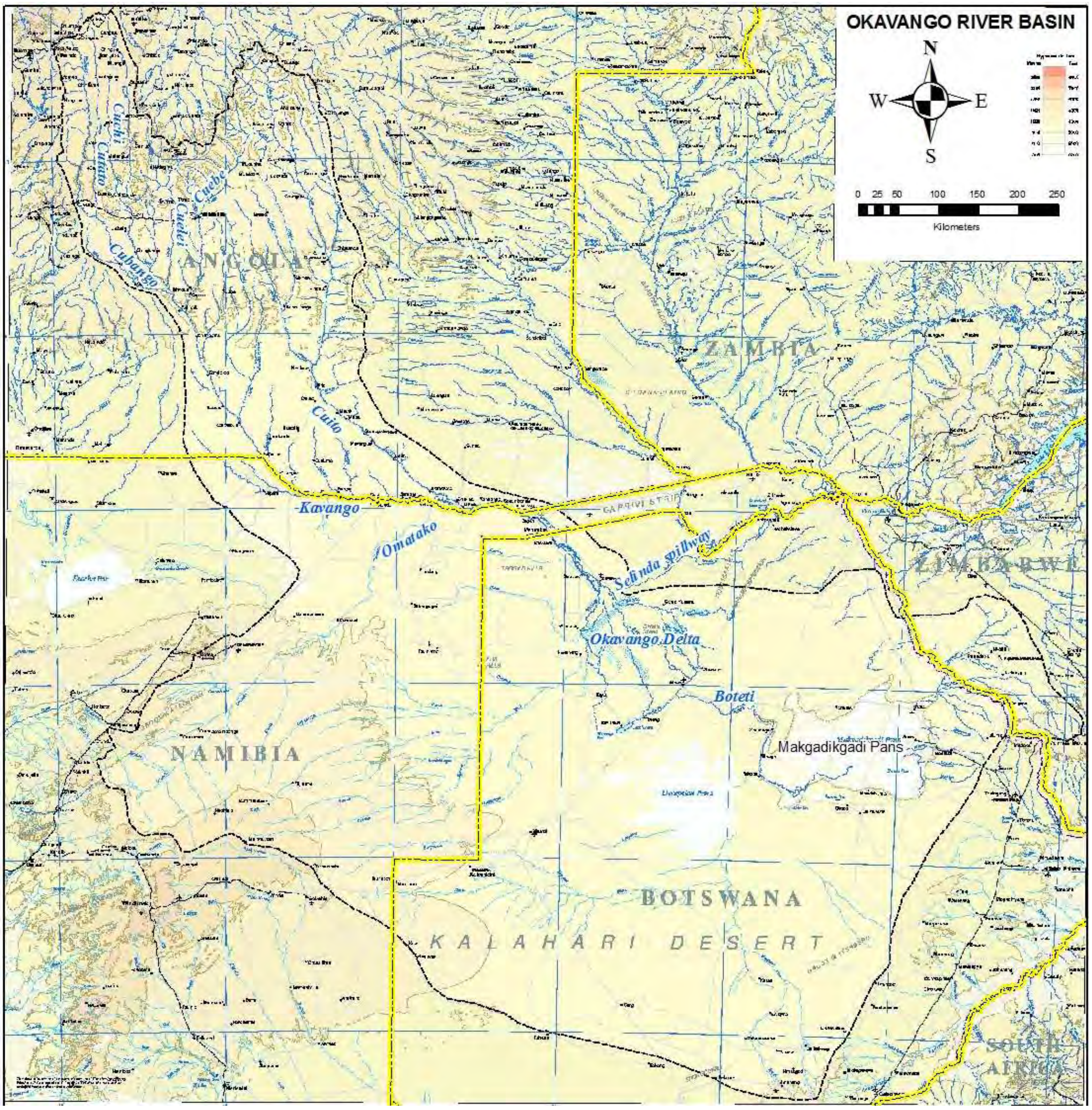

Figure E-1 : The Okavango River Basin

E.3. Delineation of the Okavango Basin into Integrated Units of Analysis

Within the Okavango River Basin, representative areas that are reasonably homogeneous in character were delineated and used to represent much wider areas. (EPSMO/Biokavango Report Number 4; *Delineation Report*). One or more representative sites were chosen in each area as the focus for data-collection activities. The results from each representative site could then be extrapolated over the respective wider areas. The existing and new hydrological models were selected and configured to provide scenario flow sequences at these sites.

The sites chosen by the national teams are given in Table E-1.

Table E-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 Falls
6	Botswana	Okavango	Panhandle at Shakawe
7	Botswana	Khwai	Xakanaka in Delta
8	Botswana	Boteti	Chanoga

E.4. Hydrological Modeling of the Basin

A hydrological working group consisting of hydrologists from the three co-basin states was established to develop and populate the hydrological and hydraulic models for the river basin and the delta and to develop flow scenarios. The work was undertaken during the course of five week-long hands-on workshops in Maun, Gaborone and Windhoek.

In order to provide the hydrological information required for the EFA, a suite of existing and new models were used. The models were selected and configured to provide current day (baseline) and scenario flow sequences at the eight EFA sites. Details of the models and data that were used to configure these are provided in EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models.*

The models which were selected for use in the EFA are:

- **Catchment hydrology:** Estimates of naturalised (undeveloped) long-term runoff were obtained from an existing Pitman-based rainfall-runoff model developed as part of the EU funded WERRD and TwinBAS projects (Hughes *et. al.* 2006). The model was configured to provide runoff sequences at the outlets of 24 distinct sub-catchments upstream of the Delta.
- **Systems Model:** As part of this project, the monthly time-step WEAP systems model was selected and used to configure a reference (Present Day), Low, Medium and High Development scenarios. Inputs to the model include the undeveloped runoff sequences for 24 sub-catchments produced by the Pitman model, irrigation scheme and urban abstractions, in channel dams for irrigation

water supply, inter-basin transfers, run-of-river and storage based hydropower schemes.

- **HOORC Delta Model:** A semi-conceptual model which was previously developed by the Harry Oppenheimer Okavango Research Centre (HOORC) (Wolski et. al. 2006) was used to model inundation frequencies and extents at the Delta EFA sites. The model operates on a monthly time step and includes a dynamic ecotope model that simulates the responses of vegetation assemblages to changes in hydrological conditions. Scenario inflows to the model are provided by the WEAP simulations of basin runoff.
- **DWA Delta Model:** A MIKE-SHE / MIKE 11 hydrodynamic model which was previously configured by Botswana DWA and DHI for the Okavango Delta Management (ODMP) project (IHM Report, 2005) was used to model flow velocities and depths at the Delta EF sites. Scenario flow sequences simulated with WEAP for Mohembo were used as inflow sequences for the Delta model, after disaggregating the monthly flow sequences to a daily time step.
- **Thamalakane/Boteti Model:** Delta outflows simulated by the HOORC model are routed along the Thamalakane/Boteti system with a linear reservoir spreadsheet model (Mazvimavi, 2008) to derive scenario flow sequences at the Boteti EF site. The model was incorporated into the HOORC Delta Model and improved to provide estimates of wetted river length and state changes of the system.
- **Disaggregation and Hydro-Statistics:** A custom utility was developed to disaggregate the simulated monthly WEAP flow sequences to daily flow sequences, to delineate flow seasons (dry, wet and transition) for each year of the 43 year long sequences, and to calculate ecologically relevant flow statistics (“flow indicators”).

E.5. The Present Water Resources Situation

Figure E-2 shows the accumulation of mean annual runoff along the main tributaries of the Okavango upstream of the Delta. The runoff estimates are based on Pitman modeling undertaken for the WERRD and TwinBas studies, and incorporated into the WEAP model developed for the Okavango EFA Study. The estimates are for the period spanning October 1959 to September 2002. Runoff of about 10 200 million m^3/a is generated in the upper catchments of the basin (upstream of the confluences of the Cubango and Cuartir Rivers in the west, and the Cuito and Longa Rivers in the east). Downstream of these points, the catchments of the lower Cubango/Kavango and Cuito River contribute very little additional runoff. Large losses and some abstractions reduce the cumulative present day runoff to about 9 600 million m^3/a at the upper end of the Delta at Mohembo.

Current water abstractions in the upper basin (upstream of Mohembo) amount to about 60 million m3/a (or about 47 million m^3/a if the demands from the nearly completed

Missombo irrigation scheme on the Cuebe River is excluded). In very dry years (1:20 year drought conditions), the flows in the river are significantly restricted as shown by the flows in Figure E-3. Only about 3 000 million m^3/a might be derived from the Cubango and 3 100 million m^3/a from the Cuito, yielding only 6 100 million m^3/a at Mohembo.

Runoff generated in the Cubango River catchments is somewhat more than the contribution of the Cuito River catchments (5 600 and 4 600 million m^3/a, respectively). Simulated average monthly hydrographs for the two rivers just upstream of their confluence are shown in Figure E-4. The figure illustrates the striking difference in the seasonality of the two rivers, and also shows that discharges in the Cuito River during the low flow months of September and October are on average about twice those of the Cubango/Kavango.

The impact of upstream developments on inflows to the Delta can be assessed in terms of changes to the extent, duration and frequency of flooding in the Delta. For the Okavango EFA Study, these changes have been related to changes in vegetation assemblages (EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models*). Figure E-5 shows a timeline of vegetation changes in the Eastern Delta under present levels of water use in the upstream basin. It can be seen that the proportion of grassland and savanna on the periphery of the Delta expands in dry periods such as the one that occurred in the mid-1990s.

Flows in the Thamalakane / Boteti River system receives outflows from the Delta and is highly susceptible to changes in the flooding regime of the Delta. In addition, the length of river that is wetted by inflows in any given year depends on the volume of inflows and state of the groundwater aquifers in previous years. The HOORC model was used to simulate state changes (changes from a wet river, isolated pools or dry riverbed) along a 200 km reach of the Boteti River under different Delta flooding regimes. The sensitivity of the wetted length to inflows (note the dry period in the 1990s) can clearly be seen from Figure E-6.

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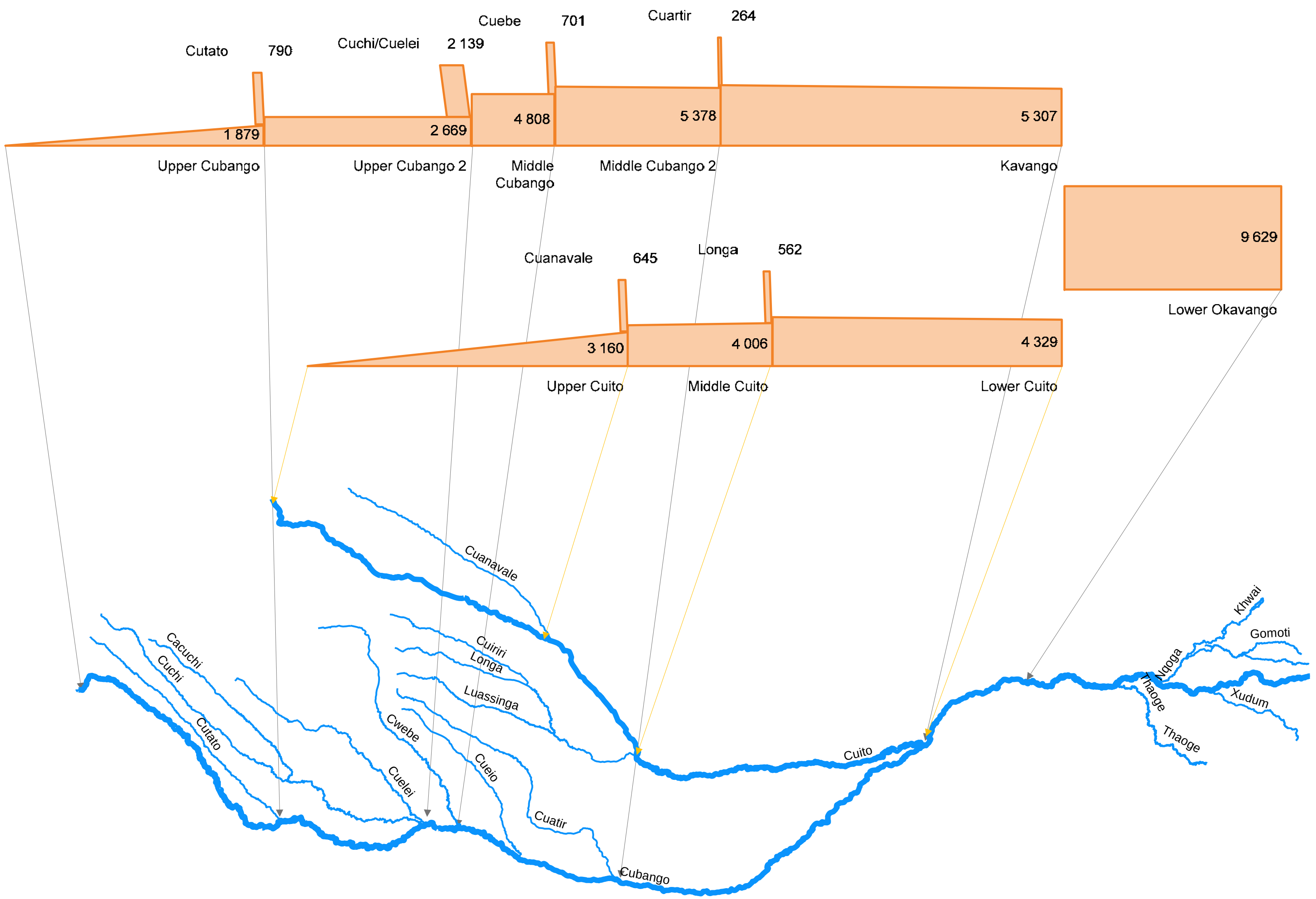

Figure E-2: Mean Annual Runoff (10^6 m^3/a) - Present Day

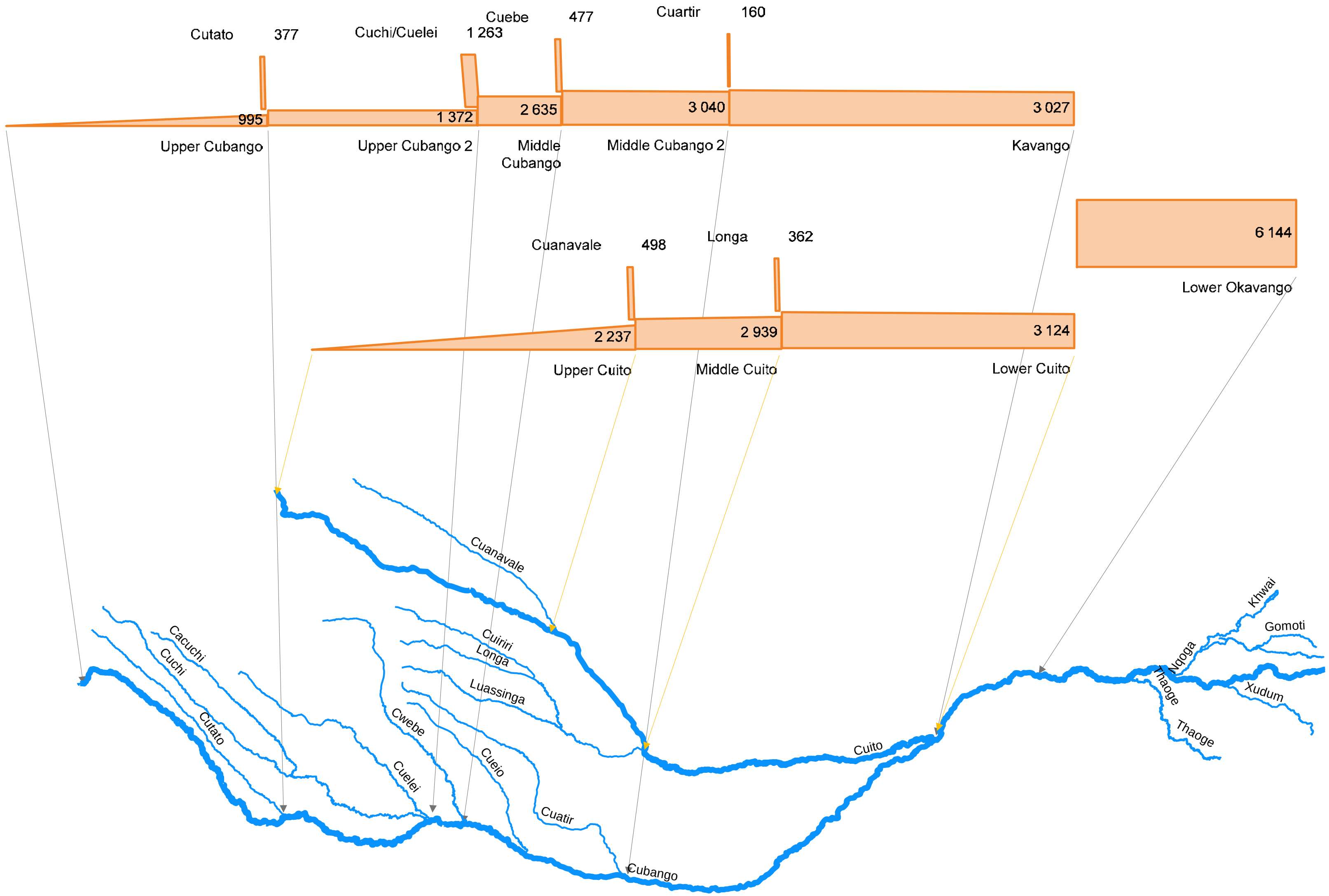

Figure E-3 : Runoff in the driest year in 20 (10^6 m^3/a)

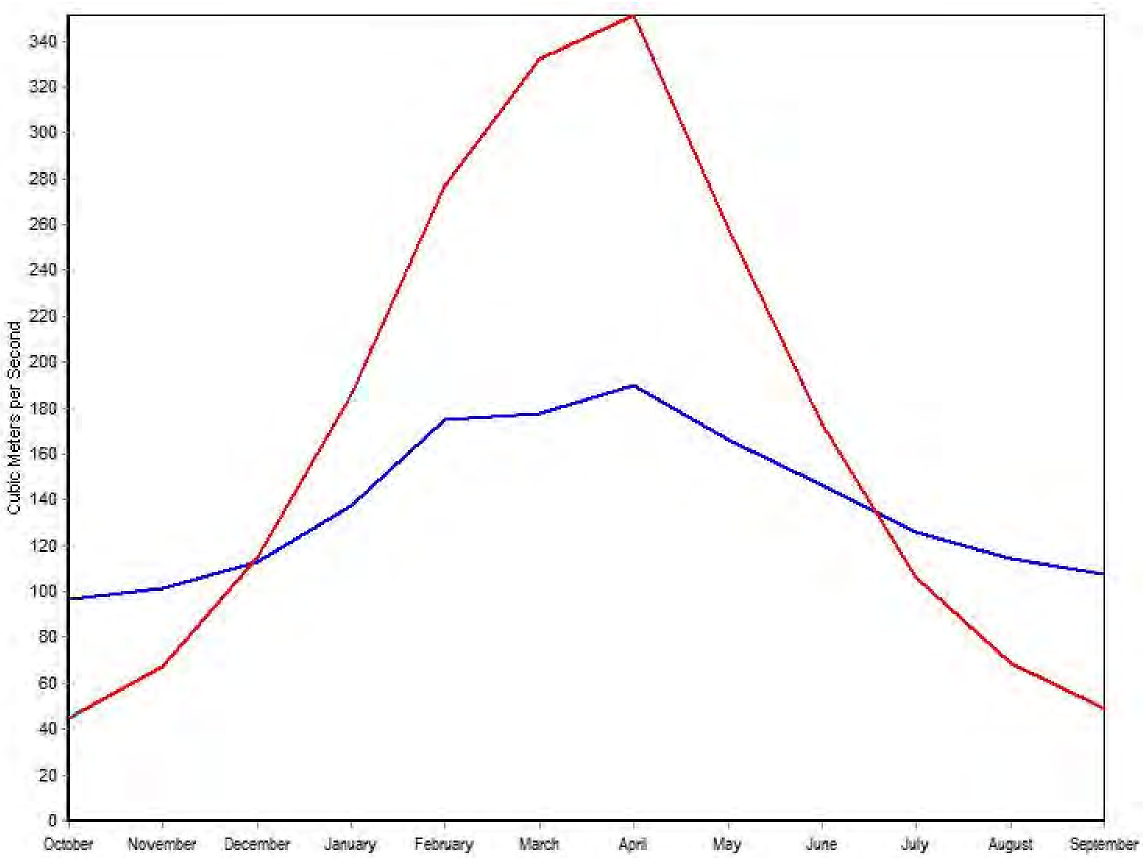

Figure E-4 : Simulated hydrographs of the Cuito River (blue) and Cubango/Kavango River (red)

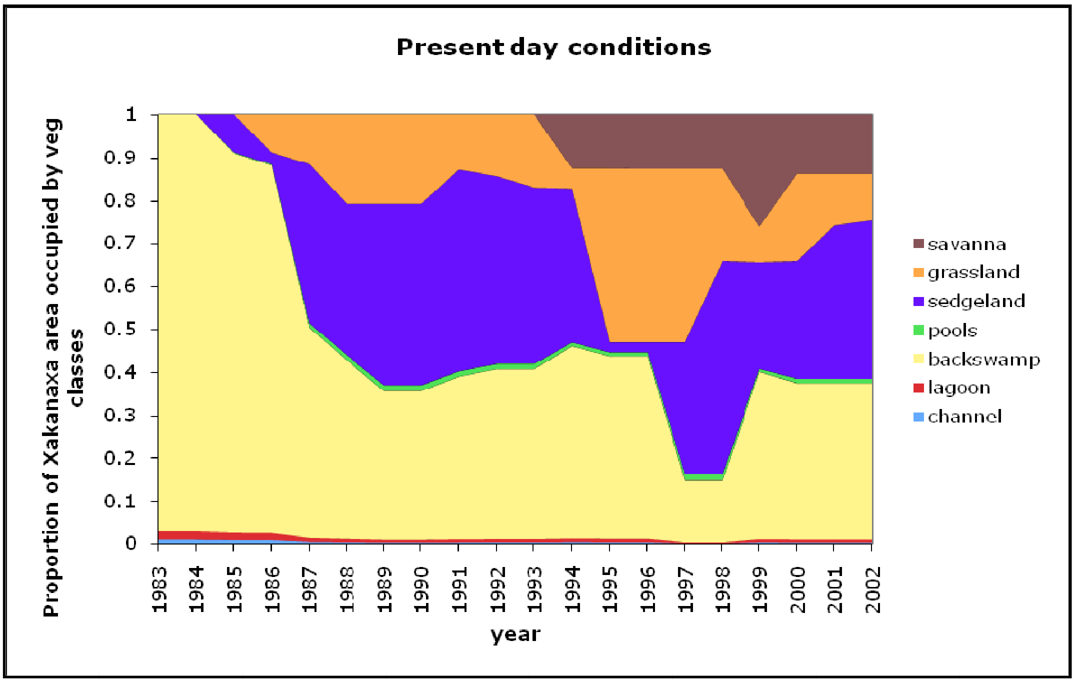

Figure E-5 : Vegetation Response to Flooding - Xakanaxa, Present Day

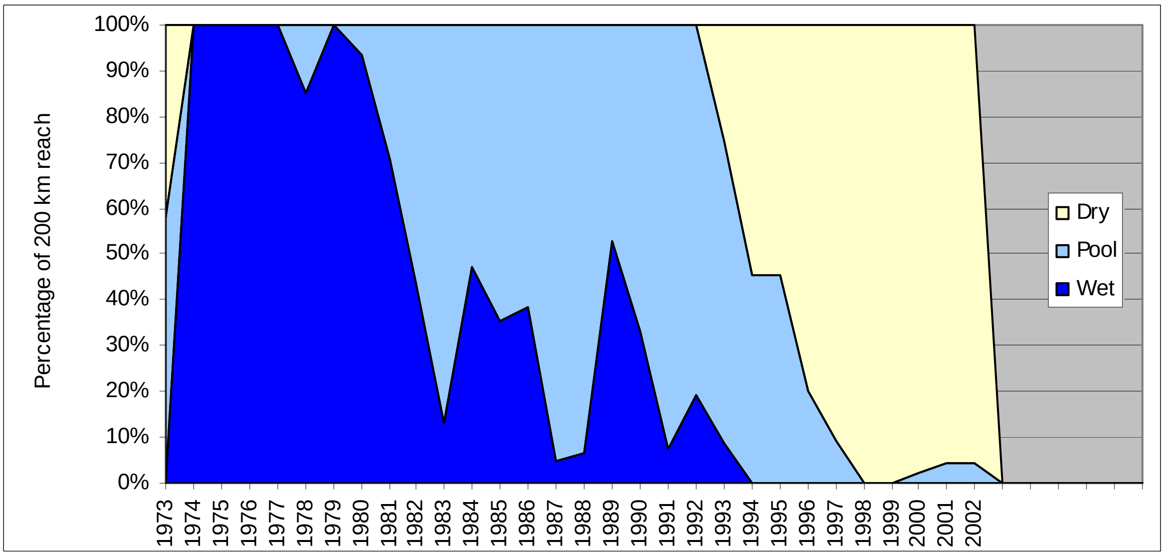

Figure E-6 : Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the present-day simulated conditions given climatic conditions that prevailed from 1973-2002.

E.6. Scenario Selection for the EF Study

While the decision support tools that will be put in place could in future be used to make preliminary assessments of the socio-economic and ecological consequences of specific projects, the aim of the current study is not to do project level assessments, but to provide a planning framework which encompasses most of the water resource development aspirations of the three co-basin states. This would ensure that OKACOM has information at hand to assess the consequences of development pathways spanning a range that is as wide as possible. For this reason preference was given to the selection of a set of scenarios that cover a broad continuum of development and that are positioned at regular intervals across this continuum, rather than an approach that is based on an issue-driven, ad hoc selection of scenarios.

The present, relatively undeveloped state of the basin provides a known reference point from which extrapolations can be made to assess future development states. This "Present Day" state represents one of the four scenarios that were assessed as part of the study. (A climate change scenario will be assessed as an extension to the current project.) The four development scenarios were constructed along the following lines:

- The Present Day scenario includes all existing water resource developments, notably:
  - About 2 700 ha of irrigation in Namibia
  - The urban water demands of Menongue and Cuito Cuanavale (Angola), Rundu (Namibia), and Maun (Botswana)

- A low water use scenario which is based on the continuation of historical growth in water demands in the three countries. Growth rates in Angola reflect the recent

acceleration associated with resettlement in de-mined areas. Increased water consumption is mainly due to growth in urban and rural domestic, livestock and irrigation water demands. The largest water demands are represented by:
  - About 3 100 ha of irrigation in Namibia
  - About 18 000 ha of irrigation along the Cuebe River in Angola
  - One storage based and three run-of-river hydropower stations in Angola

- A medium growth, or "business-as-usual" scenario which includes
  - About 8 400 ha of irrigation in Namibia
  - Development of a first phase of the Eastern National Carrier (17 Mm^3/a) for water supply from the Kavango to Grootfontein and Windhoek,
  - About 198 000 ha of irrigation at various locations in Angola
  - One storage based and four run-of-river hydropower stations in Angola

- A high growth scenario which includes:
  - About 15 000 ha of irrigation in Namibia.
  - About 338 000 ha of irrigation at various locations in Angola
  - Completion of all planned hydropower stations in Angola, i.e. one storage based and nine run-of-river hydropower stations in Angola ,
  - Completion of a second phase of the Eastern National Carrier (total capacity 100 Mm3/a),
  - Development of a storage based water supply scheme for urban and industrial water supply from a dam in the Boteti River to Maun.
  - At these levels of demand, it was necessary to introduce a hypothetical dam in the upper basin (Cuchi River) with a capacity of about 500 million m^3 to provide for shortfalls in irrigation water supply and inter-basin transfers.

Irrigation water demands make up the largest component of future water use. In Angola, the high growth scenario provides for 338 000 ha in the upper catchments of the Cubango River and in the lower reaches of the Cuito River, but excludes some 170 000 ha of previously identified irrigation development upstream of the confluence of the Kavango and Cuito Rivers. The Angolan team decided not to include this area due to a perception that the low flows in the Kavango would not be sufficient to meet the associated demand. In Namibia, the High scenario provides for about 15 000 ha of irrigation development upstream and downstream of the confluence of the Kavango and Cuito Rivers. This area includes the so-called "Green Scheme" and respects the decision by the Namibian Departments of Agriculture Water Affairs (Policy Document No. 7/2/10/3) to limit the abstraction rate out of the Okavango River upstream of the confluence with the Cuito to 5.5 m^3/s, and downstream to 27 m^3/s. The water resource developments that were included in the scenarios are described in more detail in EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models*.

The outcomes of scenarios depend on what is included as a water-resource development. Changing the location, size or any other aspects of a possible development will change the expected future flow regime and thus the expected ecological and social implications.

E.7. Hydrological Consequences of the Water Use Scenarios

General comments

The hydrological consequences of the water use scenarios can be summarised as follows:

- Current day inflows to the Delta of about 9 600 million m^3/a decrease by about 370, 880 and 2 900 million m^3/a relative to the present day mean annual runoff for the Low, Medium and High development scenarios, respectively.
- Most of the water resource developments associated with the Low and Medium scenarios are located in the Cuchi and Cuebe catchments, and the effects of these can be seen in the middle and lower reaches of the Cubango / Kavango River. As an example, dry season low flows at Kapako (and Rundu) would be reduced to about 50% of present day values.
- The combined water abstractions in the upper basin for the High scenario equate to about 3 600 million m^3/a. Of this, by far the largest component is made up of irrigation water demands (3 300 million m^3/a in Angola and 223 million m^3/a in Namibia), followed by the relatively smaller demands of the ENWC transfer (100 million m^3/a), and the combined urban demands of Menongue, Cuito Cuanavale and Rundu (22 million m^3/a).
- In the High development scenario, large tracts of irrigation developments are located along the lower reaches of the Cuito River. This has the effect of considerably reducing the Cuito River's strong base flow contribution to the lower Okavango River. The combined effect of all upstream developments substantially reduces the permanent swamp area in the Delta, and virtually dries up the Boteti River.
- The hydrological impacts of the developments in the Cubango/Kavango sub-basin (upstream of the confluence with the Cuito) is mitigated to some extent by the presence of two large storage dams – a hydropower storage near Mucundi on the Cubango River (Low scenario), and another in the Cuchi catchment (High scenario). While the main purpose of the Mucundi Dam is to provide generating head for hydropower, hydropower releases in the dry season is available for downstream abstractions such as the Eastern National Carrier.
- It is important to note that, were the storage dams not present, the postulated future demands under the High scenario would not be met in its entirety. A test was done by removing the storage dams, and re-simulating the High scenario. It can be seen that, for example, the ENWC monthly water abstractions cannot be met for a much longer percentage of time, were the dams not in place.

Site 1 - Capico

All of the developments envisaged for Capico were inserted into the Low Scenario, and so the following consequences apply to all three scenarios. The developments are: run-of-river abstractions that feed 28 000 ha of irrigation, increased urban supply for up to 100 000 more people and a small run-of-river HEP diversion at Liapeca. These result in the mean annual runoff in the Cuebe dropping to about half, because of water being diverted into croplands. Diversions take place year round, but the biggest volumes are diverted during the dry season. Figure 5-6 shows that in all future scenarios low flows are virtually depleted for about 25% of the simulation period. The impact is greater in the dry season, which starts 3 months earlier, is more than 4 months longer and has flows close to zero. The wet season is 3 months shorter and the volume of flood water is about half of present.

Site 2 – Mucundi

All of the developments for Capico still apply, and in addition further major developments in hydropower generation and croplands are included. Run-of-river HEP schemes with diversion structures are added with each scenario, but one storage based scheme with a substantial dam wall. Irrigated cropland gradually increases to a maximum of 175 000 ha, all areas using run-of-river abstraction, except for a large dam on the Cuchi River, which is introduced in the High Scenario. The impacts on flow are not as severe as at Capico because of the contribution of undeveloped tributaries. Mean annual runoff declines gradually to about 80% of present, and the dry season starts about a month earlier and lasts up to 2 months longer. Because of the continual abstractions, dry-season flows fall to less than half of present flows in the Low and Medium Scenarios, but they increase again in the High Scenario due to dam releases. Wet-season flows start later and with lesser floods, because of filling of the dams on the Cubango and Cuchi, and are up to a month shorter.

Site 3 – Cuito Cuanavale

Most developments included for the Cuito River are downstream of the Cuito-Cuanavale site and so do not affect it. The scenarios include 50 000 more people in urban areas and a small run-of-river HEP diversion on the Cuito River upstream of Cuito Cuanavale. These do not have a noticeable impact on the flow regime although the HEP infrastructure might have a, presently unknown, impact on sediment movement along the river. If only flow changes are considered, the developments included for this site would have a minimal impact on the river ecosystem.

Site 4 – Kapako

All developments included for Capico and Mucundi are upstream of this site and so are included, and in addition a further 48 000 ha of run-of-river irrigation in the Kapako area is added gradually through the scenarios. There are no significant tributaries between Mucundi and Kapako and so flow changes upstream are transmitted downstream without amelioration of other inflows. Figure 5-8 shows the elevation of low flows (tail-end of the duration curve) under the High scenario due to dry season releases from the two postulated storage dams in the Cubango sub-basin. The annual volume of water flowing down the river progressively declines to 80% of present and the dry-season flow falls by about half and the dry season extends up to 1.5 months longer. The wet season is shorter by about the same length of time with up to a 30% drop in volume but little change in flood onset time and size of flood peak.

Sites 5 and 6 : Popa Rapids and Panhandle

All developments upstream in Capico, Mucundi, Cuito Cuanavale and Kapako are included, plus a gradual increase of run-of-river irrigation along the lower Okavango and a large increase along the lower Cuito River in the Medium and High scenarios to more than 178 000 ha above present (mostly in Angola), up to 130 m^3/s more diversion in Namibia for urban supply, and three additional run-of-river HEP structures, one with a dam wall height of 7.5 m. These translate as a decline to 69% of mean annual runoff and a dry season that starts up to

2 months earlier and is 3 months longer than present. Under the High Scenario, dry-season flows drop to 18% of present. The flood season onset and peak are only slightly affected but it is up to 2 months shorter and declines to about two-thirds of its present volume.

The Delta (Site 7 – Xakanaka)

Due to the declining upstream inflows into the Delta, there is a decrease in all major types of permanent swamp to as low as 22% of present under the High scenario, and an increase in seasonal swamps into these areas. Dry flood-plain savanna also expands to more than four times its present area, representing a significant drying-out of the Delta.

Delta Outflows (Site 8 – Boteti)

The Thamalakane / Boteti River system receives outflows from the Delta and is highly susceptible to changes in the flooding regime of the Delta. In addition, the length of river that is wetted by inflows in any given year depends on the volume of inflows and state of the groundwater aquifers in previous years. Flows in the system normally exhibit dry and wet cycles of many years in length. Through the scenarios the number of years it contains water would progressively decline until in the High Scenario it would be completely dry for most of the time, holding water only in the wettest years.

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Acronyms and abbreviations

DWA	Department of Water Affairs, Botswana
DWAF	Department of Water Affairs and Forestry, Namibia
EFA	Environmental Flow Assessment
ENWC	Eastern National Water Carrier
EPSMO	Environmental Protection and Sustainable Management of the Okavango River Basin
ha	hectare
HEP	Hydro-Electric Power (Station)
HOORC	Harry Oppenheimer Okavango Research Centre
IUA	Integrated Units of Analysis
MAR	Mean Annual Runoff
OBSC	Okavango Basin Steering Committee
OKACOM	Okavango River Basin Water Commission
PD	Present Day
SAP	Strategic Action Programme
TDA	Transboundary Diagnostic Analysis

1. INTRODUCTION

1.1. Background

An Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project is being implemented under the auspices of the **Food and Agriculture Organization** of the United Nations (UN-FAO). One of the activities is to complete a transboundary diagnostic assessment (TDA) for the purpose of developing a Strategic Action Plan for the basin. The TDA is an analysis of current and future possible causes of transboundary issues between the three countries of the basin: Angola, Namibia and Botswana. The Okavango Basin Steering Committee (OBSC) of the Okavango River Basin Water Commission (OKACOM) noted during a March 2008 meeting in Windhoek, Namibia, that future transboundary issues within the Okavango River basin are likely to occur due to developments that would modify flow regimes. The OBSC also noted that there was inadequate information about the physico-chemical, ecological and socioeconomic effects of such possible developments. OBSC recommended at this meeting that an Environmental Flow Assessment (EFA) be carried out to predict possible development-driven changes in the flow regime of the Okavango River system, the related ecosystem changes, and the consequent impacts on people using the river's resources.

The EFA is a joint project of EPSMO and the Biokavango Project. The EFA methodology is based on the evaluation of a reference flow regime ("natural" or "present day") and a range of future flow regimes resulting from water resource developments to make predictions of change for a number of ecological indicators; these usually cover channel geomorphology, water quality, riverine vegetation, fish and aquatic macro-invertebrates. For the EFA, modified future flow regimes are produced with hydrological (and hydraulic) models of the river basin and the delta.

This report (Volume 6) is the second of two reports produced by the EFA hydrological working group. It provides an overview of the hydrological characteristics of the basin and describes the outcomes of the hydrological modelling of present and possible future flow regimes.

The report should be read in conjunction with the Hydrology: Data and Models Report (Volume 5), which describes the models, hydrological data and development information that form the basis for the simulation of flow regimes at different points along the Okavango River system, including the Delta.

1.2. Objectives of the EF assessment

There were two main objectives.

- Complete a basin-wide EFA of the Okavango River system as a major part of the wider Technical Diagnostic Analysis. This would be done through several subsidiary objectives:
    - Collate all existing hydrological data on the river system and set up a basin hydrological model that could simulate flows under various possible future development scenarios
    - Reach agreement with the three riparian governments on the scenarios to be explored

- Bring together specialists in a range of relevant disciplines from across the basin to share knowledge and data, and reach consensus on the:
  - relationships between flow and a series of biophysical indicators of the river system
  - relationships of the condition of the ecosystem and social indicators
- Develop a DSS that would capture these relationships and produce predictions of ecological and social change for each scenario that would complement the macroeconomic predictions emanating from a separate exercise
- Incorporate the EFA findings in the TDA document.

- Promote basin-wide communication and collaboration, and build capacity in collaborative basin-wide Integrated Water Resource Management in all disciplines in all three countries. This was done by appointing a full biophysical and socio-economic team from each of the three countries, with planning, coordination and training done by a Process Management Team.

1.3. The Study Area

1.3.1 Topography and Drainage

Extent of the 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 (in Namibia, the river is called the Kavango), and the Okavango Delta. This basin includes the Omatako River catchment in Namibia which is topographically linked to the Okavango River, but due to the low mean annual rainfall (less than 400 mm/year in the headwaters), the river is ephemeral. Due to the sandy nature of the terrain, no surface runoff reaches 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. The Selinda spillway is located in a local depression and provides an occasional link to the Zambezi River. In times of high flow the Okavango overtops a local high point in the Selinda and spills toward the Cuando/Chobe/Linyanti system (2009 Satellite images provided the first recorded evidence of overflow from the Kavango Panhandle reaching the Kwando/Linyanti/Chobe/Zambezi system through the Selinda Channel). On the basis of topography, the Okavango River Basin thus includes the Makgadikgadi Pans and Nata River Basin and has an occasional link to the Zambezi Basin. 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.

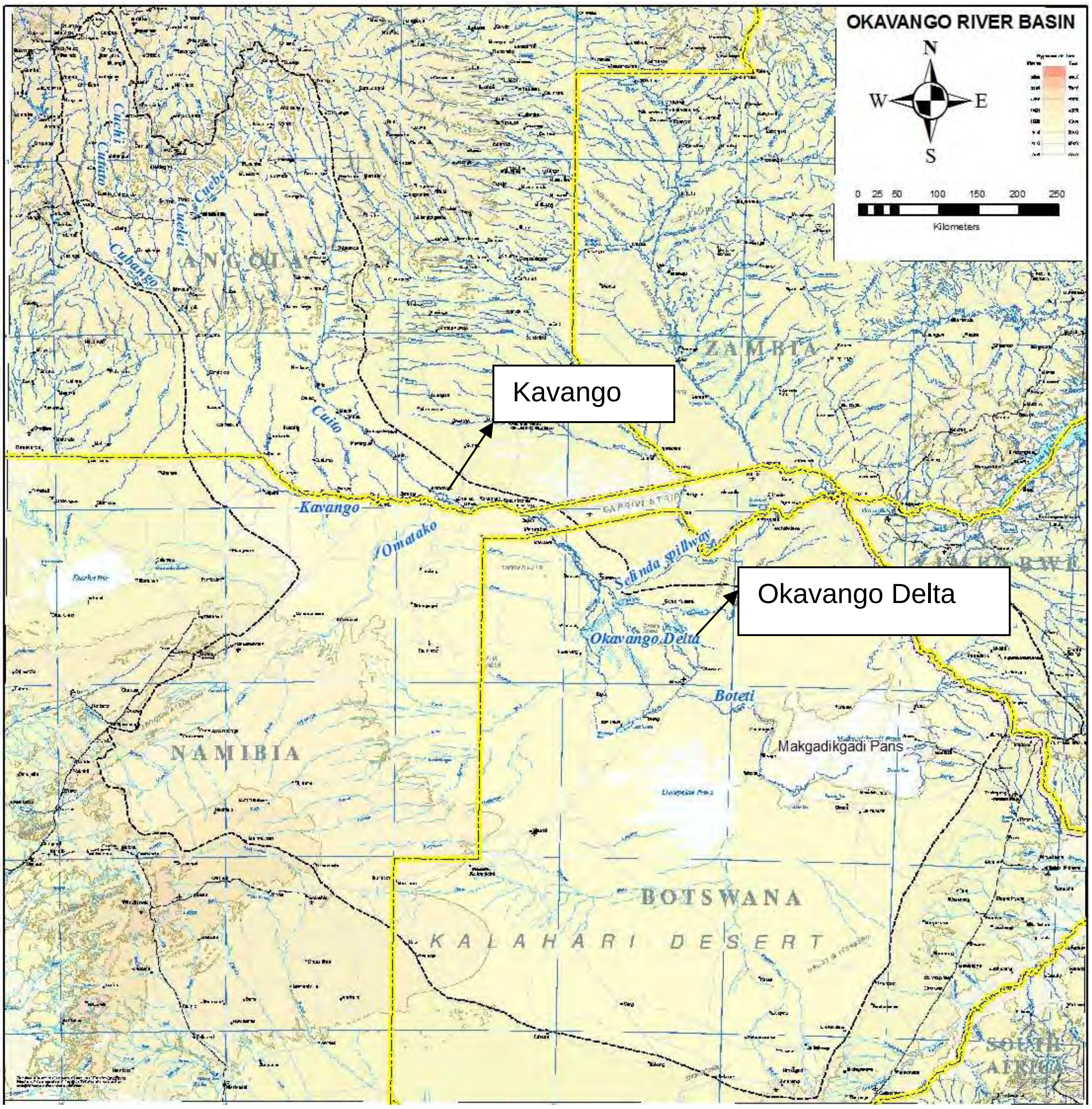


Figure 1-1 The Okavango River Basin

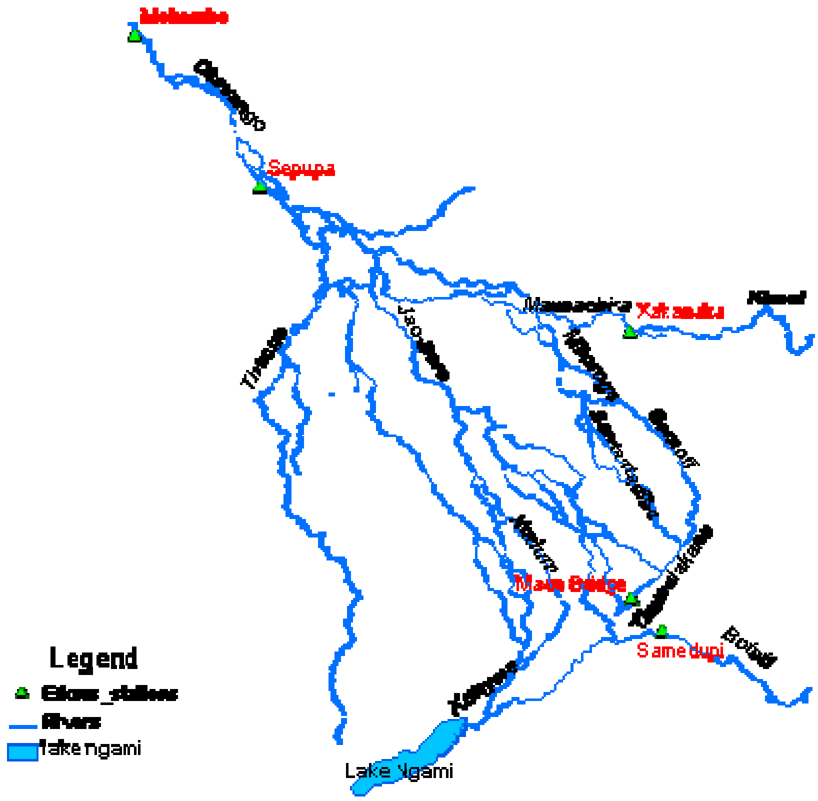


Figure 1-2 The Okavango River Delta, showing drainage into the Thamalakane / Boteti System

The Okavango River Basin upstream of the Delta

The upstream basin is drained by the two main tributaries of the Okavango, namely the Cubango River in the west, and the Cuito River in the east. The western headwaters of the Cubango River are characterised by a series of north-south flowing tributaries with a high drainage density draining the western highlands at an altitude of around 1800m. From here, the Cubango River flows south through a gently undulating landscape for about 600 km before it turns toward the east, forming the border between Angola and Namibia. The confluence of the Cuito and Okavango Rivers is located about 300km after the Cubango River first reaches the Namibian border.

The Cuito River rises further to the east than the Cubango River but mean annual precipitation is of the same order as for the upper Cubango River catchment. Unlike the Cubango River, the Cuito River meanders through some very wide flood plains in Kalahari Sand deposits in southern Angola. While river flows in the Cubango and its tributaries are characterised by a strong seasonal variation and low dry season base flows, the Cuito and its tributaries show much less seasonal variation with dampened wet season peak flows and elevated dry season base flows, mainly due to considerable groundwater recharge and discharge in this part of the basin.

Just after the village of Mukwe, the river turns more southwards, crosses the Namibian Caprivi Strip and enters Botswana. Seventy kilometres further downstream the mainstream starts to divide and the Okavango Delta is formed.

In terms of catchment area, the Omatako River in Namibia is the biggest tributary to the Okavango River, but there is no record of this ephemeral river system ever having flowed as far as the confluence.

The Okavango Delta

The Okavango Delta can be classified in terms of flow regime and habitat; permanent swamps, seasonal swamps, occasionally flooded areas, and drylands (McCarthy et al. 1988; Murray-Hudson et al. 2006). The upper part of the delta, commonly referred to as the Panhandle, consists of a 10-15 km wide and 150 km long valley within which the main channel meanders through. The Okavango River in the Panhandle splits into the western distributary, the Thaoge River, Boro River and Maunachira River. Boro sends out Xudum system in the middle reaches on its west and outflows to Lake Ngame through Kunyere River while Maunachira splits to form Mboroga and Santantadibe Rivers (Figure 1-2). Flow of the Okavango River is therefore partitioned within the delta. Over-spilling of flow from channels onto adjacent floodplains is a common feature within the delta during the high flow period, and in some cases the spilled water joins the same or different channel (Wolski and Murrary-Hudson 2006). Of the three main distributaries, the Thaoge River in the west terminates in a series of lagoons and extensive floodplains near its upper end. The Boro upstream flows through lagoons and floodplains and is a single more or less confined channel in the downstream discharging into Thamalakane River and outflows to the Boteti River. Channel banks are very porous as most of them are made of papyrus. The substratum of channels is very permeable resulting in substantial exchange of water between channels, floodplains, and groundwater.
Within the Okavango River Basin, representative areas that are reasonably homogeneous in character were delineated and used to represent much wider areas. One or more representative sites were chosen in each area as the focus for data-collection activities. The results from each representative site could then be extrapolated over the respective wider areas. The existing and new hydrological models were selected and configured to provide scenario flow sequences at these sites. The basis for selection of the sites is decribed in EPSMO/Biokavango Report Number 4; *Delineation Report*.

The sites chosen by the national teams are listed in Table 1-1 and shown on Figure 1-3.

Table 1-1 Location of the eight EFA sites

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

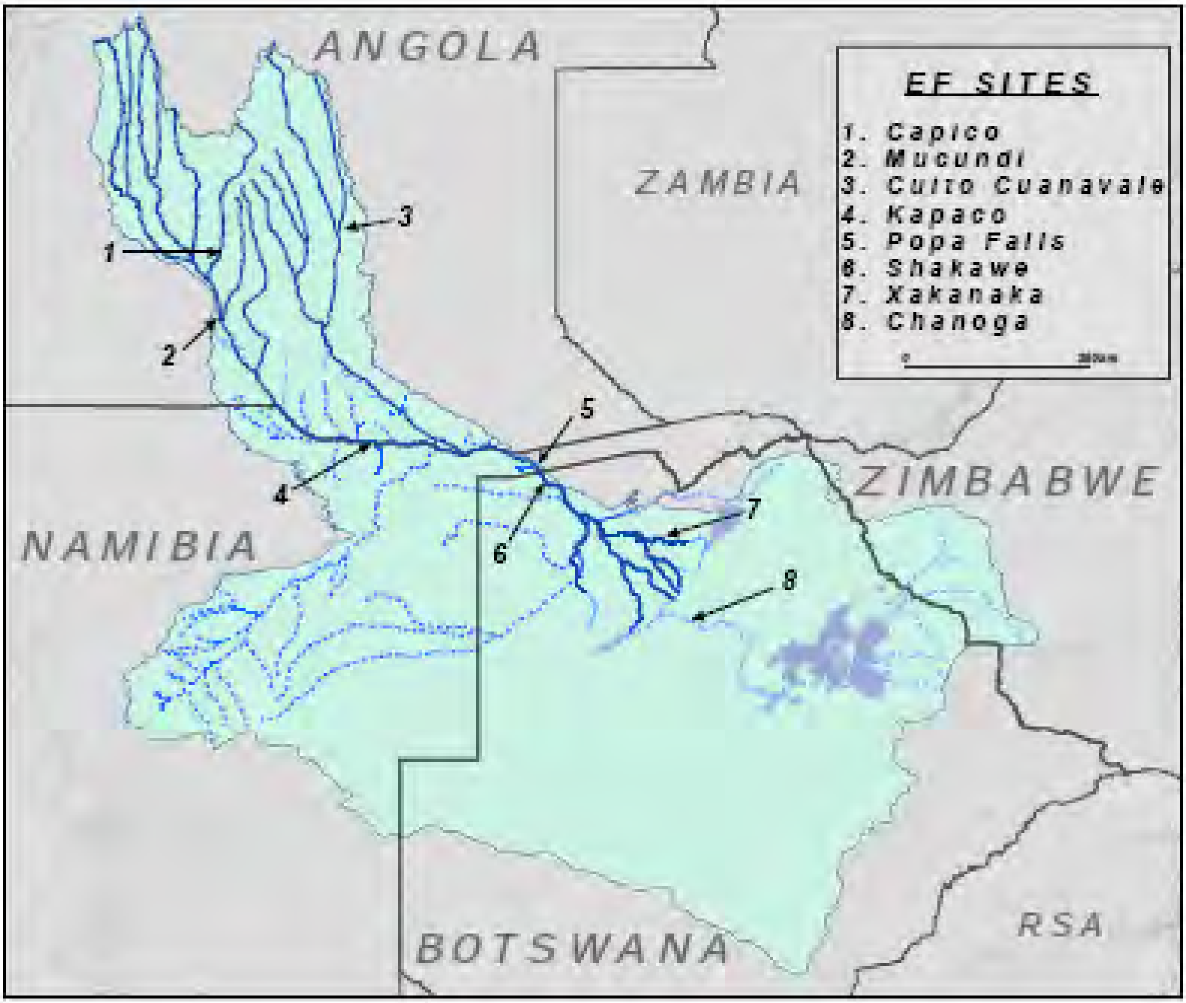


Figure 1-3 **Map showing site locations**

1.4. Layout of the report

Chapter 1: Introduction
Chapter 2: Hydrological Modeling of the Basin
Chapter 3: Current Water Resource Situation
Chapter 4: Formulation of the water use scenarios
Chapter 5: Hydrological Consequences of the Water Use Scenarios
Chapter 6: Conclusions

2. Hydrological Modeling of the Basin

2.1. Hydrological Working Group

A hydrological working group consisting of hydrologists from the three co-basin states was established to develop and populate the hydrological and hydraulic models for the river basin and the delta and to develop flow scenarios. The work was undertaken during the course of five week-long hands-on workshops in Maun, Gaborone and Windhoek.

2.2. Hydrological Models

A series of hydrological and hydraulic models have in the past been developed to reproduce flow conditions observed in the Okavango Basin and Delta. In order to provide the hydrological information required for the EFA, a suite of existing and new models were used. The models were selected and configured to provide current day (baseline) and scenario flow sequences at the eight EFA sites. Details of the models and data that were used to configure these are provided in EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models.* A short summary is provided here for ease of reference.

The modelling sequence and linkages between the models are shown in Figure 2-1 below.

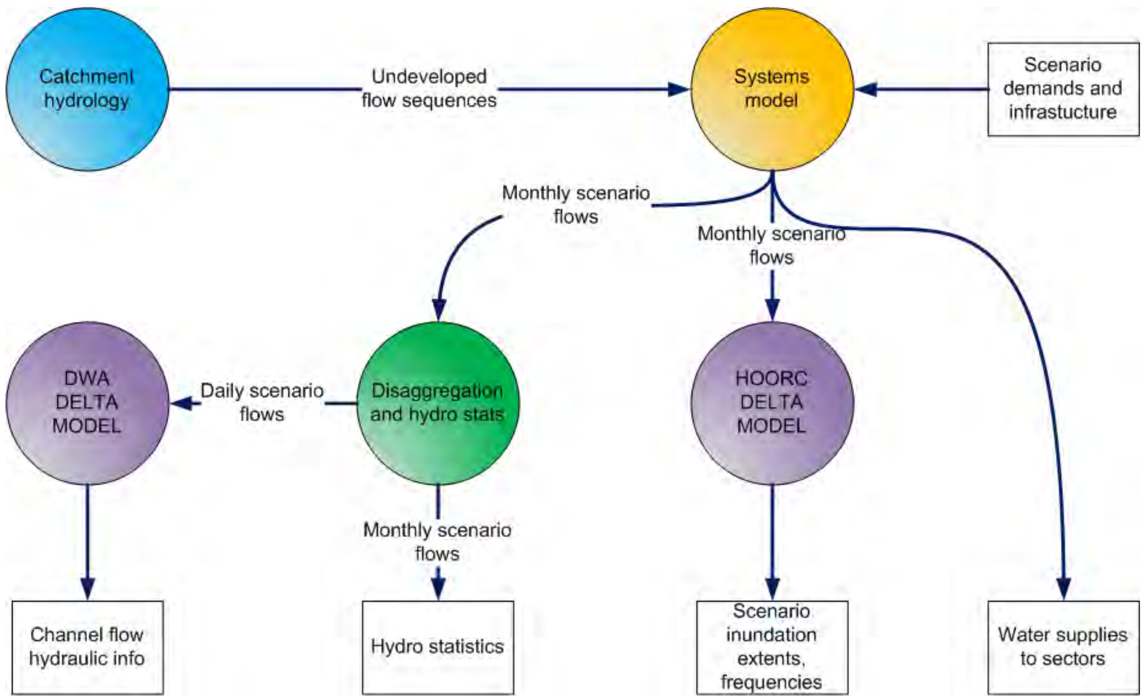


Figure 2-1 : Hydrological Modeling Components

The models which were selected for use in the EFA are:

- **Catchment hydrology:** Estimates of naturalised (undeveloped) long-term runoff were obtained from an existing Pitman-based rainfall-runoff model developed as part of the EU funded WERRD project (Hughes *et. al.* 2006).

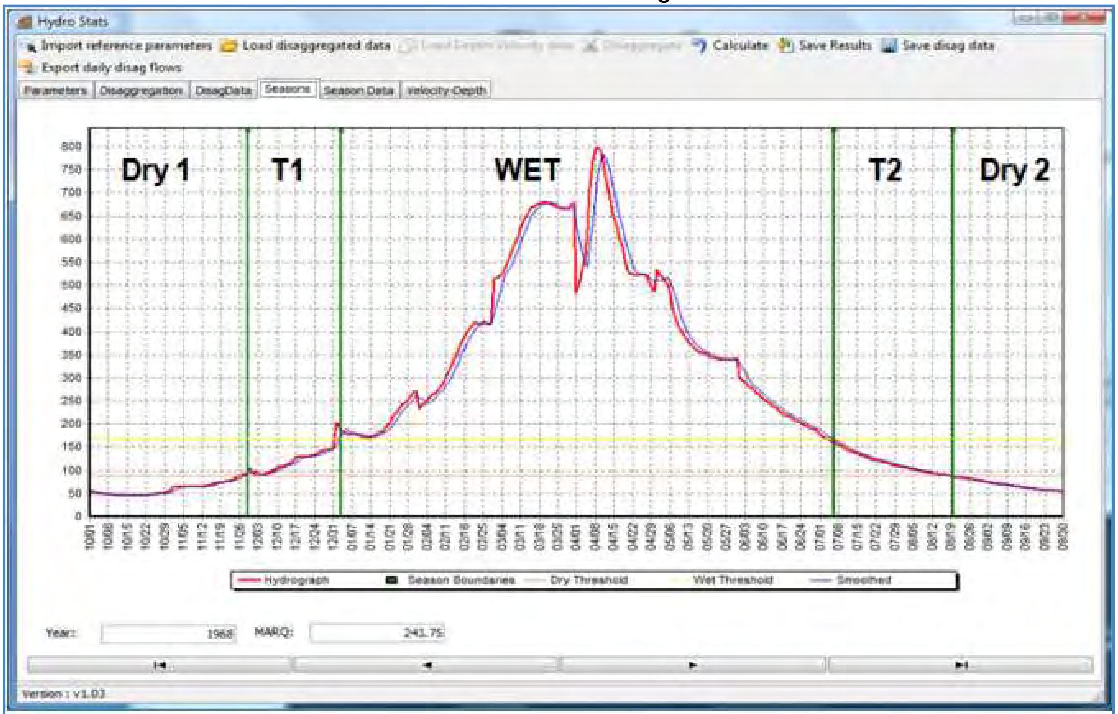
The model was configured to provide runoff sequences at the outlets of 24 distinct sub-catchments upstream of the Delta.

- **Systems Model:** As part of this project, the monthly time-step WEAP systems model was selected and used to configure a reference (Present Day), Low, Medium and High Development scenarios. Inputs to the model include the undeveloped runoff sequences for 24 sub-catchments produced by the Pitman model, irrigation scheme and urban abstractions, in channel dams for irrigation water supply, inter-basin transfers, run-of-river and storage based hydropower schemes.
- **HOORC Delta Model:** A semi-conceptual model which was previously developed by the Harry Oppenheimer Okavango Research Centre (HOORC) (Wolski et. al. 2006) was used to model inundation frequencies and extents at the Delta EFA sites. The model operates on a monthly time step and includes a dynamic ecotope model that simulates the responses of vegetation assemblages to changes in hydrological conditions. Scenario inflows to the model are provided by the WEAP simulations of basin runoff.
- **DWA Delta Model:** A MIKE-SHE / MIKE 11 hydrodynamic model which was previously configured by Botswana DWA and DHI for the Okavango Delta Management project (ODMP, 2008) was used to model flow velocities and depths at the Delta EF sites. Scenario flow sequences simulated with WEAP for Mohembo were used as inflow sequences for the Delta model, after disaggregating the monthly flow sequences to a daily time step.
- **Thamalakane/Boteti Model:** Delta outflows simulated by the HOORC model are routed along the Thamalakane/Boteti system with a linear reservoir spreadsheet model (Mazvimavi, 2008) to derive scenario flow sequences at the Boteti EF site. The model was incorporated into the HOORC Delta Model and improved to provide estimates of wetted river length and state changes of the system.
- **Disaggregation and Hydro-Statistics:** A custom utility was developed to disaggregate the simulated monthly WEAP flow sequences to daily flow sequences, to delineate flow seasons (dry, wet and transition) for each year of the 43 year long sequences, and to calculate ecologically relevant flow statistics (“flow indicators”).

2.3. Ecologically relevant flow indicators

The ecosystem response curves have been formulated to respond to variations in daily flow regimes. The catchment hydrology that was previously developed (and thus the WEAP systems model that was developed for this study) operates on a monthly time step. Disaggregation of simulated monthly volumes was done by distributing these monthly volumes according to the relative magnitude of daily flows measured at a nearby station during the corresponding month in the measured flow record. In periods for which no measured flows are available, a proxy month in the measured flow record was selected by finding a month with a measured volume that has a similar exceedance probability as the simulated volume. The disaggregated daily flow sequences were then used to delineate the dry season, a transition season leading into the wet season, a wet season, and a second transition season leading into the next year’s dry season.

A set of threshold-based rules were developed to identify the starting dates of the seasons. The rules were applied to the disaggregated daily flow sequences to calculate flow indicators for each year in the record, and for the entire flow sequence. An example of season delineation, and the rules that these are based on, are shown in **Error! Reference source not found.**. An example of the calculated flow indicators is shown in Figure 2-3

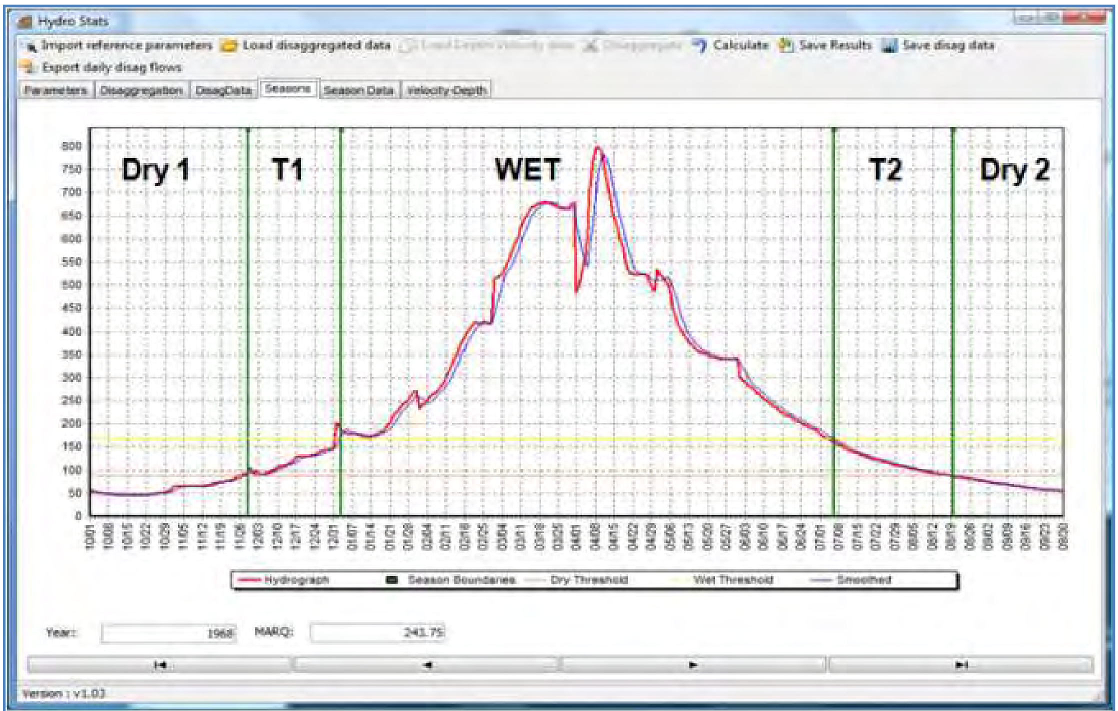


All flows averaged over 5 days

End of Dry Season:	Perennial : 2 to 6 x minimum dry-season Q (site specific)
	Ephemeral : 0.4 x mean annual Q
End of Transition 1:	first up-crossing of mean annual Q
End of Flood Season:	last down-crossing of mean annual Q
End of Transition 2:	recession rate over 15 d < 1.0 to 1.2 $m^3/s/d$ (site specific)
	OR down-crossing of Dry / T1 threshold

Error! Reference source not found.. A detailed description of the ecological relevance and selection of the flow indicators is given in EPSMO/Biokavango Report Number 2; *Process Report*.

Details on the division of the flow regime and the generation of ecologically-relevant summary statistics are provided in Report 03/2009: Guidelines for data collection, analysis and scenario creation.



All flows averaged over 5 days

End of Dry Season:	Perennial : 2 to 6 x minimum dry-season Q (site specific)
	Ephemeral : 0.4 x mean annual Q
End of Transition 1:	first up-crossing of mean annual Q
End of Flood Season:	last down-crossing of mean annual Q
End of Transition 2:	recession rate over 15 d < 1.0 to 1.2 m^3/s/d (site specific)
	OR down-crossing of Dry / T1 threshold

Figure 2-2 : Season Delineation

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MAR (m3/s):                                  289.1
Mean flood peak (m3/s)                       593.45
Mean flood vol  (Mm3):                      5737.14

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:           113.9
 *Dry season duration (Dd) [days]:           115.0
 *Max 5d flood season Q (Fq) [m3/s]:         497.7
 *Flood volume (Fv) [Mm3]:                  5269.15
 *Wet season duration (Fd) [days]:           150.0
 *T2 recession slope (T2s) [m3/s/d]:        -1.877
 *FP area of inundation (FPA) [km2]:           N/A
 *FP inundation dur (FPDi) [days]:             N/A
 *Dry season onset (Do) [cal week]:           33.0
 *Wet season onset (Fo) [cal week]:            3.0
 *FP inund onset (FPDo) [cal week]:            N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:            18.5
  Dry season duration (Dd) [days]:            42.1
  Max 5d flood season Q (Fq) [m3/s]:         231.5
  Flood volume (Fv) [Mm3]:                  2750.45
  Wet season duration (Fd) [days]:            47.5
  T2 recession slope (T2s) [m3/s/d]:         0.260
  FP area of inundation (FPA) [km2]:           N/A
  FP inundation dur (FPDi) [days]:             N/A
  Dry season onset (Do) [cal week]:            3.9
  Wet season onset (Fo) [cal week]:           13.7
  FP inund onset (FPDo) [cal week]:            N/A
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MAR (m3/s):                                  203.4
Mean flood peak (m3/s)                       557.90
Mean flood vol  (Mm3):                      3809.54

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:            21.1
 *Dry season duration (Dd) [days]:           193.0
 *Max 5d flood season Q (Fq) [m3/s]:         457.2
 *Flood volume (Fv) [Mm3]:                  3294.28
 *Wet season duration (Fd) [days]:           103.0
 *T2 recession slope (T2s) [m3/s/d]:        -3.171
 *FP area of inundation (FPA) [km2]:           N/A
 *FP inundation dur (FPDi) [days]:             N/A
 *Dry season onset (Do) [cal week]:           26.0
 *Wet season onset (Fo) [cal week]:            5.0
 *FP inund onset (FPDo) [cal week]:            N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:            11.9
  Dry season duration (Dd) [days]:            42.9
  Max 5d flood season Q (Fq) [m3/s]:         237.3
  Flood volume (Fv) [Mm3]:                  2486.67
  Wet season duration (Fd) [days]:            46.5
  T2 recession slope (T2s) [m3/s/d]:         1.058
  FP area of inundation (FPA) [km2]:           N/A
  FP inundation dur (FPDi) [days]:             N/A
  Dry season onset (Do) [cal week]:            5.0
  Wet season onset (Fo) [cal week]:           12.4
  FP inund onset (FPDo) [cal week]:            N/A
```

Figure 2-3 : Example of Flow Categories - Delta Inflows (Left: Present Day, Right: High Development)

3. Current Water Resources Situation

3.1. Climate

Rainfall in the Okavango River Basin occurs in the period from October to May, while the rest of the year is dry. The northern parts of the basin receive the highest rainfall in the December to January period, while the southern parts such as Maun have peak rainfall during January and February. Mean annual rainfall varies from about 1300 mm/a in the Huambo and Cuito areas in the headwaters of the basin, to 560 mm/a at Rundu, 550 mm/a at Mohembo, and 450 mm/a at Maun (Figure 3-1).

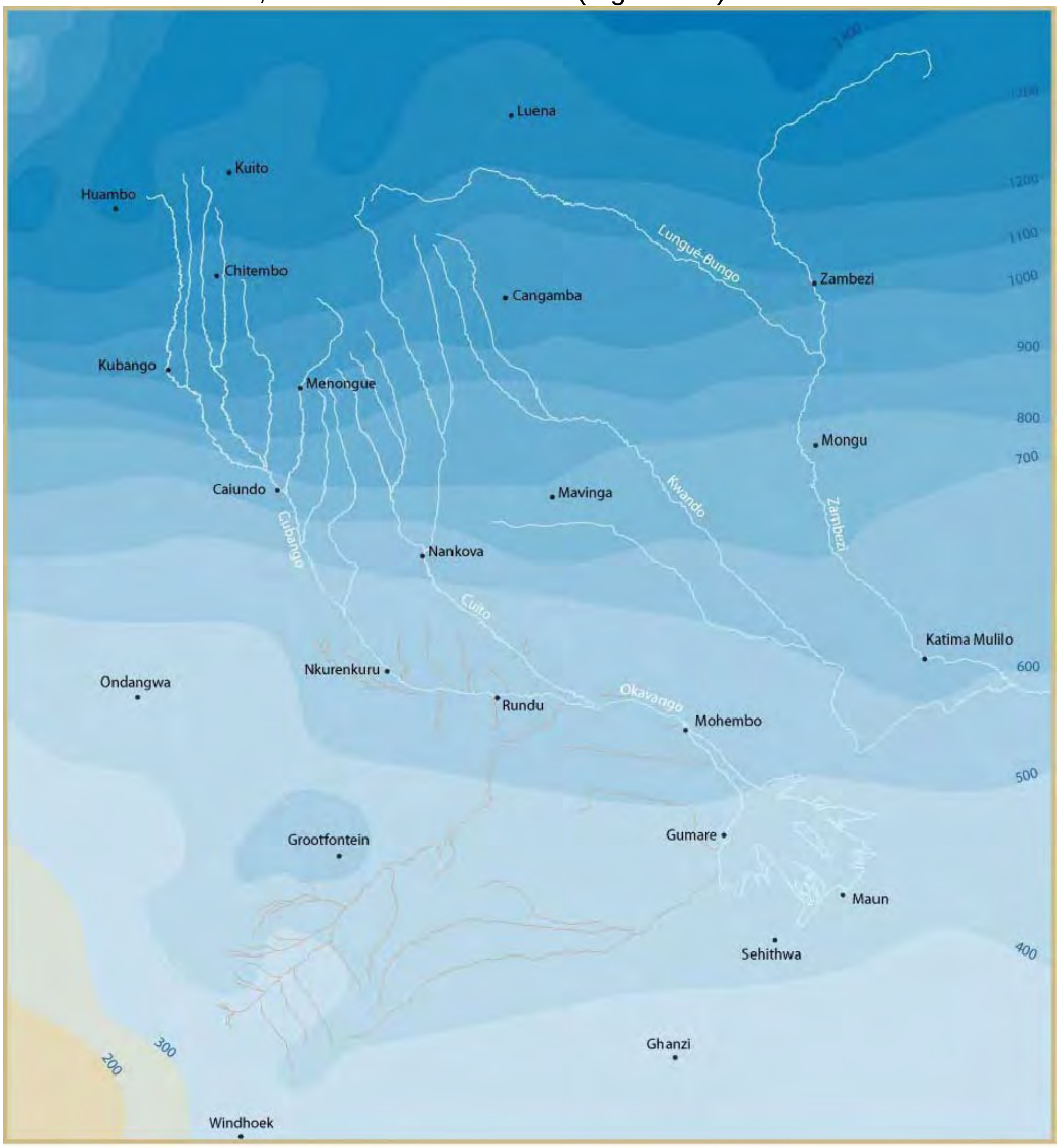

Figure 3-1 : Mean Annual Rainfall (Perennial rivers shown in white and dry tributaries shown in brown) (Source: Mendelsohn and el Obeid,)

Rainfall has a high inter-annual variability, with the coefficient of variation being 20% on the well-watered headwaters and 50% in the dry southern parts. There is a tendency for years to group, with above average rainfall for a while followed by generally years with below average rainfall. Due to the high inter-annual variability, years with extremely low rainfall occur frequently, particularly on the southern parts of the basin.

Average daily maximum temperatures range between 30-35°C from August to March in the Namibian and Botswana parts of the basin. Average minimum daily temperatures are in the 7-10°C range during the cool season, June to July. The average daily temperatures are greater than 20°C throughout the basin. Evaporation increases from the north to south in line with increasing temperatures. The mean annual open water evaporation increases from about 1350 mm/a for Menongue, to about 1950 mm/a for Rundu and 1650 mm/a for Maun. Highest evaporation rates occur in September and October (Figure 3-2 to Figure 3-4). The average monthly evaporation rate is greater than monthly rainfall for all months in the middle to southern parts of the basin, indicating a semi-arid climate.

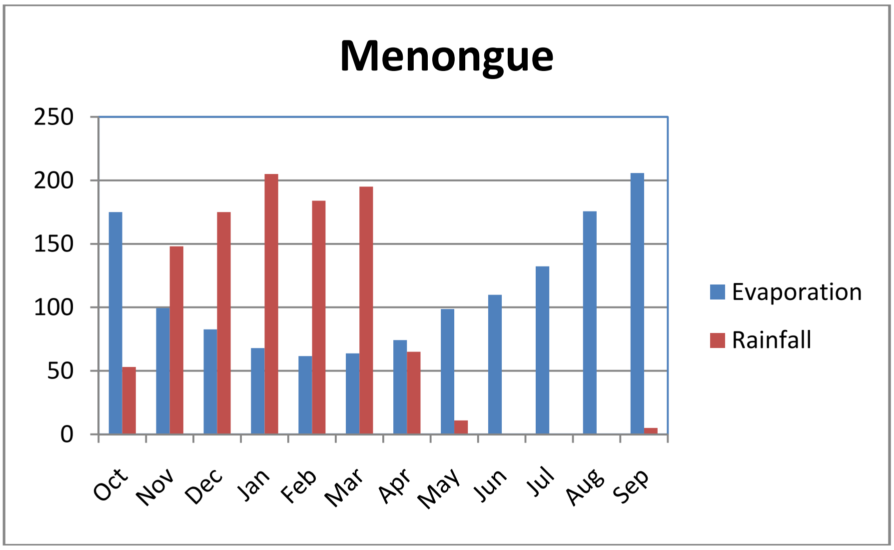

Figure 3-2 : Rainfall and gross open water evaporation at Menongue

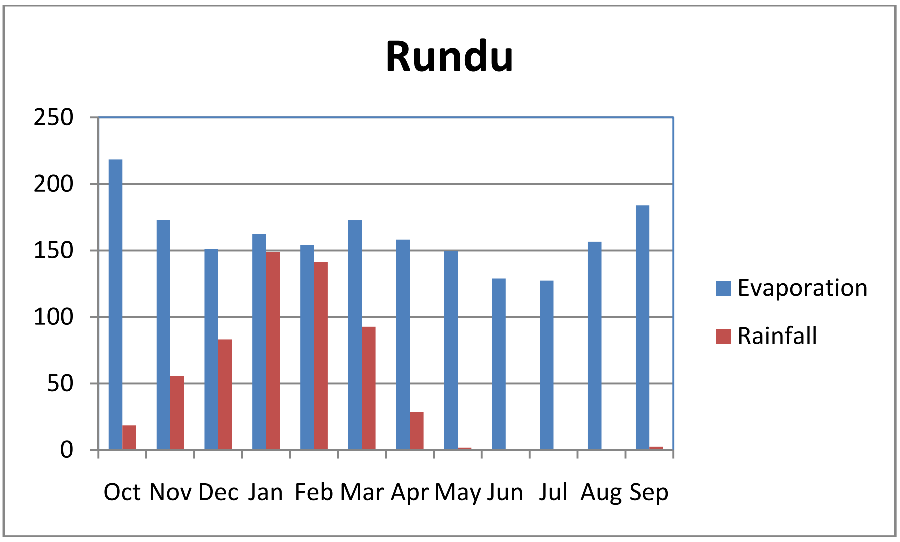

Figure 3-3 : Rainfall and gross open water evaporation at Rundu

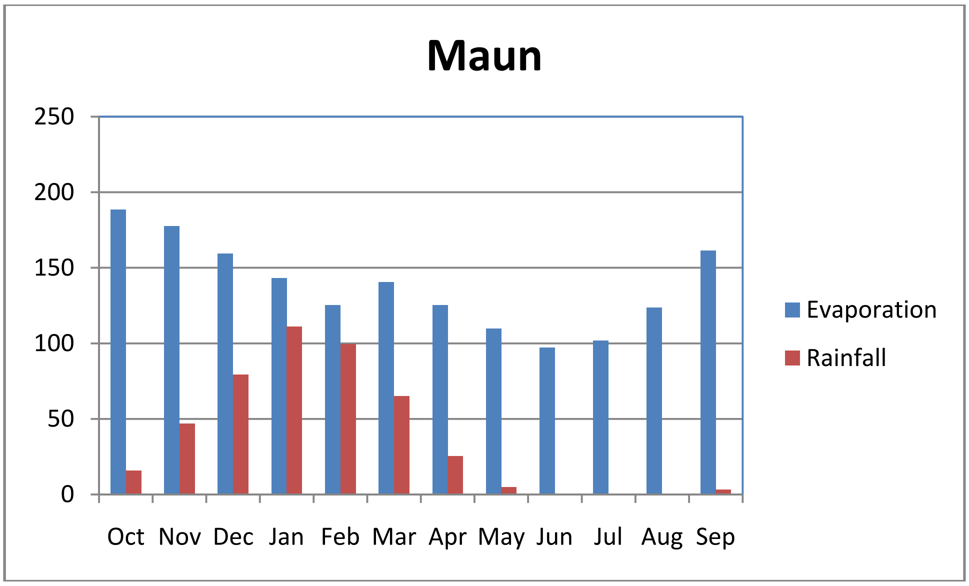

Figure 3-4 : Rainfall and gross open water evaporation at Maun

3.2. Water Resources of the Okavango River Upstream of the Delta

3.2.1 Distribution of Surface Water

Figure 3-5 shows the accumulation of mean annual runoff along the main tributaries of the Okavango upstream of the Delta. The runoff estimates are based on Pitman modeling undertaken for the WERRD and TwinBas studies, and incorporated into the WEAP model developed for the Okavango EFA Study. The estimates are for the period spanning October 1959 to September 2002. Runoff of about 10 200 million m^3/a is generated in the upper catchments of the basin (upstream of the confluences of the Cubango and Cuartir Rivers in the west, and the Cuito and Longa Rivers in the east). Downstream of these points, the catchments of the lower Cubango/Kavango and Cuito River contribute very little additional runoff. Large losses and some abstractions reduce the cumulative present day runoff to about 9 600 million m^3/a at the upper end of the Delta at Mohembo.

Current water abstractions in the upper basin (upstream of Mohembo) amount to about 60 million m3/a (or about 47 million m^3/a if the demands from the nearly completed Missombo irrigation scheme on the Cuebe River is excluded). Besides the Missombo scheme, significant Angolan demands include the urban water abstractions of Menongue (about 9 million m^3/a) and Cuito Cuanavale (about 2 million m^3/a). Namibian demands include the urban and industrial demands of Rundu (about 2.8 million m^3/a), and irrigation water demands of about 33 million m^3/a. Water demands in Botswana include rural demands of about 4 million m^3/a around the fringes of the Delta and combined urban and rural demands of Maun and surrounding areas of about 21 million m^3/a.

3.2.2 Occurrence of Droughts

In very dry years (1:20 year drought conditions), the flows in the river are significantly restricted as shown by the flows in Figure 3-6. Only about 3 000 million m^3/a might be derived from the Cubango and 3 100 million m^3/a from the Cuito, yielding only 6 100 million m^3/a at Mohembo. (The flows shown in Figure 3-6 closely resemble conditions experienced in 1998).

Figure 3-7 shows the accumulation of present day monthly runoff volumes that are equaled or exceeded for 70% of the months in the 42 year simulation period. The volumes give an indication of run-of-river yields that are available at various points in the system. It can be seen that the Cuito River plays a major role in sustaining the low flows entering the Okavango Delta.

3.2.3 Flooding

Flood Occurrence

To provide an indication of the occurrence and magnitude of floods in the study area, estimates of flood peak recurrence intervals were made by fitting a number of probability distributions to annual maxima of daily flows at Rundu and Mukwe (Figure 3-8 and Figure 3-9). For both stations, the General Extreme Value (GEV) distribution provided the best fit. Estimates of flood peaks and associated return periods are shown in Table 3-1 below.

Table 3-1 : Flood peak recurrence intervals

Station	**Rundu**	**Mukwe**
Selected Distribution	Gen. Extreme Value	Gen. Extreme Value
Parameters	k=-0.13439 s=183.8 m=443.99	k=-0.16686 s=197.86 m=570.75
Return Period (years)	Flood Peak (m^3/s)	Flood Peak (m^3/s)
1:2	510	641
1:5	694	833
1:10	801	942
1:20	894	1034
1:50	1002	1138
1:100	1075	1206

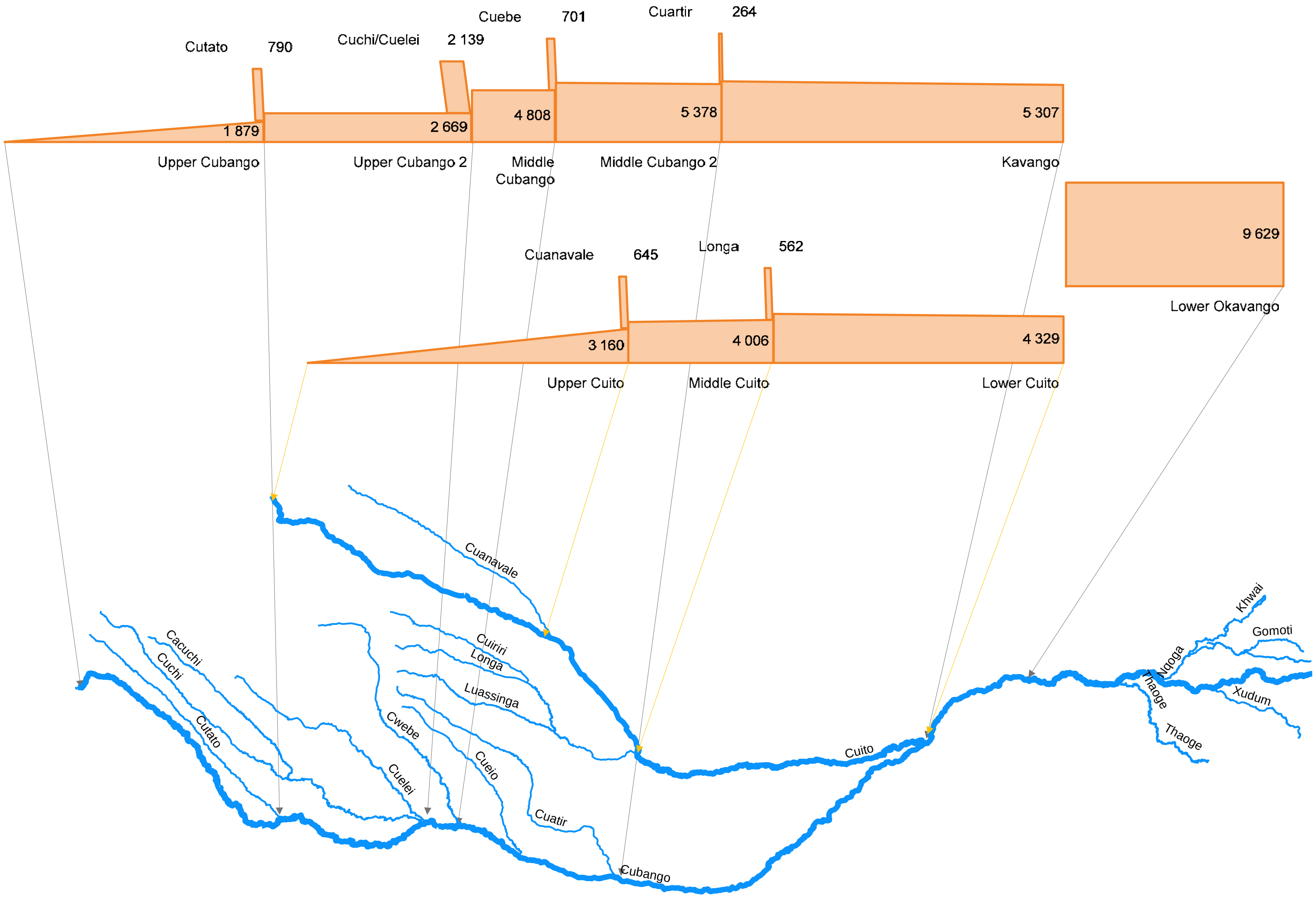

Figure 3-5: Mean Annual Runoff (10^6 m^3/a) - Present Day

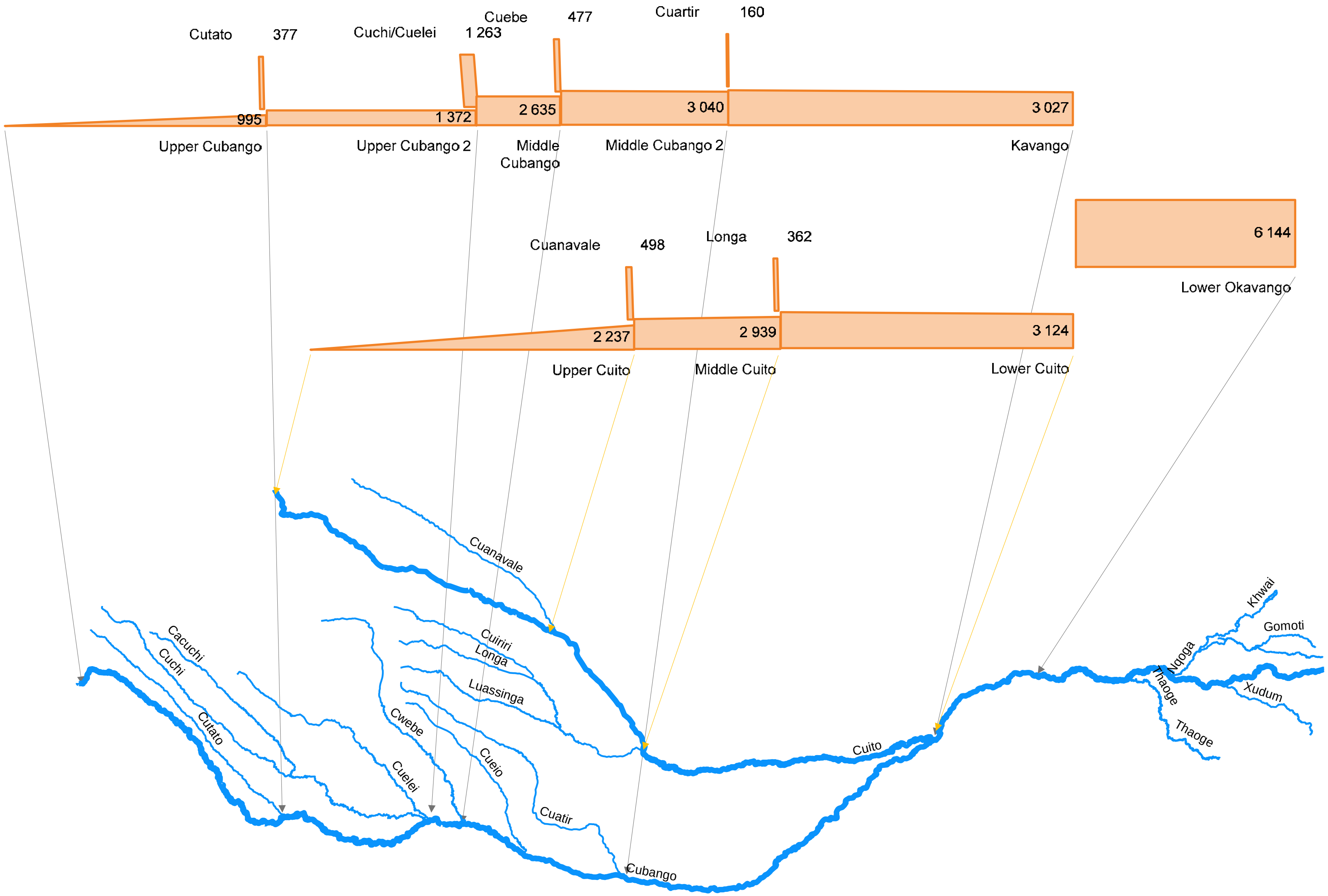

Figure 3-6 : Runoff in the driest year in 20 (10^6 m^3/a)

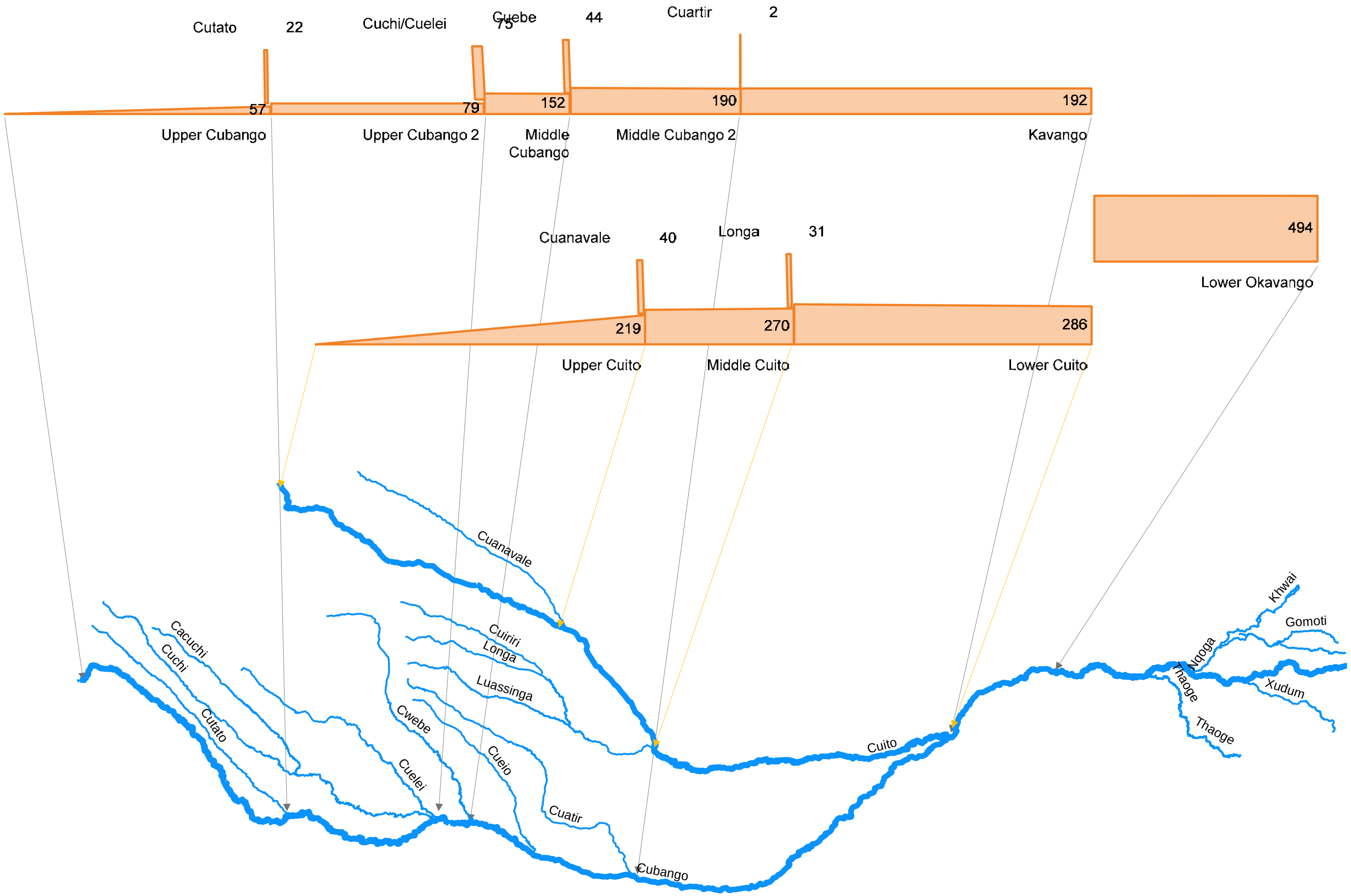

Figure 3-7 : 70% Exceedance Monthly Runoff (10^6 m^3)- Present Day

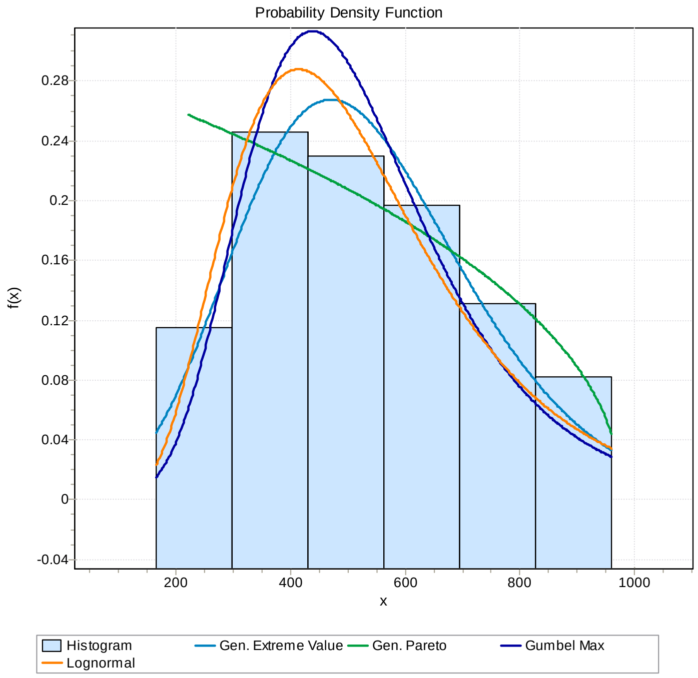

Figure 3-8 : Flood Frequency Distribution of Annual Maximum Daily Flows - Rundu (1945-2005)

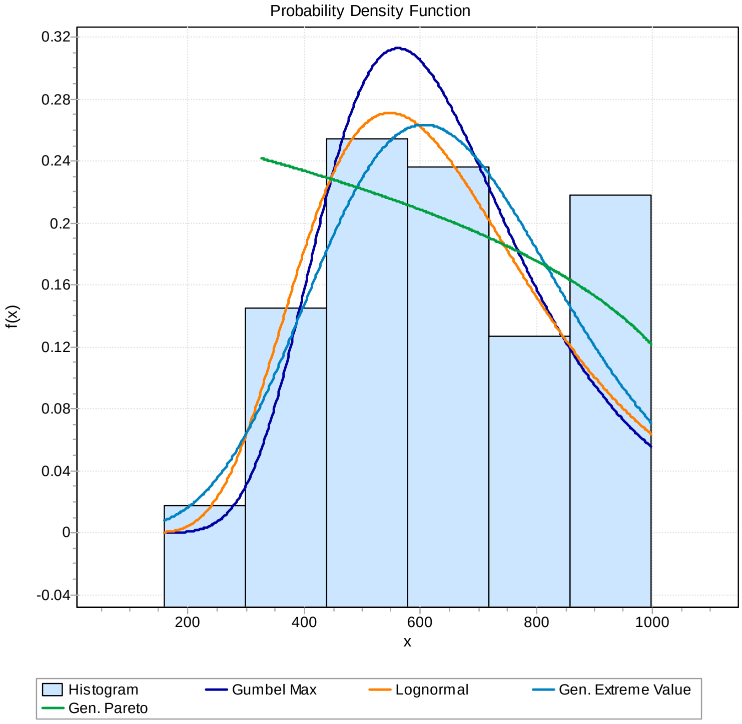

Figure 3-9 : Flood Frequency Distribution of Annual Maximum Daily Flows - Mukwe (1949-2003)

The Rundu and Mukwe flow measuring stations are located upstream and downstream of the confluence of the Kavango and Cuito Rivers, respectively. From Table 3-1 it can be seen that flood peak contributions from the Cuito River cause a relatively small increase to flood peaks downstream of the confluence. This is due to the difference in flood response (lag) times of the two sub-basins, with the Cubango/Kavango floods rising much faster, and peaking at higher levels, than the Cuito.

The 2009 Flood

The Cuvelai and Okavango regions experienced one of the worst flood disasters during the year 2009. In Namibia, the 2009 flood affected six regions in northern and north eastern regions (Caprivi, Kavango, Ohangwena, Oshana, Oshikoto and Omusati region) from early February 2009. Although the flood waters have completely drained off in the four northern central regions, many areas along the Zambezi, Chobe, Kwando rivers and Lake Liambezi basin in Caprivi region were still inundated in May 2009.

The causes of the flood was a combination of the above-normal rainfall received in affected regions and the high inflows in the Cuvelai basin, Kwando and Kavango rivers with flood waters from southern Angola. The Caprivi region floods were due to the high inflows of the Zambezi River from heavy rain falls in Zambia.

The flood in the Cuvelai was higher than the flood that occurred in 2008, which then was already said to be the highest in living memory. The floods in the Kavango and Zambezi rivers were the highest on record since 1969, and the flood in the Kwando River was the highest on record (starting in the sixties). Satellite images provided the first recorded evidence of overflow from the Kavango Panhandle reaching the Kwando/Linyanti/Chobe/Zambezi system through the Selinda Channel.

Due to the extensive nature and potential long term impact of the floods, on 17 March 2009 the President of the Republic of Namibia H.E. President Hifikepunye Pohamba declared a national emergency for the flood affected areas appealing for external assistance.

Although historically flooding in Cuvelai basin, Kavango, Zambezi and Chobe rivers have been occurring, the 2009 flood has so far been the largest in terms of the geographical area affected. The extensive nature of the impact of the 2009 floods was attributed to increased population settlement in the Cuvelai basin and in the flood plains in Caprivi and Kavango regions, road and rail construction and emerging informal settlements in peri-urban areas that interfered with the natural river flows. Flooding in some urban areas in Ondangwa, Outapi, Helao Nafidi and Katima Mulilo was mainly due to inadequate storm water drainage. The other major risk factor were the construction of public and private infrastructure such as railway line, roads, homes and schools in the flood plain without disaster risk reduction considerations (Figure 3-10). There certainly is a need to find a lasting solution to people who are continuously affected by floods due to their location in the flood prone areas.

Figure 3-10 : A school and homes situated in the flood plain in Caprivi region

Road construction and small culverts contributed to flooding as these impeded the flow of storm water (Figure 3-11 and Figure 3-12 below).

Figure 3-11 : Construction in the north that partly contributed to flood damages

Figure 3-12 : Culverts constructed in the northern central regions were too small to accommodate flood and storm water

Impact of the 2009 Flood Disaster

The 2009 flood disaster caused an estimated N$1.7 billion (1% of Gross Domestic Product) worth of damages and losses to the public and the private sectors. The private sector experienced N$800.4m worth of damages and N$600.3m losses and thus experienced the higher burden of the flood impact. The PDNA, Nam-VAC and other local assessments revealed that, the productive sector mainly agriculture, commerce (trade and markets) were among the worst affected sectors with an estimated 70-80% loss of crop production in the 2009/10 consumption year (NamVac 2009). The flood disaster affected people that were recovering from another devastating flood disaster of 2008 thus further compromising the resilience of the affected communities. Furthermore the cumulative effect of 2008 and 2009 floods preceded by a devastating drought of 2007 severely have reduced the resilience of a significant number of severely poor and poor households. Table 3-2 below shows the impact of the 2009 flood disaster by region.

The six affected regions are resident to nearly sixty percent (60%) of Namibia's population and thus have the highest population densities. Due to the high population concentrations in the flood high risk regions, the 2009 flood disaster affected 56.1% of the total population flood affected regions making up 32% of the county's population see Table 1 below. Flood disaster in the four central northern regions where 41% of the population resides has brought in a new dimension to NDMS in Namibia. NDMS was used to dealing with no more than 20,000 people requiring emergency humanitarian support caused by floods in any year mostly confined to Caprivi region. In the past two years it has had to deal with first ten times and then thirty times more i.e. 215,257 in 2008 and 677,542[1] in 2009 (Directorate Emergency Management: Report on National Response to 2008 Flood Disaster and FEMCO report 2009).

Table 3-2 : Impact of the 2009 flood disaster

Region	Caprivi	Kavango	Ohangwena	Omusati	Oshana	Oshikoto	Total
Total population (2009)[2]	**87,058**	**257,347**	**261,323**	**243,657**	**176,586**	**181,304**	**1,207,275**
Number of people affected	26,263 (30.2%)	9,000 (3.5%)	133,703 (51.2%)	228,842 (93.9%)	161,916 (91.7%)	117,818 (65%)	**677,542 (56.1%)[3]**
No displaced	26,263	9,000	12,056	401	8,549	276	**56,545**
Number in relocation camps	19,738	4,718	1,296	564	2,478	138	**28,932**
Number deaths	3	0	22	32	48	0	**105**
No of schools affected	29	7	63	107	83	39	**328**
No of school children affected	6,571	2,366	24,355	39,163	15,301	6,014	**93,770**
Health facilities affected	4	2	10	10	5	1	**32**
Health facilities closed	1	0	0	0	4	1	**5**
No of SMEs affected	0	28	387	250	350	53	**1,068**

[1] Figure worked out based on the population of the affected constituencies and based on the 2001 population projections.
[2] Population projection 2009. Source: Namibia Population Projection. 2001.
[3] People affected as a percentage of total population in the affected regions

No of farmers with crop fields affected	2,790	968	5,671	4,392	3,437	7,496	**24,754**
Hectares of crop fields damaged	2,854	362.41	10,117	15,652	6,900	17,323	**53,208**
Number of livestock affected	3,000	0	0	0	0	0	**3,000**
Number of livestock lost	18	0	2,161	693	2,093	5,038	**10,003**
Number of wild life	300	0	0	0	0	0	**300**
Number of roads damaged	2	2	5	12	8	4	**33**

Source: FEMCO, Kavango and Caprivi Regional Councils' flood report 2009.

3.2.4 Hydrological Functions of the Cubango and Cuito Rivers

The northern parts of the Cubango sub-basin are underlain by Pre-Cambrian granites, some Karoo Group sandstone and mudstone. The hard rock has low hydraulic conductivity and is overlain with a relatively thin mantle of Kalahari sand which is interrupted by outcrops of granite along the banks of the Cubango, Cutato, Cuchi, Cuelei and Cuebe Rivers. The sub-basin has a high surface water drainage density, with numerous small tributaries draining the area from north to south. Together, these factors indicate limited groundwater storage, which explains the low dry season base flows and strong seasonal variation of discharge observed in the Cubango River. This is illustrated by the fact that, on average, the driest six months of the year contribute only about 23% of the total annual runoff of the Cubango River.

Water demands for irrigation and urban use peak during the dry season. Unless wet season flows are stored in dams, yields of water abstraction schemes are limited by the availability of dry-season flows. In the Cubango/Kavango sub-basin, this places a relatively low ceiling on water availability for consumptive use. This was illustrated in the simulation of the scenarios, where it was shown that, even under low water development conditions, planned developments along the Cuebe River would virtually dry-up the currently perennial river. In recognition of this fact, the Namibian Department of Agriculture and the Department of Water Affairs has taken a decision to limit the Namibian abstraction rate out of the Okavango River upstream of the confluence with the Cuito to 5.5 m^3/s, and downstream to 27 m^3/s (Liebenberg, 2009).

The Cuito sub-basin is underlain by thick deposits of Kalahari sands and is characterised by low drainage density, high baseflows, and a relatively small seasonal variability, indicating considerable groundwater recharge and discharge. In sharp contrast with the Cubango, 40% of the total annual runoff occur during the six driest months of the year. Runoff generated in the Cubango River catchments is somewhat more than the contribution of the Cuito River catchments (5 600 and 4 600 million m^3/a, respectively). Simulated average monthly hydrographs for the two rivers just upstream of their confluence are shown in Figure 3-13. The figure illustrates the striking difference in the seasonality of the two rivers, and also shows that discharges in the Cuito River during the low flow months of September and October are on average about twice those of the Cubango/Kavango.

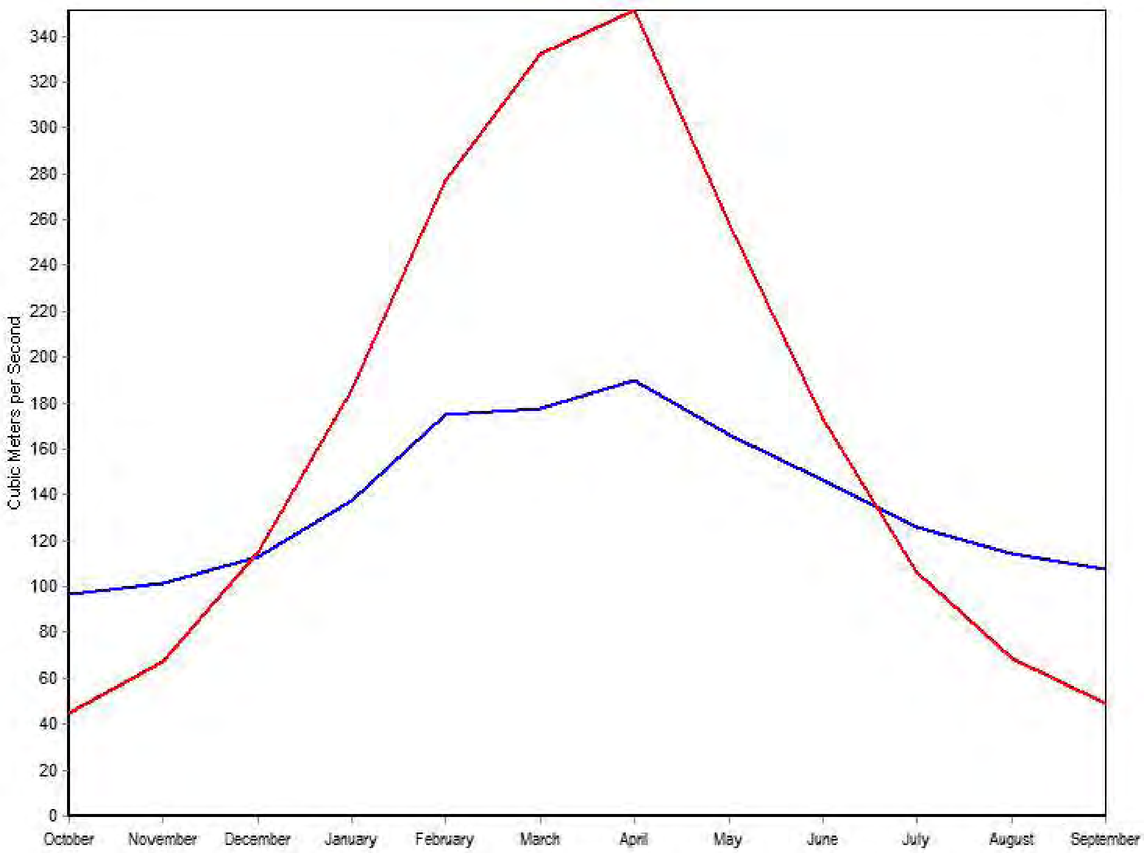

Figure 3-13 : Simulated hydrographs of the Cuito River (blue) and Cubango/Kavango River (red)

3.3. The Delta

The impact of upstream developments on inflows to the Delta can be assessed in terms of changes to the extent, duration and frequency of flooding in the Delta. For the Okavango EFA Study, these changes have been related to changes in vegetation assemblages (EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models*). Figure 3-14 shows a timeline of vegetation changes in the Eastern Delta under present levels of water use in the upstream basin. It can be seen that the proportion of grassland and savanna on the periphery of the Delta expands in dry periods such as the one that occurred in the mid-1990s.

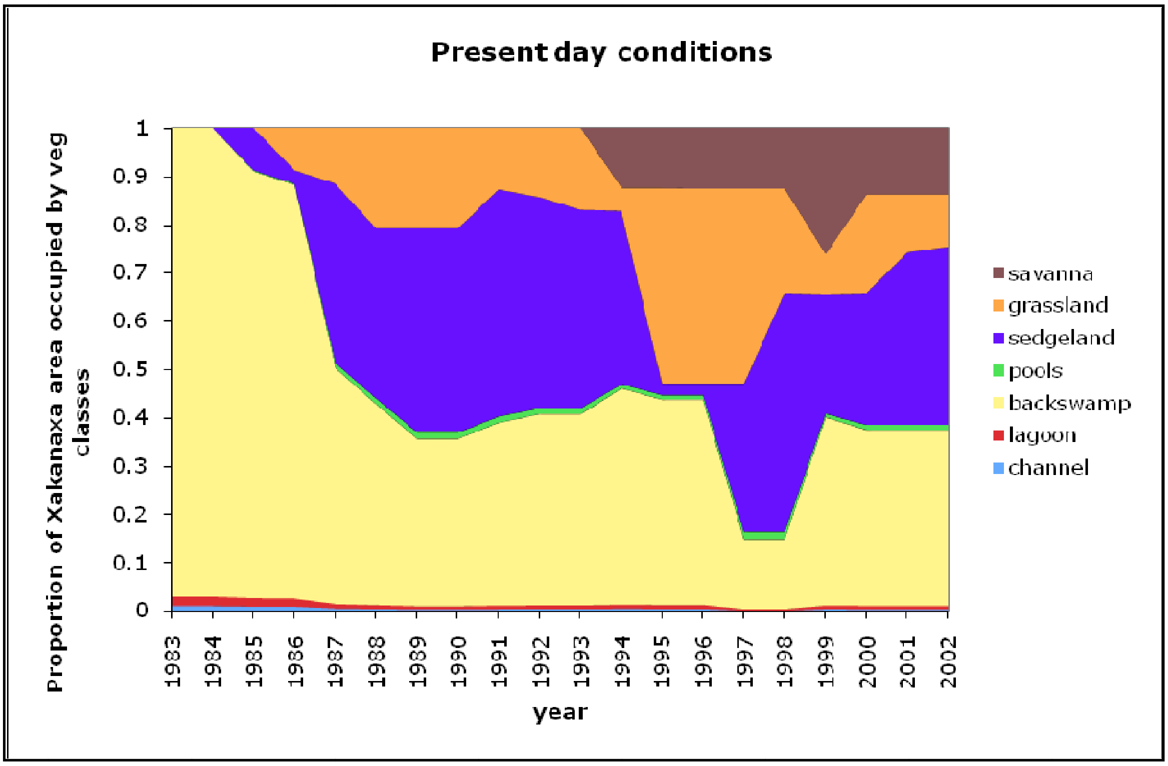

Figure 3-14 : Vegetation Response to Flooding - Xakanaxa, Present Day

3.4. The Boteti River

Flows in the Thamalakane / Boteti River system receives outflows from the Delta and is highly susceptible to changes in the flooding regime of the Delta. In addition, the length of river that is wetted by inflows in any given year depends on the volume of inflows and state of the groundwater aquifers in previous years. The HOORC model was used to simulate state changes (changes from a wet river, isolated pools or dry riverbed) along a 200 km reach of the Boteti River under different Delta flooding regimes. The sensitivity of the wetted length to inflows (note the dry period in the 1990s) can clearly be seen from Figure 3-15.

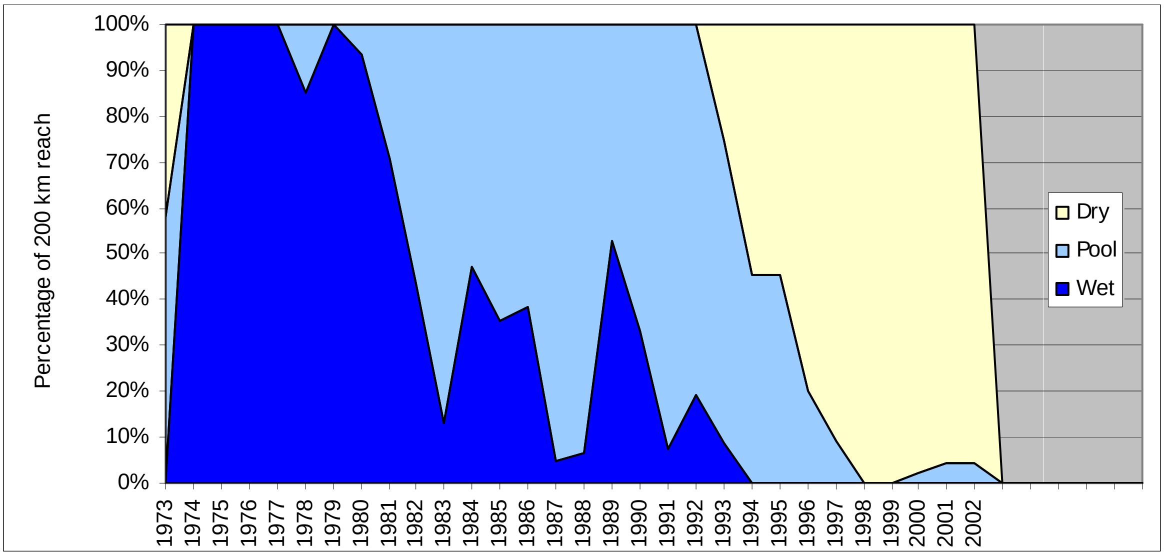

Figure 3-15 : Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the present-day simulated conditions given climatic conditions that prevailed from 1973-2002.

3.5. Variability of Okavango Stream Flows

River flows in the Okavango River Basin exhibit strong seasonal and inter annual variability.

3.5.1 Seasonal Variability

In the upper parts of the basin the seasonal variability corresponds closely to the occurrence of rainfall, but in the semi-arid Delta the high flow season occurs several months after the rainy season. Seasonal river flow patterns in different parts of the basin vary widely. River flows in the Cubango and its tributaries are characterised by a strong seasonal variation and low dry season base flows, while the Cuito and its tributaries show much less seasonal variation with dampened wet season peak flows and elevated dry season base flows, mainly due to considerable groundwater recharge and discharge in this part of the basin.

Seasonal flooding in the Okavango Delta is the result of a complex interaction of local, regional and basin-wide influences (McCarthy et al. 2000). At the upstream end of the Delta, the flood peak occurs in April, and moves slowly across the Delta, taking 3–4 months to travel to Maun. Seasonal variation in the western parts of the Delta is strong compared to the eastern parts where water levels show little seasonal variation.

Delta outflows arrive in Maun during May and June. The magnitude of flooding in the Delta, antecedent groundwater levels and other factors determine the distance that water travels along the Thamalakane and Boteti Rivers.

3.5.2 Inter Annual Variability

In the Okavango River Basin, measured stream flows exhibit a long-term cyclic behaviour pattern of the order of 65 years, with a maximum in the 1960s, and a minimum in the late 1990s. The cause for this is still unknown but it was found to be statistically significant by Mazvimavi and Wolski (2006).

Figure 3-16 shows the average annual runoff measured at Mukwe, upstream of the Delta. The 1930s and 1940s had generally below average runoff, while above average runoff occurred during the 1950s to 1980s. This was followed by an abnormally dry period in the 1990s. The system is currently in a wetter period.

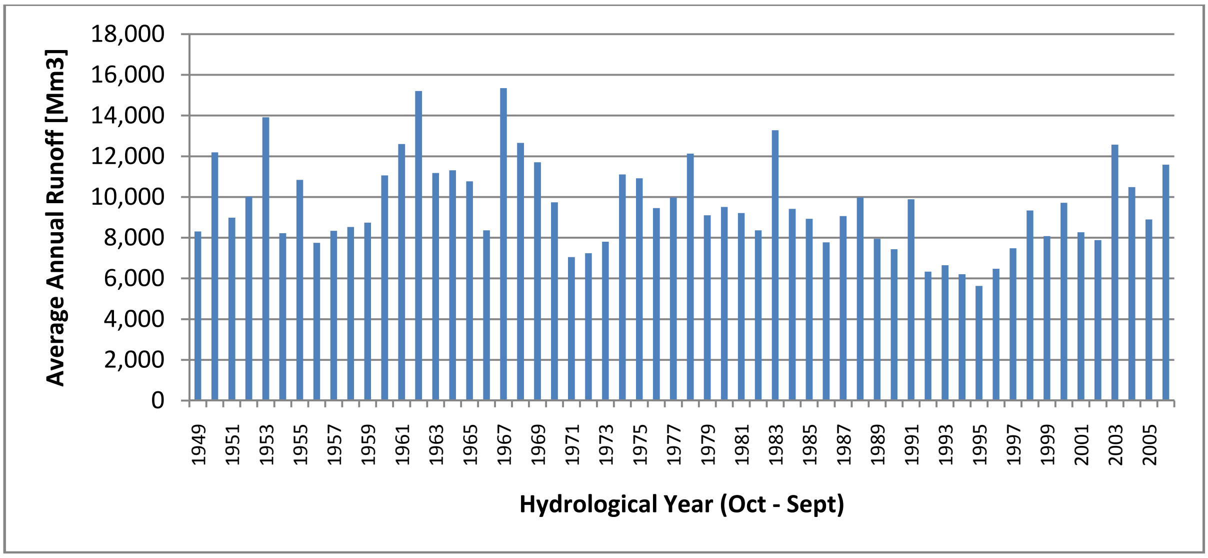

Figure 3-16 : Average Annual Runoff at Mukwe

River flow measurements made on Thamalakane River at Maun, and Boteti River at Samedupi and Rakops show that the 1972-80 period was characterised by very high flows (Figure 3-17). The highest flow occurred in July 1979. Very low flows occurred from 1990 to 2008, and the whole section of the Boteti River from Chanoga to its distal end including Rakops was dry during this period (Mazvimavi 2008).

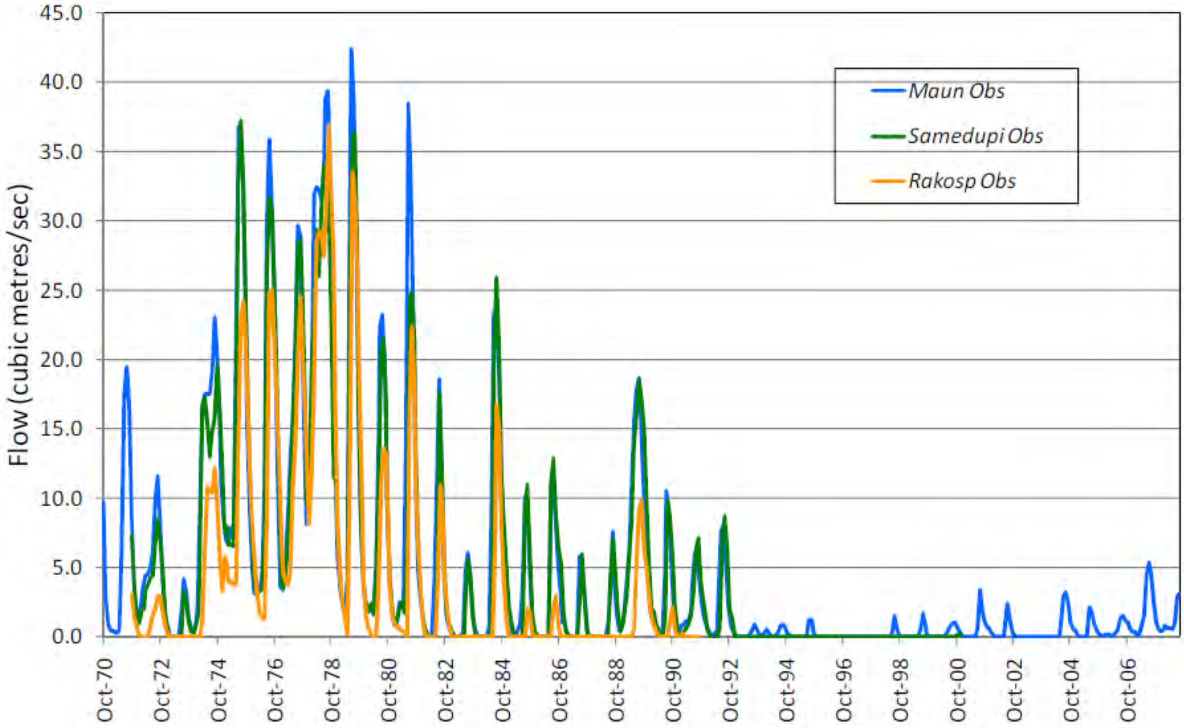

Figure 3-17 : Observed monthly flows at at Maun, Samedupi and Rakops

3.6. Groundwater

3.6.1 Geology and aquifer stratigraphy

The Angolan Headwaters

The western headwaters of the basin are underlain by Pre-Cambrian granites and some Karoo Group sandstone and mudstone. The granites underwent various orogenic and magmatic processes which formed gneisses, migmatites and other metamorphic rocks. The hard rock has low hydraulic conductivity and is overlain with a relatively thin mantle of Kalahari sand. The Kalahari sand layer is interrupted by outcrops of granite along the banks of the Cubango, Cutato, Cuchi, Cuelei and Cuebe Rivers. Together, these factors contribute to the low base flows and strong seasonal variation of discharge observed in the Cubango River and its tributaries (Hughes et al. 2006).

The eastern headwaters are located on a much thicker layer of Kalahari sands, and consequently have a larger base flow component and less seasonal variation of discharge.

The Lower Basin

Toward the south, in the vicinity of the Namibia/Angola border, the basin is underlain by basal rocks of the Damara Sequence, followed by the Karoo Sequence sediments overlain and intruded by volcanic rocks and covered by the Cretaceous Kalahari Group sediments (NGDC. 1991). The soils in this part of the basin are made up of light coloured sands, limestone, silicified sandstones and orchreous sands of the Kalahari Sequence that are low in organic matter content. The sandy soils are enriched with silt deposited by the Okavango River in terraces and floodplains (Hydrology Division, 1994).

Two aquifer types are common in this area, (a) Primary Kalahari aquifers i.e. sand and sand stones that hold water in intergranular pore space and (b) Secondary aquifers *i.e.* fractured aquifers that hold water in the fractures and weathered strata. Some boreholes in the area penetrate the primary aquifer of the Kalahari which extends from the surface to approximately 350 m deep (NGDC. 1991).

According to the Hydrogeological Map of Angola (scale 1:250.000), the yield of boreholes situated nearby the Cuito River, in the downstream section of the basin, is less than 1 litre per second (3.6 m^3/h). Namibian drilling reports for Rural Water Supply show that the groundwater yields in the Kavango region are relatively good with 90% of boreholes drilled having a possibility of yielding more than 1m^3/h in the Kalahari aquifers, and less in areas were fractures are intersected. Boreholes yields along the Okavango River in Namibia range between 0 - 8m^3 /h, with areas that yield more than 10m^3/h where boreholes are drilled deeper than 100m into the Kalahari aquifers, (NGDC. 1991).

In areas were the water is intersected in fractures, the water level is normally higher than those in the Kalahari aquifers (Christelis & Struckmeier, 2001).

In areas were the Kalahari aquifers have a shallow groundwater gradient, the Kavango River recharges the aquifers but in most sections the river gains groundwater. (NGDC.1991).

The Okavango Delta

The Okavango Delta lies within a north-easterly trending half graben, related to the east African Rift System (Hotchins et al 1976). The major boundary structures are the Thamalakane and Kunyere faults with a down throw to the north-west and are still active.

The Gumare Fault has a parallel strike to the major faults. The oldest rocks in the region are of the metavolcanic Kgwebe Formation and metasedimentary Ghanzi Group of upper Proterozoic age. Karoo Supergroup rocks unconformably overlie lower proterozoic basement rock outcrops south west of the delta at Lake Ngami (on the graben side of the Kunyere Fault). The Kalahari Group sediments occur as Aeolian sands in the grabens of the Panhandle of the Delta.

Three major aquifers formations occur in the Delta region. These are the Basement rocks, Karoo and Kalahari Group sediments. Where Karoo and Basement rocks are present at shallow depth, also form locally important aquifers. The Kalahari group sediments comprise the most important known aquifers.

3.6.2 Recharge and Discharge

There is no consistent description of groundwater recharge over the entire basin. In the lower basin in the vicinity of the Angola/Namibia border, shallow aquifers of less than 20m are recharged directly either by rainfall and emphemeral runoff while deeper aquifers are recharged from the Kalahari basin margins or the underlying fractured aquifers. Studies on water level elevation and hydrochemical evidence suggests significant recharge from the Otavi Group dolomites in the Tsumeb –Grootfontein area. The eastern boundary of the Cuvelai - Etosha Basin seems to be discharging into the Kavango Basin (Christelis & Struckmeier, 2001). Discharges from the aquifer are by means of abstractions, inter-basin flow, and discharge of groundwater to the river where the river is incised into the aquifer.

Recharge in the Okavango Delta has been estimated to be of the order of 7 to 10mm/annum (ODMP 2008**).**

3.6.3 Groundwater quality

Groundwater quality in the Kavango area is variable with “stripes” of saline water in Kalahari aquifer where calcrete is present, and other areas with high fluoride concentrations. Groundwater in the Kalahari aquifer along the banks of the river often show poor quality due to its iron and manganese content, which occasionally exceeds the safe limits for drinking water. During flood events, the river recharges the aquifer and improves the groundwater quality.

Total dissolved solids (TDS) concentrations in groundwater along the Kavango River are of the order of 1000 mg/l. In isolated areas values of more than 3000 mg/l have been recorded and the lowest value of 36 mg/l has been recorded at Shakashi.

The shallow aquifers surrounding the Okavango Delta are generally saline, but interspersed with freshwater lenses along the ephemeral streams that are recharged by the wetlands of the Okavango Delta (Campbell et al. 2006; McCarthy et al. 1998). The freshwater lenses around the streams are important for water supply.

Groundwater quality in the Delta itself is characterised by salt accumulation zones in the islands with TDS values of up to 20 000 mg/l, surrounded and underlain by a fresh aquifer with TDS of around 180 mg/l, and a deeper saline aquifer with TDS of around 2 600 mg/l.

4. Formulation of the Water Use Scenarios

4.1. Introduction

The objective of the Okavango EFA is to provide information on the ecological, socio-economic and macro-economic consequences of realizing the water resource development aspirations of the three co-basin states. To ensure that OKACOM has information at hand to assess the consequences of development pathways spanning a range that is as wide as possible, preference was given to the selection of a set of scenarios that cover a broad continuum of development and that are positioned at regular intervals across this continuum.
The water use scenarios are simply ways of exploring possible management options. None of the scenarios, as laid out in this study will necessarily happen but they can inform negotiations on cooperative basin development.

Several previous studies have been undertaken to assess the impacts of future water resource developments in the Okavango basin and in the delta. The assessments have in most cases focused on the effect that future water resource developments may have on water resource availability in the upstream basin, and on the hydrological functioning of the delta. The Okavango EF Study is building on this work by using changes in river flows and water resource availability to predict the ecological and socio-economic consequences of the development scenarios. The study is also unique in the sense that assessments of river health in the upstream basin enjoy equal priority with assessments of impacts on the delta.

4.2. Previous Studies

Scenario based planning exercises have been undertaken for the Water and Ecosystem Resources in Regional Development (WERRD) and TwinBas projects, the Sharing Water (USAID, 2004) project, and the Okavango Delta Management Plan (ODMP) (Government of Botswana, 2005).

A hydrological model of the upstream basin (Pitman-based Spatsim) was developed for the WERRD project, and refined as part of the TwinBas project. Scenario assessments that were undertaken for the recent Sharing Water and ODMP projects were based on this hydrology.

A prototype planning model was developed for the Sharing Water project and used to (a) assess the extent to which postulated demands in the upstream basin can be met, and (b) to simulate the impact of future developments on the extent of flooding in the delta. The modeling work was undertaken with a systems model of the basin (WEAP) which included a coarse, regression-based predictor of delta inundation. The scenarios that were assessed are:

- A **baseline** (no change, present day) scenario
- Scenario 1 - **Growth in Existing Demand**. A steady increase of growth in domestic and agricultural water demands. No major scheme developments.
- Scenario 2 - **Growth in Existing Demand, Angola Irrigation, Okavango Link to Central Namibia**. As for Scenario 1, but with the introduction of accelerated irrigation demand in Angola, and the implementation of the Central Namibian Water Supply Scheme.
- Management Strategy 1 – **Angolan Surface Storage**. As for Scenario 2, but with the introduction of a large dam downstream of the confluence of the

Cubango and Cutato Rivers. The purpose of the dam is to provide water supply for Scenario 2 demands that cannot be met, and also to provide flood control.

A hydrological model of the basin (Pitman-based Spatsim) and a hydrodynamic delta model (MIKE 11 / MIKE SHE) were used to assess a range of development scenarios for the Okavango Delta Management Plan. The impacts of the development scenarios were assessed in terms of changes to the hydrological functioning of the delta, primarily changes in frequency, extent and depth of inundation. The scenarios that were assessed are:

- **Upstream water resources developments**: dams and irrigation schemes in Angola and Namibia. Construction of three run-of-river and seven storage based hydropower schemes. Large (54 500 ha) expansion of irrigated areas in Angola, and relatively small (7 500 ha) expansion of irrigation in Namibia.
- **Deforestation** in Angola and Namibia. Simulated as the clearing of a 2km riparian buffer.
- Surface and ground water **abstractions from the delta**. Increased abstraction from the delta, from about 17 Mm^3/year to 25 Mm^3/year for domestic, livestock, game, small scale irrigation and construction water use.
- **Clearing major blocked channels in the delta**.
- Regional **climate changes**. Reduction in delta inflows of about 38%, reduction in precipitation over the delta of about 9%, and a temperature increase of about 2.2 °C.
- Combinations of the above scenarios

There are two significant differences in the approaches that were adopted to construct scenarios for the Sharing Water and ODMP projects:

- The ODMP scenarios were based on static development states in the basin (i.e. water demands were projected to a planning horizon of 2025 and kept constant over the simulation period) , whereas the Sharing Water scenarios were based on growing water demands and timed implementation of new water infrastructure over a 13 year simulation period.
- The Sharing Water scenarios span a development continuum from the baseline, no development scenario, to a high development scenario (Management Strategy 1). For the ODMP, an issue-based list of development scenarios were identified and assessed individually before combining groups of scenarios to determine the most adversarial combination.

4.3. Scenario Selection for the EF Study

4.3.1 Approach

For the EF Study, scenarios that are based on static development states were preferred. It is possible to model dynamic basin development with growing demands and timed implantation of water resources developments, but for scenario based planning, this introduces unnecessary complexities regarding the coincidence of water resource developments with hydrologic events.

While the decision support tools that will be put in place could in future be used to make preliminary assessments of the socio-economic and ecological consequences of specific projects, the aim of the current study is not to do project level assessments, but to provide a planning framework which encompasses most of the water resource development aspirations of the three co-basin states. This would ensure that OKACOM has information at hand to assess the consequences of development pathways spanning a range that is as wide as possible. For this reason preference was given to the selection of a set of scenarios that cover a broad continuum of development and that are positioned at regular intervals across this continuum, rather than an approach that is based on an issue-driven, ad hoc selection of scenarios.

A two step approach to the selection and construction of scenarios was followed:

- Step 1: An agreed number of possible future development states, ranging from a baseline, no (or present) development to a high development state were described.
- Step 2: The broad descriptions were fleshed out with a selection of water resource developments that were comprised of a mixture of actual, planned developments, and hypothetical developments that could conceivably be implemented at some point in the future.

4.3.2 Selected Scenarios

The present, relatively undeveloped state of the basin provides a known reference point from which extrapolations can be made to assess future development states. This "Present Day" state represents one of the four scenarios that will be assessed as part of the study. (A climate change scenario will be assessed as an extension to the current project.) The four development scenarios were constructed along the following lines:

- The Present Day scenario includes all existing water resource developments, notably:
    - About 2 700 ha of irrigation in Namibia
    - The urban water demands of Menongue and Cuito Cuanavale (Angola), Rundu (Namibia), and Maun (Botswana)

- A low water use scenario which is based on the continuation of historical growth in water demands in the three countries. Growth rates in Angola reflect the recent acceleration associated with resettlement in de-mined areas. Increased water consumption is mainly due to growth in urban and rural domestic, livestock and irrigation water demands. The largest water demands are represented by:
    - About 3 100 ha of irrigation in Namibia
    - About 18 000 ha of irrigation along the Cuebe River in Angola
    - One storage based and three run-of-river hydropower stations in Angola

- A medium growth, or "business-as-usual" scenario which includes
    - About 8 400 ha of irrigation in Namibia
    - Development of a first phase of the Eastern National Carrier (17 Mm^3/a) for water supply from the Kavango to Grootfontein and Windhoek,
    - About 198 000 ha of irrigation at various locations in Angola
    - One storage based and four run-of-river hydropower stations in Angola

- A high growth scenario which includes:
    - About 15 000 ha of irrigation in Namibia
    - About 338 000 ha of irrigation at various locations in Angola
    - Completion of all planned hydropower stations in Angola, i.e. one storage based and nine run-of-river hydropower stations in Angola ,
    - Completion of a second phase of the Eastern National Carrier (total capacity 100 Mm3/a),
    - Development of a storage based water supply scheme for urban and industrial water supply from a dam in the Boteti River to Maun.

- o At these levels of demand, it was necessary to introduce a hypothetical dam in the upper basin (Cuchi River) with a capacity of about 500 million m^3 to provide for shortfalls in irrigation water supply and inter-basin transfers.

Irrigation water demands make up the largest component of future water use. In Angola, the high growth scenario provides for 338 000 ha in the upper catchments of the Cubango River and in the lower reaches of the Cuito River, but excludes some 170 000 ha of previously identified irrigation development upstream of the confluence of the Kavango and Cuito Rivers. The Angolan team decided not to include this area due to a perception that the low flows in the Kavango would not be sufficient to meet the associated demand. In Namibia, the High scenario provides for about 15 000 ha of irrigation development upstream and downstream of the confluence of the Kavango and Cuito Rivers. This area includes the so-called “Green Scheme” and respects the decision by the Namibian Departments of Agriculture Water Affairs (Policy Document No. 7/2/10/3) to limit the abstraction rate out of the Okavango River upstream of the confluence with the Cuito to 5.5 m^3/s, and downstream to 27 m^3/s. It is based, not only on the low flow in the river, but also on assumptions that a portion of the minimum flow should be reserved for environment, that there would be no regulation by dams upstream, that a demand peak factor 3 would be applicable for the month with the lowest flow and that the other countries would adopt the same approach. This limitation is far more than the limitation by the availability of dry-season flows.[4] The water resource developments that were included in the scenarios are described in more detail in EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models*.

4.3.3 General comments on the in- or exclusion of scenario water demands

Water demands from wildlife

Wildlife also exert a water demand, and there are standard unit water requirements for different species of game (Table 4-1). However, the hydrological models used by the TDA are based on the assumption that water use by game (and natural vegetation) is an integral part of the hydrological cycle and is accounted for prior to arriving at a reference, or “naturalised” condition. Thus, the naturalised runoff has already been “reduced” by water use by game and natural vegetation. It should therefore not be added back into the water balance as a “demand”, as this would be double-counting. The exception to this rule is if game concentrations are expected to increase beyond long-term historical levels, but this is considered unlikely.

Table 4-1 : Estimated wildlife water consumption (adult animals)

Species	Water Dependence	Water Consumption (Litres/day)
Blue Wildebeest	WD	9
Buffalo	WD	31
Burchell’s Zebra	WD	12
Common Duiker	WI	1
Eland	WI	23
Elephant	WD	225
Gemsbok	WI	9
Giraffe	WI	40
Impala	WD	2.5

[4] Clarification provided by G Van Langehove, 2009.

Kudu	WD	9
Red Hartebeest	WD	5.5
Reedbuck	WD	3
Roan	WD	10
Sable	WD	9
Springbok	WI	1.5
Steenbok	WI	0
Tsessebe	WD	5
Warthog	WI	3.5
Waterbuck	WD	9

Wild water-dependent (WD; obligate drinkers) and water-independent (WI) species and estimated consumption per adult animal per day (du P Bothma *et al*. 2002; du Toit 2002). A: aquatic species, SA: semi-aquatic species.

Deforestation

The water related benefits of forestation have been the subject of much debate recently. Research undertaken in India, Costa Rica, South Africa and Tanzania as part of the Forestry Research Programme of the UK Department for International Development (Hayward, 2005) have lead the authors of the study to conclude that forests reduce overall water availability in catchments. The studies indicate that there are areas where forests do increase localised rainfall through moisture harvesting from clouds, but that these areas tend to be isolated and small, and that the increased transpiration from the trees themselves tends to cancel out the benefits of increased precipitation.

Counter views are expressed by researchers who, while conceding that “newly established tropical plantations evaporate more water directly to the atmosphere in comparison to nonforest vegetation”, hold that deep aquifers, mature trees and climate feedback combine to reduce the negative water budget impacts (Chappel, Bonnel, 2006), and that if other, non-water related benefits are taken into account when assessing the public benefits of forests, the overall public benefit would be positive.

The impacts of deforestation on water availability in the Okavango River Basin was initially assessed as part of the TwinBas project, and subsequently used to assess the impacts on the flooding regime of the Delta as part of the Okavango Delta Management Plan (ODMP, 2008). The approach was based on the view that forests reduce water availability in catchments, and conversely, that deforestation would lead to a reduction in evapotranspiration by catchment vegetation, less storage of rain water in the vegetation and the root zone, resulting in more rapid and increased runoff to the rivers. It was assumed that increased population pressure along the river banks would lead to deforestation of a 2km wide band along the main river courses. Analysis of the hydrological impacts of the deforestation scenario indicated that average inflow to the delta would increase by around 7%, with an associated increase in average ground water levels (+0.03m) in the Delta. These increases were partially offset by increased evapotranspiration from the greater flooded area. Outflows from the delta were minimally affected.

Other hydrological impacts that were not assessed as part of these studies, but that can be attributed to deforestation include an increased occurrence of minor flood events (stormflows rather than peak flows), soil erosion, downstream sedimentation and associated water quality problems. Prolonged, severe soil degradation could also affect infiltration and groundwater recharge, thereby increasing surface runoff and lowering base flows in the rivers.

Water Resource Developments

The outcomes of scenarios depend on what is included as a water-resource development. Changing the location, size or any other aspects of a possible development will change the expected future flow regime and thus the expected ecological and social implications.
The water resource developments that formed part of each water-use scenario are summarised in Table 4.2 and displayed in **Error! Reference source not found.** and Figure 4-2.

Table 4.2 Water-resource developments included in each scenario

<table>
<tr><th rowspan="2">Site</th><th rowspan="2">Present</th><th rowspan="2">Low</th><th>Medium</th><th>High</th></tr>
<tr><th>Low schemes plus:</th><th>Medium schemes plus:</th></tr>
<tr><td rowspan="5">Site 1
Capico</td><td>Menongue: 246 000 people</td><td>Menogue: 257 000 people</td><td>Menogue: 30 000 people</td><td>Menogue: 70 000 people</td></tr>
<tr><td rowspan="4"></td><td colspan="3">Irrigation: Missombo 1000 ha, weir diversion</td></tr>
<tr><td colspan="3">Irrigation: Menongue Agriculture 10 000 ha, pump sump on river bank</td></tr>
<tr><td colspan="3">Irrigation: Ebritex 17 000 ha, pump sump on river bank</td></tr>
<tr><td colspan="3">HEP: Liapeca, run-of-river, low weir, turbines d/s</td></tr>
<tr><td rowspan="8">Site 2
Mucundi</td><td colspan="4">ALL CAPICO DEVELOPMENTS PLUS:</td></tr>
<tr><td rowspan="7"></td><td colspan="3">HEP: Cuvango – Existing / not functioning. Rehabilitation in 2009. 40m high reservoir, 1250 Mm3, Qmax = 3.5 m3/s</td></tr>
<tr><td colspan="3">HEP: Cuchi – (Kaquima (Malobas)). Run-of-river. H = 14m, Qmax = 3 m3/s</td></tr>
<tr><td colspan="3">HEP: Maculungungu (on Cubango u/s Caiundo). Run-of-river. H = 22m, Qmax = 24 m3/s</td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td>HEP: Cutato. Run-of-river. H = 30m, Qmax = 6 m3/s</td></tr>
<tr><td>HEP: Rapides do Cuelei. Run-of-river. H = 22m, Qmax = 8 m3/s</td></tr>
<tr><td>Irrigation: Cuchi, 15 000 ha, pump intake</td><td colspan="2">Irrigation: Cuchi, 150 000 ha, pump intake</td></tr>
<tr><td></td><td colspan="2">Irrigation : Cuvango, 10 000 ha, pump sump on river bank</td></tr>
<tr><td rowspan="2">Site 3
Cuito
Cuanavale</td><td>Cuito Cuanavale: 110 435 people</td><td>Cuito Cuanavale: 115 000 people</td><td>Cuito Cuanavale: 128 600 people</td><td>Cuito Cuanavale: 160 000 people</td></tr>
<tr><td></td><td></td><td colspan="2">HEP: Cuito Cuanavale (13 km u/s confluence). Diversion, Run-of-river. H = 7m, Qmax = 90 m3/s</td></tr>
</table>

Site	Present	Low	Medium	High
			Low schemes plus:	Medium schemes plus:
Site 4 Kapako	ALL CAPICO & MUCUNDI DEVELOPMENTS PLUS:			
	Irrigation: Kahenge 300 ha, pump intake on river bank	Irrigation: Kahenge 700 ha, pump intake on river bank	Irrigation: Kahenge 900 ha, pump intake on river bank	
			Irrigation: Rundu Future 1100 ha, pump intake on river bank	
				Irrigation: Cuangar Calai 45 000 ha, pump intake on river bank
Site 5&6 Popa and Panhandle (Shakawe)	ALL CAPICO, MUCUNDI, KAPAKO AND CUITO CUANAVALE DEVELOPMENTS PLUS:			
			Irrigation: Longa 10 000 ha, pump intake on river bank	
				Irrigation: Calais Dirico 35 000 ha, pump intake on river bank
				Irrigation: Calais Dirico B 60 000 ha, pump intake on river bank
	Irrigation: Mukwe 560 ha, pump intake on river bank			
	Irrigation: Rundu-Mashare 521 ha, pump intake on river bank	Irrigation: Rundu-Mashare 551 ha, pump intake on river bank		
	Irrigation: Ndiyona 870 ha, pump intake on river bank	Irrigation: Ndiyona 1270 ha, pump intake on river bank		
	Rundu Urban, Tower on right bank, 2.8 Mm3/a	Rundu Urban, Tower on right bank, 3.0 Mm3/a	Rundu Urban, Tower on right bank, 3.4 Mm3/a	Rundu Urban, Tower on right bank, 4.3 Mm3/a
			Irrigation: Mukwe Future 4000 ha, pump intake on river bank	Irrigation: Mukwe Future 10 600 ha, pump intake on river bank
			Eastern National Water Carrier (ENWC) for water supply from Kavango to Namibia, Tower on right bank, 17 Mm3/a	Eastern National Water Carrier (ENWC) for water supply from Kavango to Namibia, Tower on right bank, 100 Mm3/a
				HEP: Popa Falls. Run-of-river, Weir at Site 2. H = 7.5 m, Qmax = 280 m3/s, 22.5 Mm3 capacity.
				HEP: Cuito – M'Pupa. Run-of-river. H = 5m, Qmax = 100 m3/s
				HEP: Cuito – Chamavera (d/s M'Pupa). Run-of-river. H = 6m, Qmax = 100 m3/s

Site	Present	Low	Medium	High
			Low schemes plus:	Medium schemes plus:
Site 7 Khwai (Xakanaka)	ALL CAPICO, MUCUNDI, KAPAKO, CUITO CUANAVALE AND POPA/PANHANDLE DEVELOPMENTS			
Site 8 Boteti	ALL CAPICO, MUCUNDI, KAPAKO, CUITO CUANAVALE, POPA/PANHANDLE DEVELOPMENTS, PLUS:			
				Dam at Samedupi (37 Mm^3)

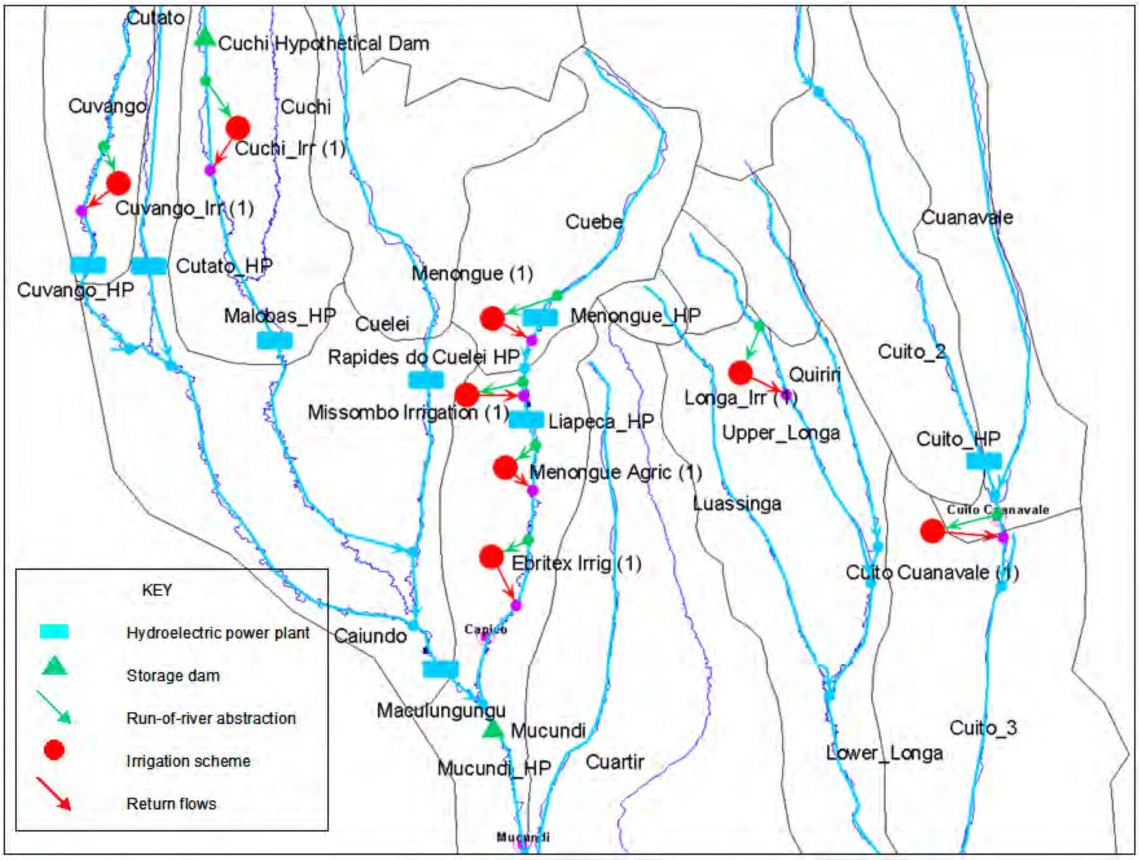

Figure 4-1 : Approximate positions of water-resource developments included in the wateruse scenarios in the upper portion of the catchment

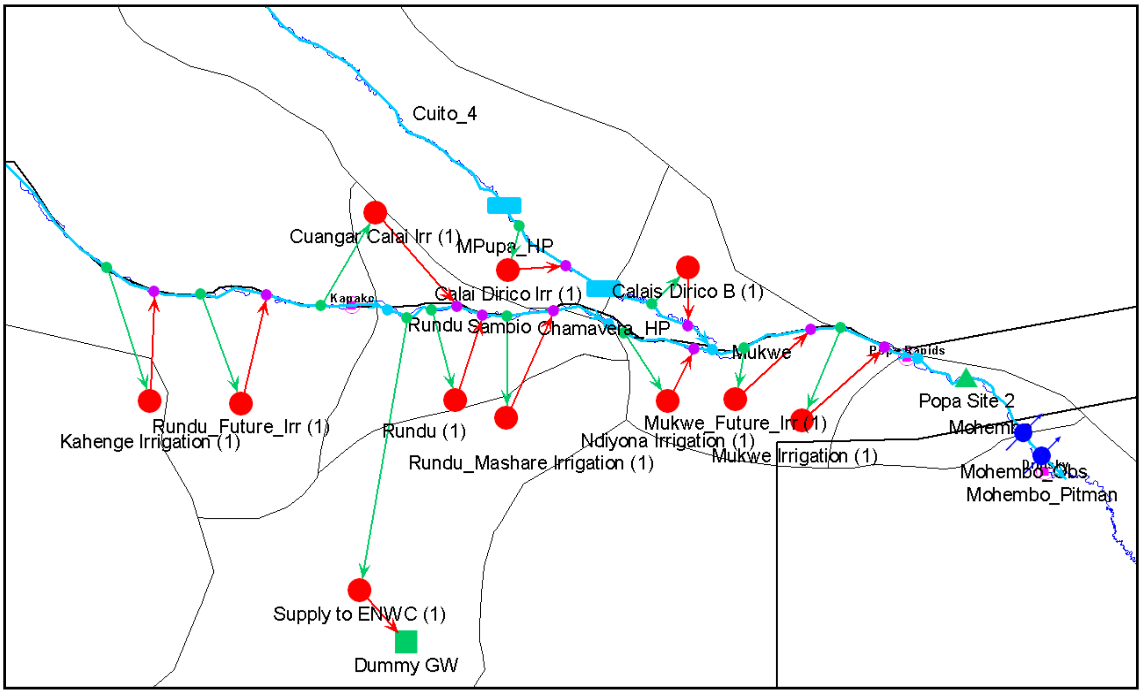

Figure 4-2 **Approximate positions of water-resource developments included in the water-use scenarios in the lower portion of the catchment.**

5. Hydrological Consequences of the Water Use Scenarios

5.1. Introduction

The hydrological modeling of the three scenarios yielded times series of monthly flows for a 43-year hydrological period (1959 - 2001) for the river sites (Sites 1-6) and a 20-year hydrological period (1983 - 2002) for the Delta (Site 7) and Boteti (Site 8). For each scenario, the level of water use outlined in Table 4.2 was imposed on the full hydrological period.

It is important to emphasise that the modeling period (1959/60 – 2001/02), show a declining trend in mean annual runoff (Figure 5-1). This trend was primarily driven by climatic conditions, as was borne out by a reversal of the trend in 2004-2009.

Thus, for the river sites (Sites 1, 2, 3, 4, 5 and 6), the present-day situation is defined as a 43-year hydrological period (1959 - 2001) with 2008 levels of water use applied throughout.

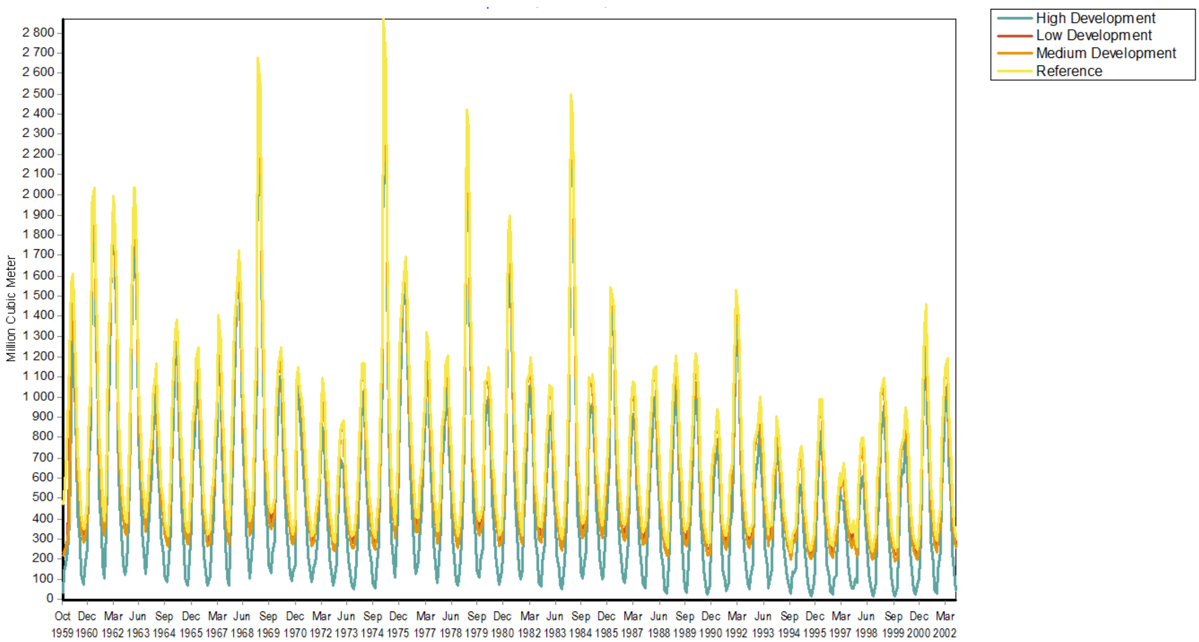

Figure 5-1 Simulated monthly inflows to the Delta – all scenarios (1959-2001).

For the delta (Site 7) and the Boteti River (Site 8), the present-day situation is defined as a 20-year hydrological period (1983 - 2002) with 2008 levels of water use applied throughout. Figure 5-1 shows simulated inflows to the Delta for the 1959-2003 period and illustrates the fact that all of the upstream developments envisaged in a particular scenario would be in place for the entire time.

To facilitate comparison between the scenarios, each scenario comprises the same hydrological period as the present-day scenario, with its water use levels applied throughout.

5.2. Presentation and Discussion of Results

The hydrological consequences of the three future water use scenarios are discussed in the remainder of this chapter. Impacts are described in separate sections dealing with the upstream basin, the Delta, and the Boteti. In each section a site-by-site discussion of the changes that were observed in the flow regime is given:

- For the river and floodplain sites in the upper basin, the impacts of the water use scenarios are described in terms of changes to the monthly flow duration curves, and the ecologically relevant flow indicators that were derived from the disaggregated daily time series (refer to Section 2.3). Listings of the flow indicators that were calculated for each site and each scenario are provided in Appendix A.
- For the Delta sites, the impacts of the water use scenarios are described in terms of changes to the vegetation assemblages that were modeled with the HOORC Delta Model. The Botswana DWA MIKE SHE-MIKE 11 Integrated Hydrologic Model (IHM) was used to develop discharge-depth and discharge-velocity relationships at the Delta sites. The relationships were used by the ecological specialists to translate simulated flows (median wet season flood peaks and dry season minimum flows) to depths and discharges in order to populate some of the eco-system response curves. The relationships are provided in EPSMO/Biokavango Report Number 5; *Hydrology: Data and Models*.
- For the Boteti site, hydrological impacts are described in terms of state changes observed over the period of simulation (i.e. whether the river is inundated, contains disconnected pools, or is dry).

5.3. The Upstream Basin

5.3.1 General comments

Figure 5-3 to Figure 5-5 show changes in mean annual runoff (MAR) associated with the Low, Medium and High development scenarios relative to the reference (present day) scenario. It can be seen that:

- Inflows to the Delta decrease by about 370, 880 and 2 900 million m^3/a relative to the present day MAR for the Low, Medium and High development scenarios, respectively.
- Most of the water resource developments associated with the Low and Medium scenarios are located in the Cuchi and Cuebe catchments, and the effects of these can be seen in the middle and lower reaches of the Cubango / Kavango River. As an example, dry season low flows at Kapako (and Rundu) would be reduced to about 50% of present day values.
- The combined water abstractions in the upper basin for the High scenario equate to about 3 600 million m^3/a. Of this, by far the largest component is made up of irrigation water demands (3 300 million m^3/a in Angola and 223 million m^3/a in Namibia), followed by the relatively smaller demands of the ENWC transfer (100 million m^3/a), and the combined urban demands of Menongue, Cuito Cuanavale and Rundu (22 million m^3/a).
- In the High development scenario, large tracts of irrigation developments are located along the lower reaches of the Cuito River. This has the effect of considerably reducing the Cuito River's strong base flow contribution to the lower Okavango River, and as will be seen later, the combined effect of all upstream developments substantially reduces the permanent swamp area in the Delta, and virtually dries up the Boteti River.

- The hydrological impacts of the developments in the Cubango/Kavango sub-basin (upstream of the confluence with the Cuito) is mitigated to some extent by the presence of two large storage dams – a hydropower storage near Mucundi on the Cubango River (Low scenario), and another in the Cuchi catchment (High scenario). While the main purpose of the Mucundi Dam is to provide generating head for hydropower, hydropower releases in the dry season is available for downstream abstractions such as the Eastern National Carrier.
- It is important to note that, were the storage dams not present, the postulated future demands under the High scenario would not be met in its entirety. A test was done by removing the storage dams, and re-simulating the High scenario. It can be seen that, for example, the ENWC monthly water abstractions cannot be met for a much longer percentage of time, were the dams not in place.

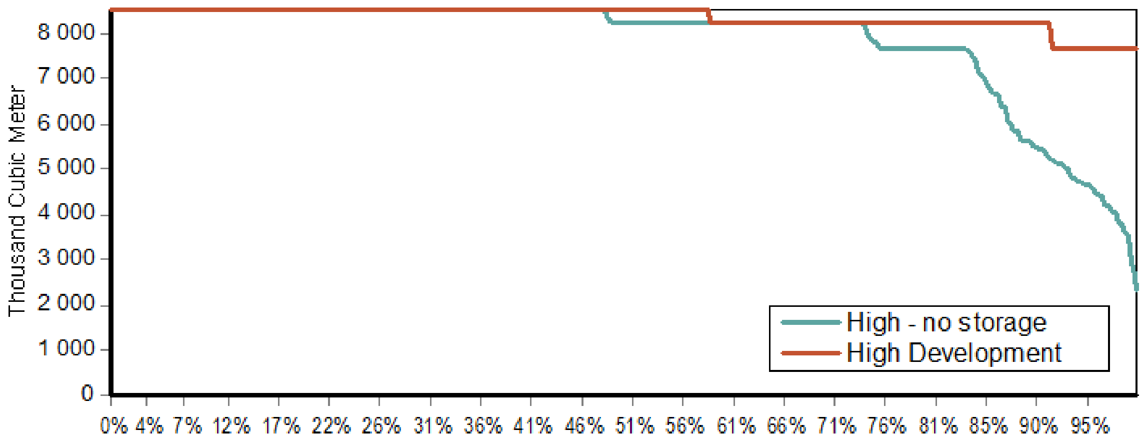

Figure 5-2 : Percentage of time (months) that the ENWC abstraction is met

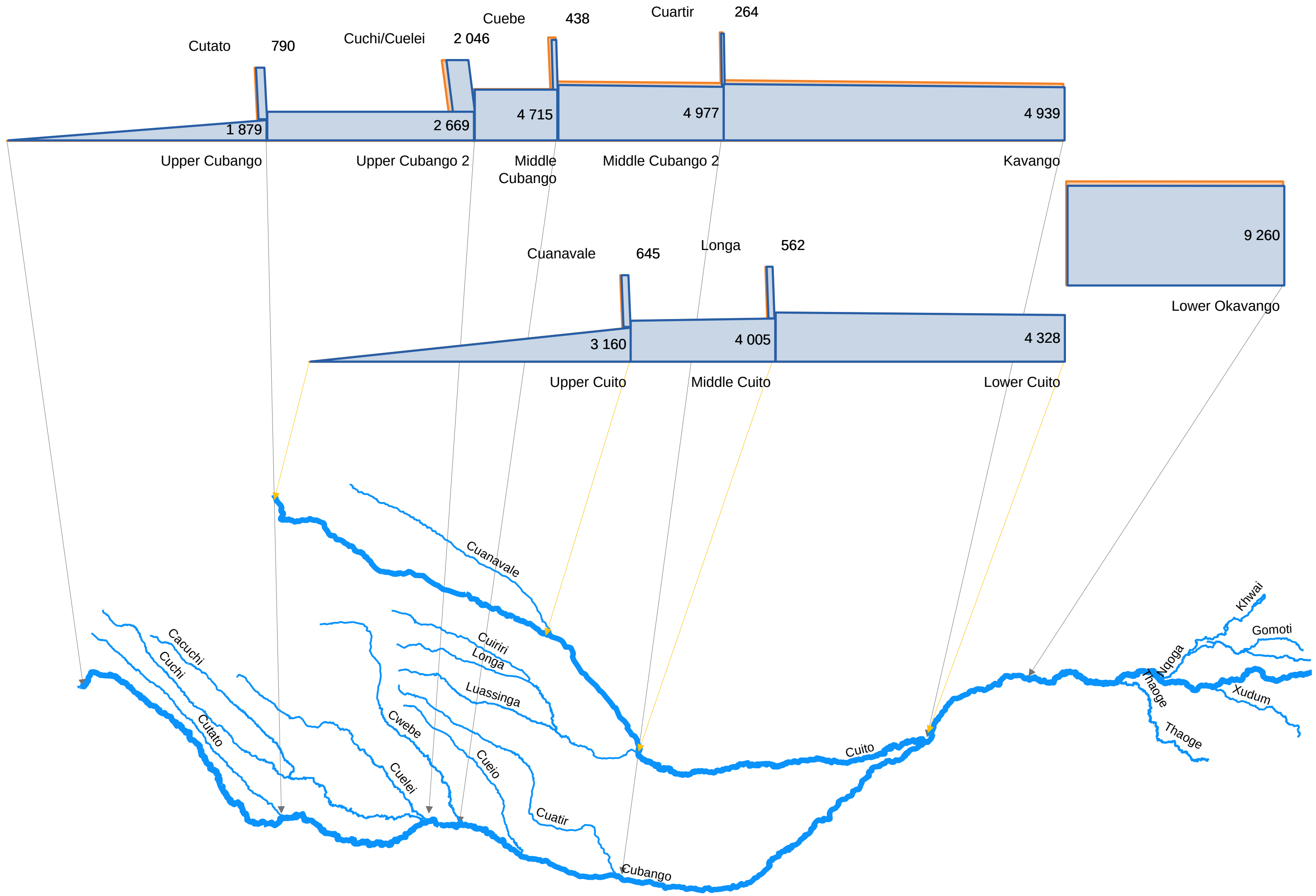

Figure 5-3 : Mean Annual Runoff (10^6 m^3/a) - Low Water Use (Blue) compared to Present Day (Orange)

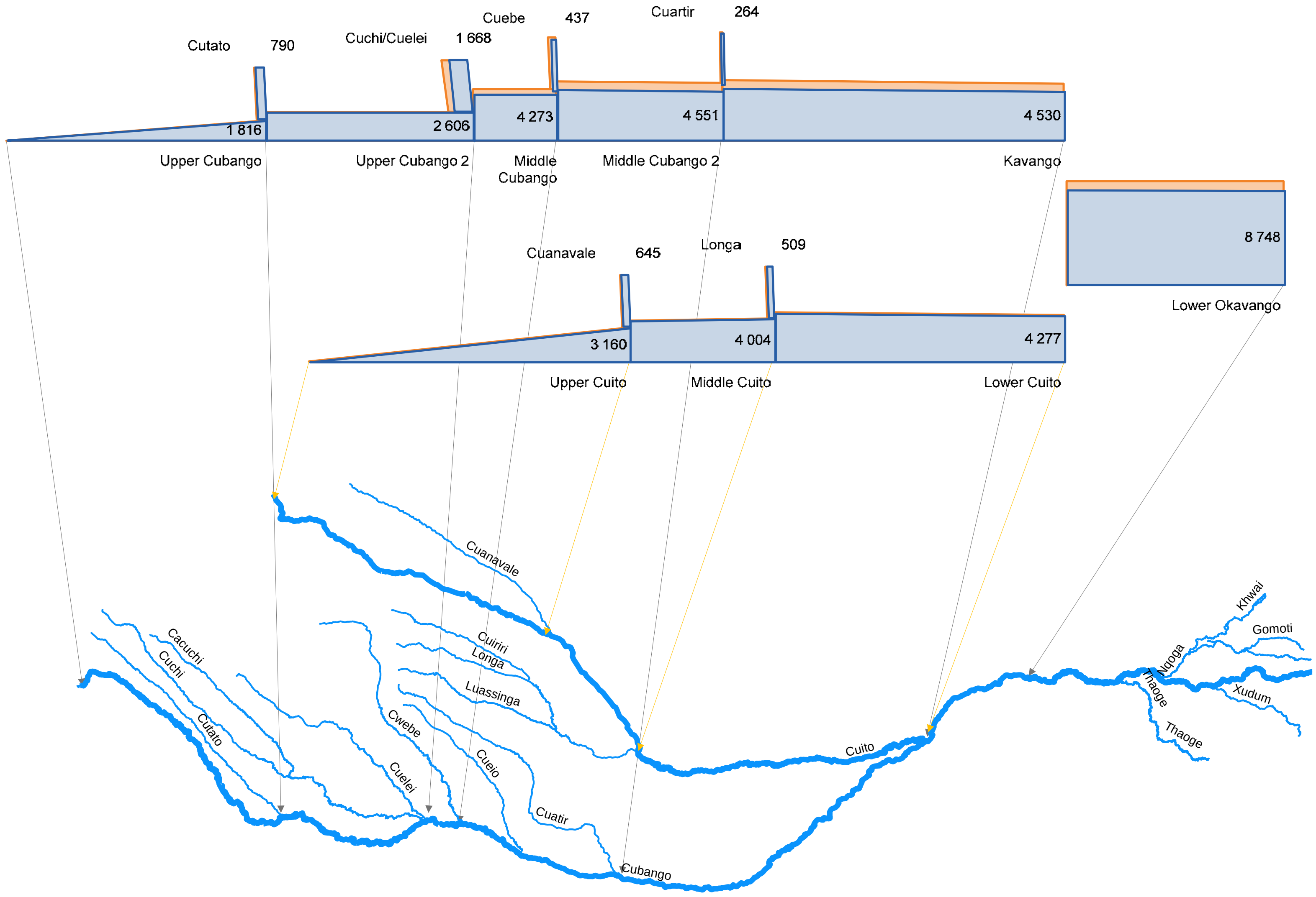

Figure 5-4 : **Mean Annual Runoff (10^6 m^3/a) - Medium Water Use (Blue) compared to Present Day (Orange)**

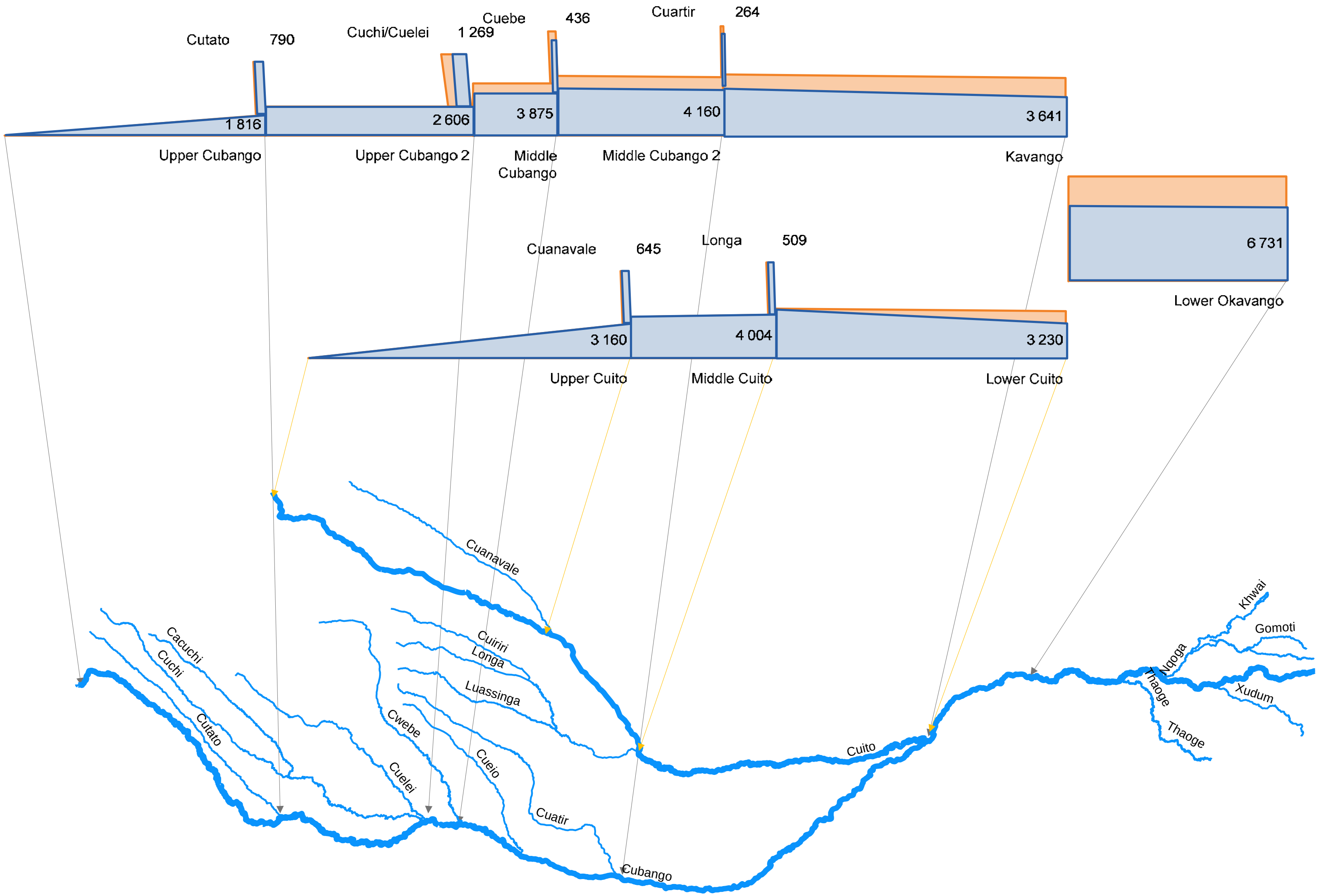

Figure 5-5 : **Mean Annual Runoff (10^6 m^3/a) - High Water Use (Blue) compared to Present Day (Orange)**

5.3.2 Site 1 - Capico

All of the developments envisaged for Capico were inserted into the Low Scenario, and so the following consequences apply to all three scenarios. The developments are: run-of-river abstractions that feed 28 000 ha of irrigation, increased urban supply for up to 100 000 more people and a small run-of-river HEP diversion at Liapeca. These result in the mean annual runoff in the Cuebe dropping to about half, because of water being diverted into croplands. Diversions take place year round, but the biggest volumes are diverted during the dry season. Figure 5-6 shows that in all future scenarios low flows are virtually depleted for about 25% of the simulation period. The impact is greater in the dry season, which starts 3 months earlier, is more than 4 months longer and has flows close to zero. The wet season is 3 months shorter and the volume of flood water is about half of present.

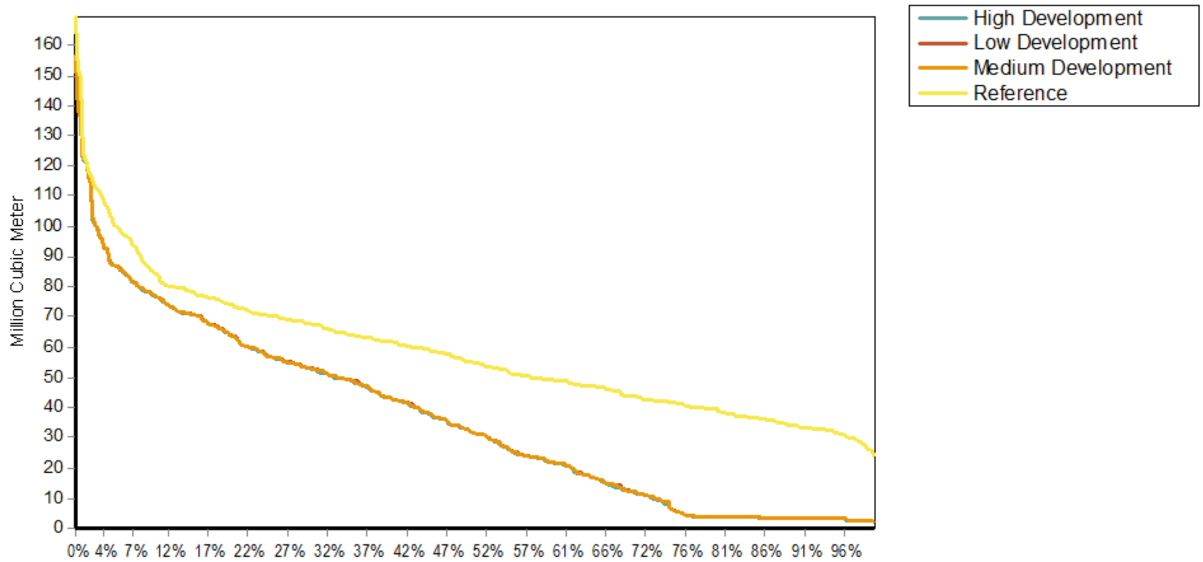

Figure 5-6 : Monthly Flow Duration Curves for the Cuebe River at Capico (Site 1)

Table 5.1 Median values for the ecologically-relevant summary statistics for each scenario for Site 1: Capico.

Flow category	PD	Low	Medium	High	Comment
Mean Annual Runoff (Mm^3/a)	22	14	14	13	All Scenarios similar and lower than PD
Dry season onset	Aug	May	May	May	All Scs similar and 11 wks earlier than PD
Dry season duration (days)	86	212	212	213	All Scs similar and approx 18 wks longer than PD (ie ends later and starts earlier)
Dry season minimum flow ($m3s$-1)	12	0.4	0.3	0.3	All Scs similar. Drastic drop from PD
Flood season onset	Dec	Jan	Jan	Jan	All Scs similar and delayed by about 7 weeks compared to PD
Flood season peak ($m3s$-1)	38	35	35	35	All Scs similar and slightly smaller than PD
Flood season volume (Mm^3)	456	231	231	230	All Scs similar and half of PD
Flood season duration (days)	197	97	97	97	All Scs similar and approx 14 wks shorter than PD

PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario

5.3.3 Site 2 – Mucundi

All of the developments for Capico still apply, and in addition further major developments in hydropower generation and croplands are included. Run-of-river HEP schemes with diversion structures are added with each scenario, but one storage based scheme with a substantial dam wall. Irrigated cropland gradually increases to a maximum of 175 000 ha, all areas using run-of-river abstraction, except for a large dam on the Cuchi River, which is introduced in the High Scenario. The impacts on flow are not as severe as at Capico because of the contribution of undeveloped tributaries. MAR declines gradually to about 80% of present, and the dry season starts about a month earlier and lasts up to 2 months longer. Because of the continual abstractions, dry-season flows fall to less than half of present flows in the Low and Medium Scenarios, but they increase again in the High Scenario due to dam releases (Figure 5-7). Wet-season flows start later and with lesser floods, because of filling of the dams on the Cubango and Cuchi, and are up to a month shorter.

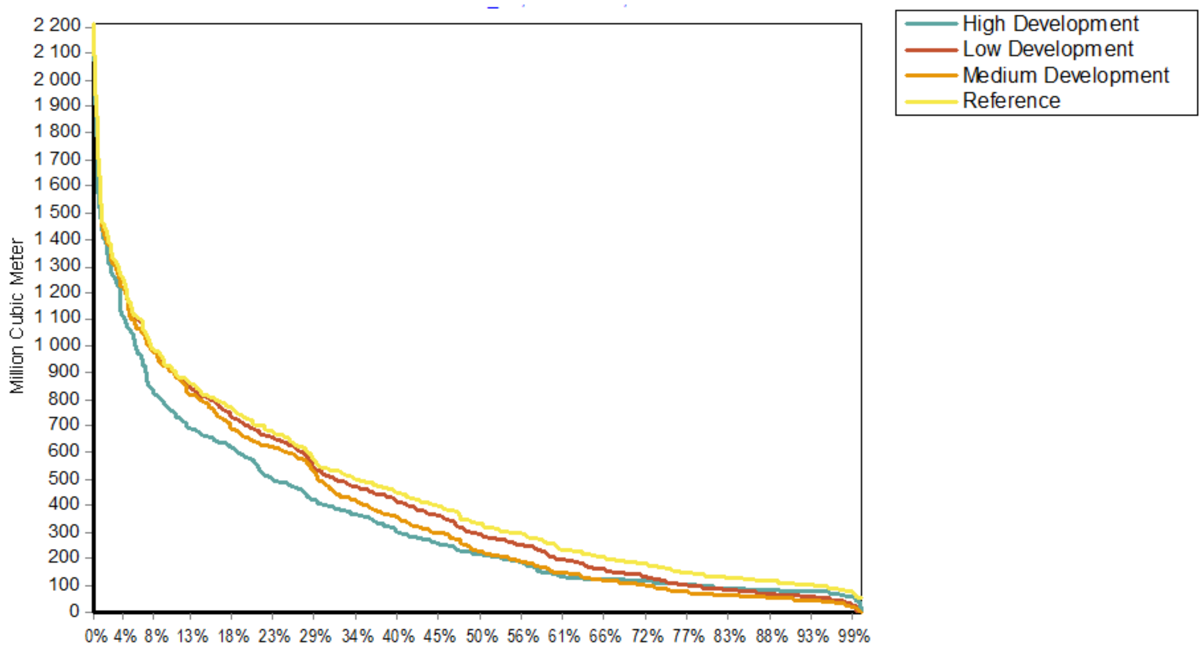

Figure 5-7 : Monthly Flow Duration Curves for the Cubango River at Mucundi (Site 2)

Table 5.2 Median values for the ecologically-relevant summary statistics for each scenario for Site 2: Mucundi.

Flow category	PD	Low	Medium	High	Comment

Mean Annual Runoff (Mm^3/a)	166	155	140	128	Gradual decline to 93%, 85%, 77% of PD
Dry season onset	July	July	July	July	All Scs similar. Onset 2-3 weeks earlier than PD.
Dry season duration (days)	96	124	143	152	Progressive lengthening of dry season by 4, 7 and 8 weeks
Dry season minimum flow (m^3s^{-1})	32	16	12	24	Min Q drops to 50% (L), 38% (M) of PD and then under H increases to 75% - dam releases in dry season
Flood season onset	Jan	Jan	Jan	Jan	Progressively delayed by 2-3 weeks
Flood season peak (m^3s^{-1})	429	430	429	401	Peak not affected until (H), when drops to 93% of PD
Flood season volume (Mm^3)	3713	3558	3178	2531	Progressive loss of volume: 96%, 86%, 68 of PD
Flood season duration (days)	148	135	123	111	Progressive shortening of flood season by 2, 3, 5 weeks

PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario.

5.3.4 Site 3 – Cuito Cuanavale

Most developments included for the Cuito River are downstream of the Cuito-Cuanavale site and so do not affect it. The scenarios include 50 000 more people in urban areas and a small run-of-river HEP diversion on the Cuito River upstream of Cuito Cuanavale. These do not have a noticeable impact on the flow regime although the HEP infrastructure might have a, presently unknown, impact on sediment movement along the river. If only flow changes are considered, the developments included for this site would have a minimal impact on the river ecosystem.

Table 5.3 Median values for the ecologically-relevant summary statistics for each scenario for Site 3: Cuito Cuanavale.

Flow category	PD	Low	Medium	High	Comment
Mean Annual Runoff (Mm^3/a)	119	119	119	119	
Dry season onset	July	July	July	July	
Dry season duration (days)	182	182	182	182	Much longer duration than other Angolan sites
Dry season minimum flow (m^3s^{-1})	80	80	80	80	Much higher flow than other Angolan sites
Flood season onset	Jan	Jan	Jan	Jan	
Flood season peak (m^3s^{-1})	163	163	163	163	Quite a small peak compared to Mucundi
Flood season volume (Mm^3)	1968	1968	1968	1968	About half of Mucundi
Flood season duration (days)	162	162	162	162	Within range of other Angolan sites

PD = simulated present day flow regime.

5.3.5 Site 4 – Kapako

All developments included for Capico and Mucundi are upstream of this site and so are included, and in addition a further 48 000 ha of run-of-river irrigation in the Kapako area is added gradually through the scenarios. There are no significant tributaries between Mucundi and Kapako and so flow changes upstream are transmitted downstream without amelioration of other inflows. Figure 5-8 shows the elevation of low flows (tail-end of the duration curve) under the High scenario due to dry season releases from the two postulated storage dams in the Cubango sub-basin. The annual volume of water flowing down the river progressively declines to 80% of present and the dry-season flow falls by about half and the dry season extends up to 1.5 months longer. The wet season is shorter by about the same length of time with up to a 30% drop in volume but little change in flood onset time and size of flood peak.

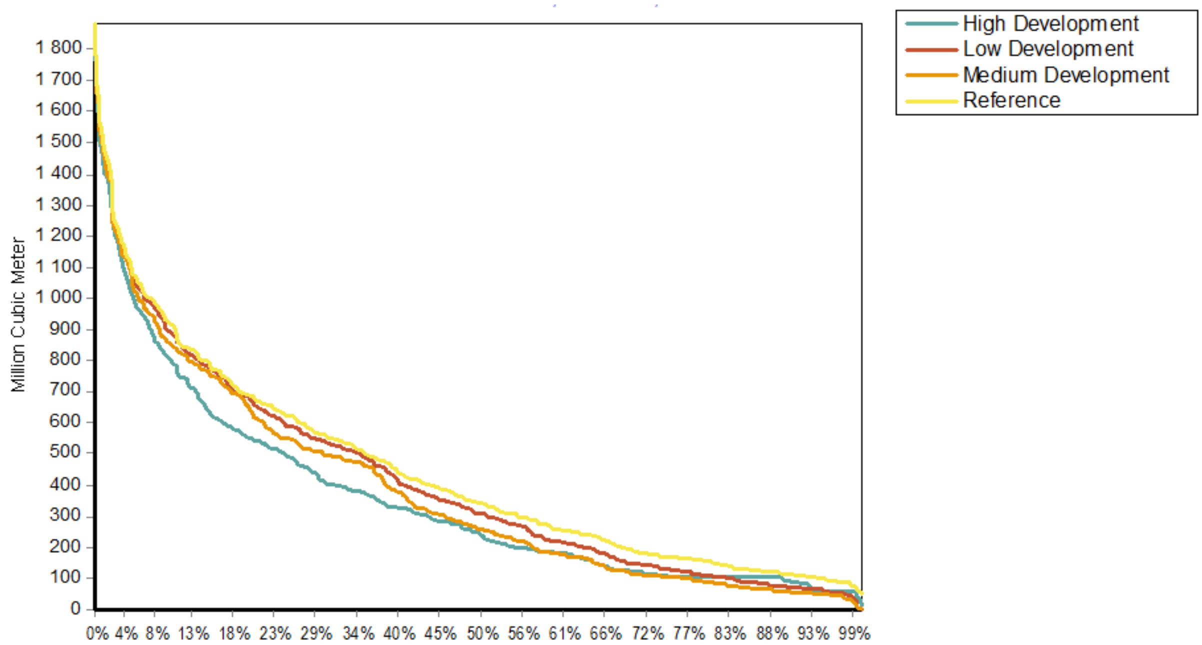

Figure 5-8 : Monthly Flow Duration Curves for the Kavango River at Kapako (Site 4)

Table 5.4 Median values for the ecologically-relevant summary statistics for each scenario for Site 4: Kapako.

Flow category	PD	Low	Medium	High	Comment
Mean Annual Runoff (Mm^3/a)	164	152	140	129	Progressive decline to 93%, 85%, 79% of PD
Dry season onset	July	July	July	July	Approx same throughout
Dry season duration (days)	135	150	168	176	Progressively longer: 2, 5, 6 weeks more than PD
Dry season minimum flow (m^3s^{-1})	35	20	15	19	Decline through L and M to 43% then increase for H to 54%
Flood season onset	Jan	Jan	Jan	Feb	Slight delay by about 2 wks in H
Flood season peak (m^3s^{-1})	452	446	453	433	Medium about same as PD; L slightly lower at 99% and H at 96% of PD
Flood season volume (Mm^3)	3694	3535	3209	2580	Progressive decline to 96%, 87%, 70% of PD
Flood season duration (days)	154	147	130	117	Progressively shorter flood season: 1, 4, 6 weeks shorter than PD

PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario.

5.3.6 Sites 5 and 6 : Popa Rapids and Panhandle

All developments upstream in Capico, Mucundi, Cuito Cuanavale and Kapako are included, plus a gradual increase of run-of-river irrigation along the lower Okavango and a large increase along the lower Cuito River in the Medium and High scenarios to more than 178 000 ha above present (mostly in Angola), up to 130 m^3/s more diversion in Namibia for urban supply, and three additional run-of-river HEP structures, one with a dam wall height of 7.5 m. These translate as a decline to 69% of mean annual runoff and a dry season that starts up to 2 months earlier and is 3 months longer than present. Under the High Scenario, dry-season flows drop to 18% of present. The flood season onset and peak are only slightly affected but it is up to 2 months shorter and declines to about two-thirds of its present volume.

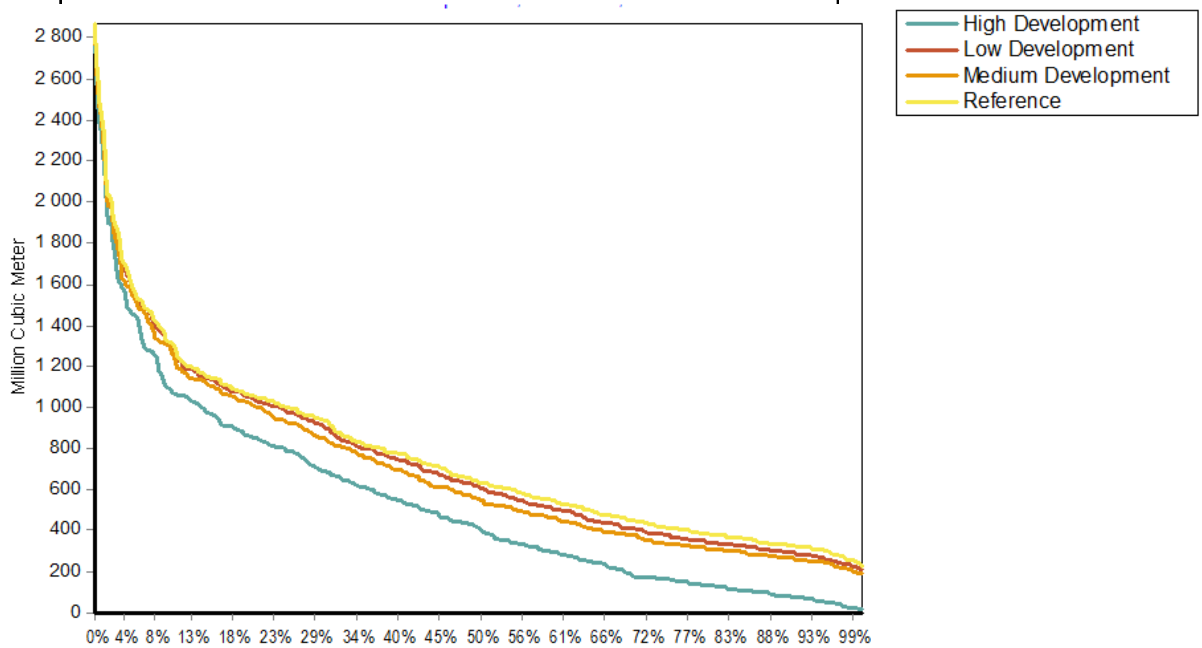

Figure 5-9 : Monthly Flow Duration Curves for the Okavango River at Popa Rapids (Site 5)

5.4. The Delta

5.4.1 General comments

Hydrological flow sequences are not particularly useful in the analysis of the Okavango Delta. The extent and frequency of flooding drive the distribution of vegetation types and habitats. Thus, while the overall proportion of inundated area may be similar in years with similar flow characteristics, the location of the inundated areas varies over time. For his reason, a semi-conceptual hydraulic model (Wolski *et al*. 2006), which was calibrated using observed flow and inundation data for the period of 1968-2002, was used to generate inundation patterns over the south-western portion of the Okavango delta, as represented by Site 7: Xakanaka. The output of the model is a series of vegetation types/habitat based on duration and frequency of inundation (

Table 5.5). The Delta and Boteti models were run over the same period (1973 to 2002), however the vegetation responses in the Delta model are dependent on conditions in antecedent years and therefore requires a “warm-up” period. The Delta vegetation responses are therefore only reported from 1983.

Table 5.5 Vegetation types used in the model

Abbreviation	Description
CH-ps	Channels in permanent swamp
L-ps	Lagoons in permanent swamp
BS-ps	Backswamp in permanent swamp
SP-sf	Seasonal pools in seasonally flooded zone
Sed-sf	Seasonal sedgeland in seasonally flooded zone
Gr-sf	Seasonal grassland in seasonally flooded zone
S-sf	Savanna- dried floodplain in seasonally flooded areas

5.4.2 Site 7: Xakanaka

Due to the declining upstream inflows into the Delta, there is a decrease in all major types of permanent swamp to as low as 22% of present under the High scenario, and an increase in seasonal swamps into these areas. Dry flood-plain savanna also expands to more than four times its present area, representing a significant drying-out of the Delta.

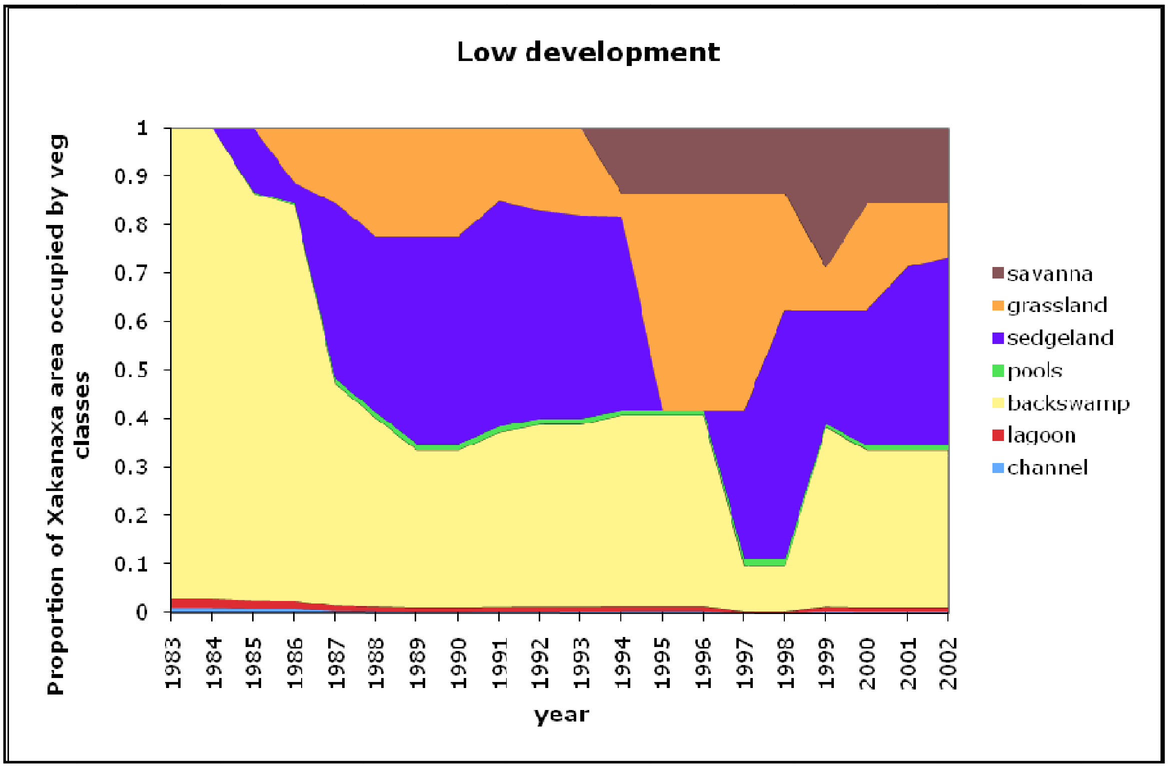

Figure 5-10 : Time series of vegetation/habitat assemblages for the Low Scenario

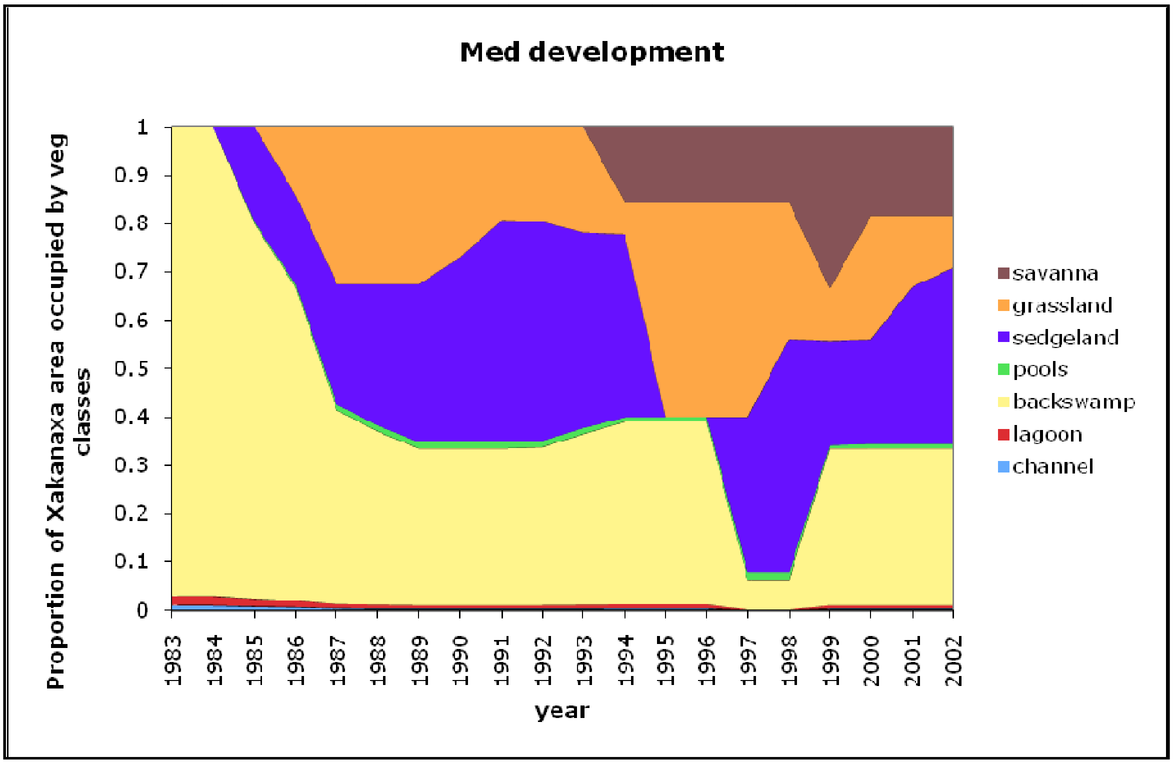

Figure 5-11 : Time series of vegetation/habitat assemblages for the Medium Scenario

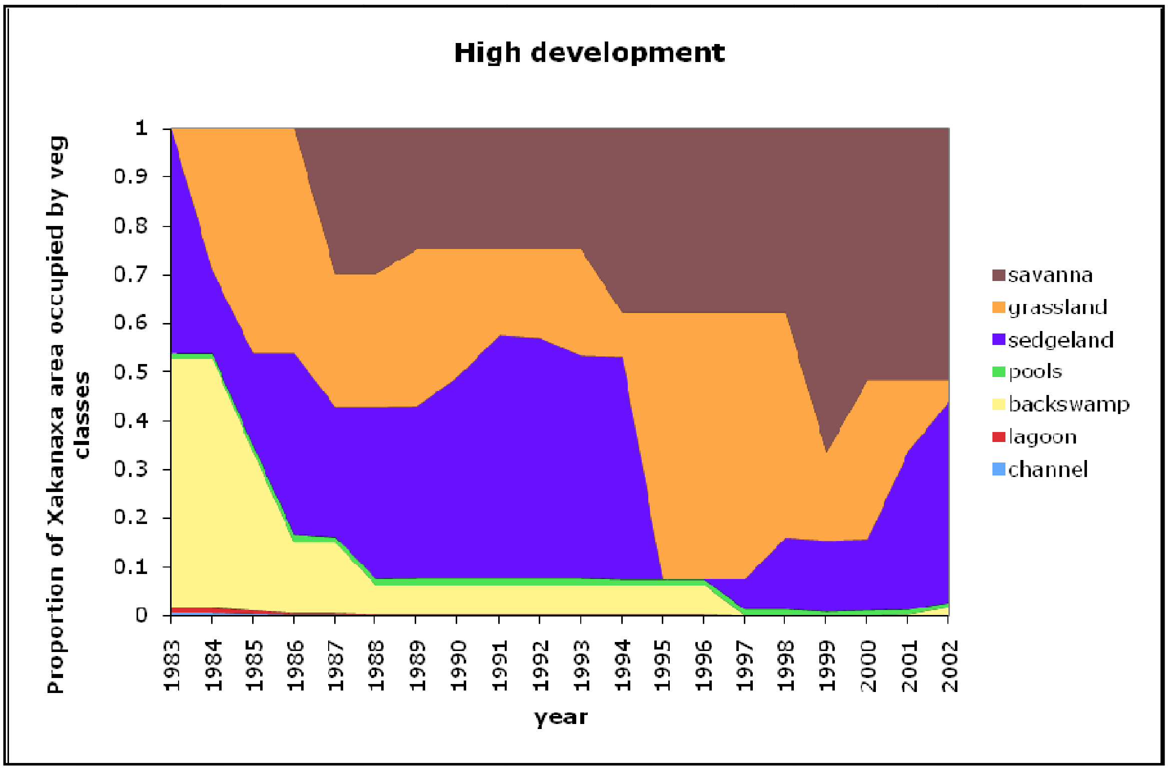

Figure 5-12 : Time series of vegetation/habitat assemblages for the High Scenario

5.5. Delta Outflows

The percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the Present day, Low, Medium and High scenarios is provided in Figure 5-13 to Figure 5-16, respectively.

Details of the model used to provide these data are provided in EPSMO/BioKavango Report 05/2009: Hydrology Report: Data and models.

The Thamalakane / Boteti River system receives outflows from the Delta and is highly susceptible to changes in the flooding regime of the Delta. In addition, the length of river that is wetted by inflows in any given year depends on the volume of inflows and state of the groundwater aquifers in previous years. Flows in the system normally exhibit dry and wet cycles of many years in length. Through the scenarios the number of years it contains water would progressively decline until in the High Scenario it would be completely dry for most of the time, holding water only in the wettest years.

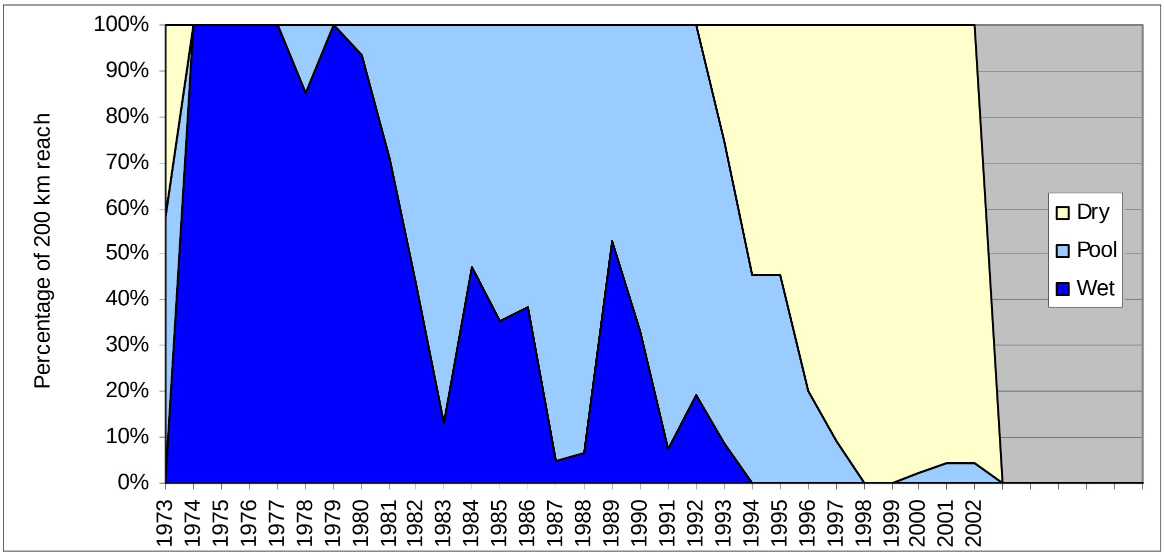

Figure 5-13 : Percentage of the Boteti River study reach that will be inundated (wet); isolated pools (pool) and dry under the Present day Scenario

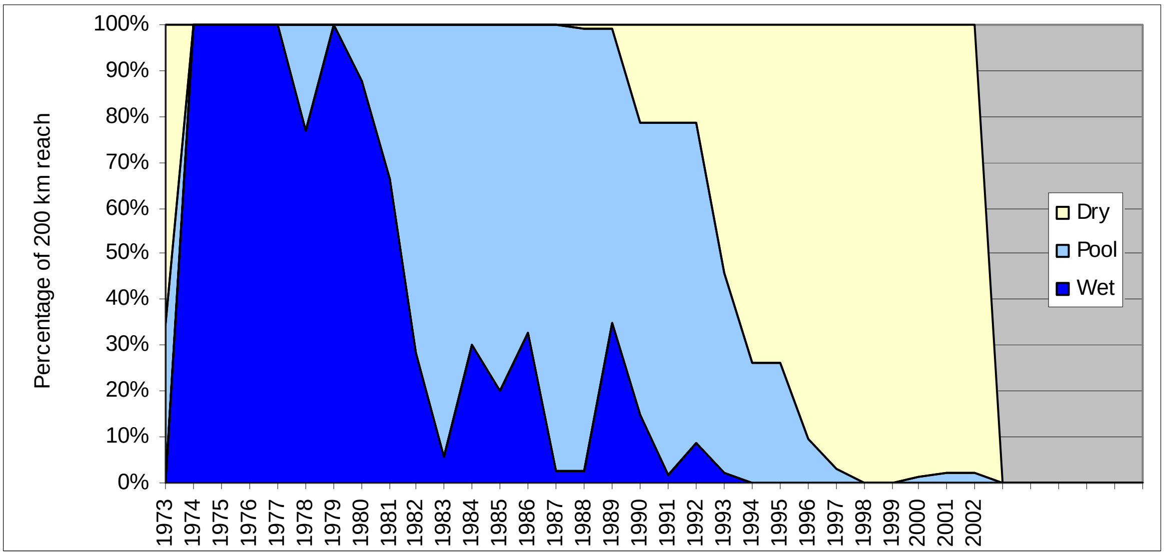

Figure 5-14 : Percentage of the Boteti River study reach that will be inundated (wet); isolated pools (pool) and dry under the Low Scenario

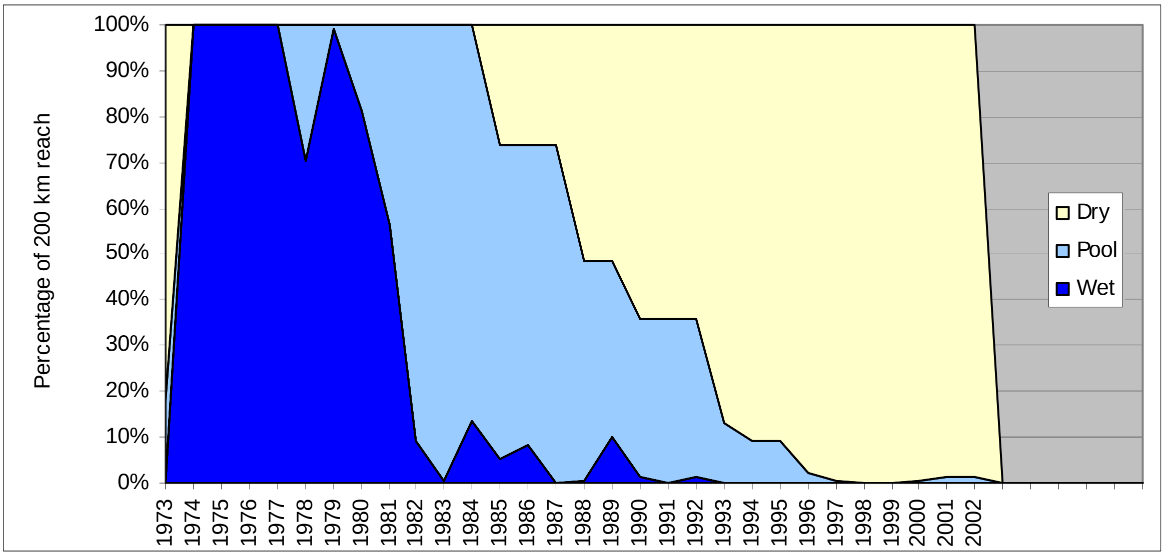

Figure 5-15 : Percentage of the Boteti River study reach that will be inundated (wet); isolated pools (pool) and dry under the Medium Scenario

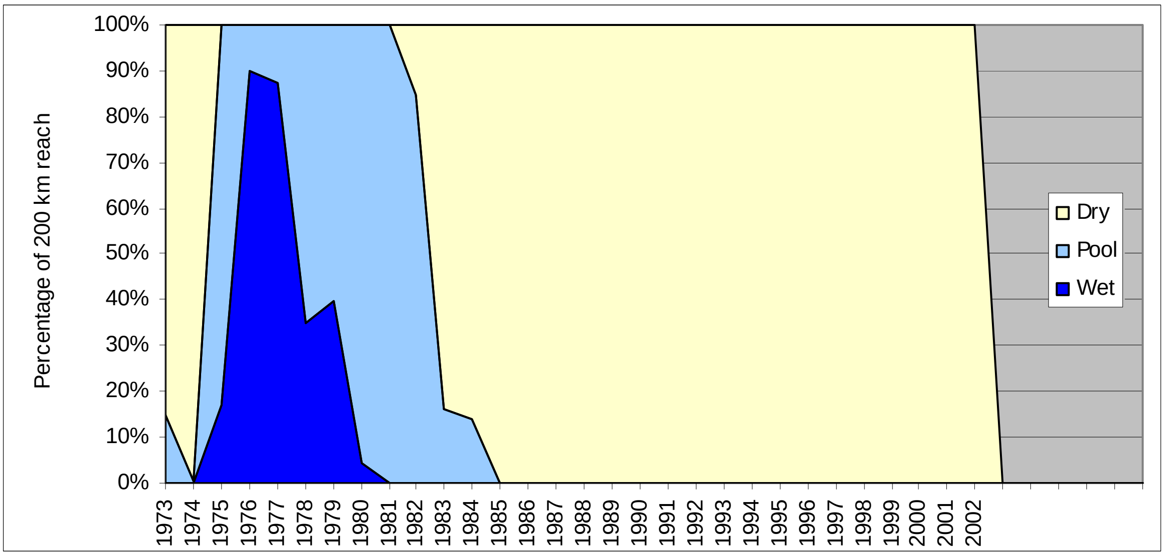

Figure 5-16 : Percentage of the Boteti River study reach that will be inundated (wet); isolated pools (pool) and dry under the High Scenario

5.6. Process followed after the generation of hydrological summary data

The hydrological summary statistics are used as inputs to the response curves that are used to predict the biophysical and social outcomes for the flow regime of interest. The response curves, and the predicted ecological and socio-economic implications of the water use scenarios are described in Report 07/2009: Scenario Report: Ecological and social predictions (Volume 1 of 2)

6. Summary and Conclusions

6.1. The Upper Basin

6.1.1 General

The hydrological consequences of the water use scenarios can be summarised as follows:

- Current day inflows to the Delta of about 9 600 million m^3/a decrease by about 370, 880 and 2 900 million m^3/a relative to the present day mean annual runoff for the Low, Medium and High development scenarios, respectively.
- Most of the water resource developments associated with the Low and Medium scenarios are located in the Cuchi and Cuebe catchments, and the effects of these can be seen in the middle and lower reaches of the Cubango / Kavango River. As an example, dry season low flows at Kapako (and Rundu) would be reduced to about 50% of present day values.
- The combined water abstractions in the upper basin for the High scenario equate to about 3 600 million m^3/a. Of this, by far the largest component is made up of irrigation water demands (3 300 million m^3/a in Angola and 223 million m^3/a in Namibia), followed by the relatively smaller demands of the ENWC transfer (100 million m^3/a), and the combined urban demands of Menongue, Cuito Cuanavale and Rundu (22 million m^3/a).
- In the High development scenario, large tracts of irrigation developments are located along the lower reaches of the Cuito River. This has the effect of considerably reducing the Cuito River's strong base flow contribution to the lower Okavango River. The combined effect of all upstream developments substantially reduces the permanent swamp area in the Delta, and virtually dries up the Boteti River.
- The hydrological impacts of the developments in the Cubango/Kavango sub-basin (upstream of the confluence with the Cuito) is mitigated to some extent by the presence of two large storage dams – a hydropower storage near Mucundi on the Cubango River (Low scenario), and another in the Cuchi catchment (High scenario). While the main purpose of the Mucundi Dam is to provide generating head for hydropower, hydropower releases in the dry season is available for downstream abstractions such as the Eastern National Carrier.
- It is important to note that, were the storage dams not present, the postulated future demands under the High scenario would not be met in its entirety. A test was done by removing the storage dams, and re-simulating the High scenario. It can be seen that, for example, the ENWC monthly water abstractions cannot be met for a much longer percentage of time, were the dams not in place.

6.1.2 Site 1 - Capico

All of the developments envisaged for Capico were inserted into the Low Scenario, and so the following consequences apply to all three scenarios. The developments are: run-of-river abstractions that feed 28 000 ha of irrigation, increased urban supply for up to 100 000 more people and a small run-of-river HEP diversion at Liapeca. These result in the mean annual runoff in the Cuebe dropping to about half, because of water being diverted into croplands. Diversions take place year round, but the biggest volumes are diverted during the dry season. Figure 5-6 shows that in all future scenarios low flows are virtually depleted for about 25% of the simulation period. The impact is greater in the dry season, which starts 3 months earlier, is more than 4 months longer and has flows close to zero. The wet season is 3 months shorter and the volume of flood water is about half of present.

6.1.3 Site 2 – Mucundi

All of the developments for Capico still apply, and in addition further major developments in hydropower generation and croplands are included. Run-of-river HEP schemes with diversion structures are added with each scenario, but one storage based scheme with a substantial dam wall. Irrigated cropland gradually increases to a maximum of 175 000 ha, all areas using run-of-river abstraction, except for a large dam on the Cuchi River, which is introduced in the High Scenario. The impacts on flow are not as severe as at Capico because of the contribution of undeveloped tributaries. Mean annual runoff declines gradually to about 80% of present, and the dry season starts about a month earlier and lasts up to 2 months longer. Because of the continual abstractions, dry-season flows fall to less than half of present flows in the Low and Medium Scenarios, but they increase again in the High Scenario due to dam releases. Wet-season flows start later and with lesser floods, because of filling of the dams on the Cubango and Cuchi, and are up to a month shorter.

6.1.4 Site 3 – Cuito Cuanavale

Most developments included for the Cuito River are downstream of the Cuito-Cuanavale site and so do not affect it. The scenarios include 50 000 more people in urban areas and a small run-of-river HEP diversion on the Cuito River upstream of Cuito Cuanavale. These do not have a noticeable impact on the flow regime although the HEP infrastructure might have a, presently unknown, impact on sediment movement along the river. If only flow changes are considered, the developments included for this site would have a minimal impact on the river ecosystem.

6.1.5 Site 4 – Kapako

All developments included for Capico and Mucundi are upstream of this site and so are included, and in addition a further 48 000 ha of run-of-river irrigation in the Kapako area is added gradually through the scenarios. There are no significant tributaries between Mucundi and Kapako and so flow changes upstream are transmitted downstream without amelioration of other inflows. Figure 5-8 shows the elevation of low flows (tail-end of the duration curve) under the High scenario due to dry season releases from the two postulated storage dams in the Cubango sub-basin. The annual volume of water flowing down the river progressively declines to 80% of present and the dry-season flow falls by about half and the dry season extends up to 1.5 months longer. The wet season is shorter by about the same length of time with up to a 30% drop in volume but little change in flood onset time and size of flood peak.

6.1.6 Sites 5 and 6 : Popa Rapids and Panhandle

All developments upstream in Capico, Mucundi, Cuito Cuanavale and Kapako are included, plus a gradual increase of run-of-river irrigation along the lower Okavango and a large increase along the lower Cuito River in the Medium and High scenarios to more than 178 000 ha above present (mostly in Angola), up to 130 m^3/s more diversion in Namibia for urban supply, and three additional run-of-river HEP structures, one with a dam wall height of 7.5 m. These translate as a decline to 69% of mean annual runoff and a dry season that starts up to 2 months earlier and is 3 months longer than present. Under the High Scenario, dry-season flows drop to 18% of present. The flood season onset and peak are only slightly affected but it is up to 2 months shorter and declines to about two-thirds of its present volume.

6.2. The Delta (Site 7 – Xakanaka)

Due to the declining upstream inflows into the Delta, there is a decrease in all major types of permanent swamp to as low as 22% of present under the High scenario, and an increase in seasonal swamps into these areas. Dry flood-plain savanna also expands to more than four times its present area, representing a significant drying-out of the Delta.

6.3. Delta Outflows (Site 8 – Boteti)

The Thamalakane / Boteti River system receives outflows from the Delta and is highly susceptible to changes in the flooding regime of the Delta. In addition, the length of river that is wetted by inflows in any given year depends on the volume of inflows and state of the groundwater aquifers in previous years. Flows in the system normally exhibit dry and wet cycles of many years in length. Through the scenarios the number of years it contains water would progressively decline until in the High Scenario it would be completely dry for most of the time, holding water only in the wettest years.

7. References

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APPENDIX A : ECOLOGICALLY RELEVANT FLOW STATISTICS

APPENDIX A1 : Site 1 : Capico

```
--------------------------------------------------
Capico Present Day

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/15 01:46:56 PM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.20
  Perennial: Min Dry Q factor:        2.10
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          0.07
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):            40.47
  Mean Flood Volume (Mm3):          437.10
  Dry/T1 threshold (m3/s):           15.40
  T1/Wet threshold (m3/s):           22.26

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                               22.3
Mean flood peak (m3/s)                   40.47
Mean flood vol  (Mm3):                  437.10

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        11.7
 *Dry season duration (Dd) [days]:        86.0
 *Max 5d flood season Q (Fq) [m3/s]:      38.5
 *Flood volume (Fv) [Mm3]:              455.84
 *Wet season duration (Fd) [days]:       197.0
 *T2 recession slope (T2s) [m3/s/d]:    -0.122
 *FP area of inundation (FPA) [km2]:       N/A
 *FP inundation dur (FPDi) [days]:         N/A
 *Dry season onset (Do) [cal week]:       33.0
 *Wet season onset (Fo) [cal week]:       45.0
 *FP inund onset (FPDo) [cal week]:        N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         1.5
  Dry season duration (Dd) [days]:        40.5
  Max 5d flood season Q (Fq) [m3/s]:      10.7
  Flood volume (Fv) [Mm3]:              210.04
  Wet season duration (Fd) [days]:        69.5
  T2 recession slope (T2s) [m3/s/d]:     0.045
  FP area of inundation (FPA) [km2]:       N/A
  FP inundation dur (FPDi) [days]:         N/A
  Dry season onset (Do) [cal week]:        5.5
  Wet season onset (Fo) [cal week]:       21.9
  FP inund onset (FPDo) [cal week]:        N/A
```

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--------------------------------------------------
Capico Low Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/15 01:50:37 PM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                10
Dry Season:
  Ephemeral: Mean Ann Q factor:      0.20
  Perennial: Min Dry Q factor:       2.10
Wet season crossings:
  Mean Ann Q factor:                 1.00
T2:
  Recession rate < (m3/s/d):         0.07
  Rate calculated over (days):         15
Reference thresholds:
  Mean Flood Peak (m3/s):           40.47
  Mean Flood Volume (Mm3):         437.10
  Dry/T1 threshold (m3/s):          15.40
  T1/Wet threshold (m3/s):          22.26

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                             13.9
Mean flood peak (m3/s)                 38.08
Mean flood vol  (Mm3):                253.56

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:       0.4
 *Dry season duration (Dd) [days]:     212.0
 *Max 5d flood season Q (Fq) [m3/s]:    36.0
 *Flood volume (Fv) [Mm3]:            230.74
 *Wet season duration (Fd) [days]:      97.0
 *T2 recession slope (T2s) [m3/s/d]:  -0.249
 *FP area of inundation (FPA) [km2]:     N/A
 *FP inundation dur (FPDi) [days]:       N/A
 *Dry season onset (Do) [cal week]:     22.0
 *Wet season onset (Fo) [cal week]:      5.0
 *FP inund onset (FPDo) [cal week]:      N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:       0.2
  Dry season duration (Dd) [days]:      46.9
  Max 5d flood season Q (Fq) [m3/s]:     9.9
  Flood volume (Fv) [Mm3]:            150.90
  Wet season duration (Fd) [days]:      49.6
  T2 recession slope (T2s) [m3/s/d]:   0.172
  FP area of inundation (FPA) [km2]:     N/A
  FP inundation dur (FPDi) [days]:       N/A
  Dry season onset (Do) [cal week]:      5.2
  Wet season onset (Fo) [cal week]:     18.1
  FP inund onset (FPDo) [cal week]:      N/A
```

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--------------------------------------------------
Capico Medium Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/15 01:53:25 PM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.20
  Perennial: Min Dry Q factor:        2.10
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          0.07
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):            40.47
  Mean Flood Volume (Mm3):          437.10
  Dry/T1 threshold (m3/s):           15.40
  T1/Wet threshold (m3/s):           22.26

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                               13.9
Mean flood peak (m3/s)                   38.07
Mean flood vol  (Mm3):                  253.02

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:         0.3
 *Dry season duration (Dd) [days]:       212.0
 *Max 5d flood season Q (Fq) [m3/s]:      36.0
 *Flood volume (Fv) [Mm3]:              230.62
 *Wet season duration (Fd) [days]:        97.0
 *T2 recession slope (T2s) [m3/s/d]:    -0.249
 *FP area of inundation (FPA) [km2]:       N/A
 *FP inundation dur (FPDi) [days]:         N/A
 *Dry season onset (Do) [cal week]:       22.0
 *Wet season onset (Fo) [cal week]:        5.0
 *FP inund onset (FPDo) [cal week]:        N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         0.2
  Dry season duration (Dd) [days]:        46.9
  Max 5d flood season Q (Fq) [m3/s]:       9.9
  Flood volume (Fv) [Mm3]:              151.30
  Wet season duration (Fd) [days]:        49.8
  T2 recession slope (T2s) [m3/s/d]:     0.172
  FP area of inundation (FPA) [km2]:       N/A
  FP inundation dur (FPDi) [days]:         N/A
  Dry season onset (Do) [cal week]:        5.2
  Wet season onset (Fo) [cal week]:       18.1
  FP inund onset (FPDo) [cal week]:        N/A
```

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--------------------------------------------------
Capico High Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/15 01:55:41 PM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.20
  Perennial: Min Dry Q factor:        2.10
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          0.07
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):            40.47
  Mean Flood Volume (Mm3):          437.10
  Dry/T1 threshold (m3/s):           15.40
  T1/Wet threshold (m3/s):           22.26

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                             13.9
Mean flood peak (m3/s)                 38.03
Mean flood vol  (Mm3):                251.98

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:       0.3
 *Dry season duration (Dd) [days]:     212.0
 *Max 5d flood season Q (Fq) [m3/s]:    36.0
 *Flood volume (Fv) [Mm3]:            230.35
 *Wet season duration (Fd) [days]:      97.0
 *T2 recession slope (T2s) [m3/s/d]:  -0.243
 *FP area of inundation (FPA) [km2]:     N/A
 *FP inundation dur (FPDi) [days]:       N/A
 *Dry season onset (Do) [cal week]:     22.0
 *Wet season onset (Fo) [cal week]:      5.0
 *FP inund onset (FPDo) [cal week]:      N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:       0.2
  Dry season duration (Dd) [days]:      47.2
  Max 5d flood season Q (Fq) [m3/s]:     9.9
  Flood volume (Fv) [Mm3]:            150.11
  Wet season duration (Fd) [days]:      49.3
  T2 recession slope (T2s) [m3/s/d]:   0.174
  FP area of inundation (FPA) [km2]:     N/A
  FP inundation dur (FPDi) [days]:       N/A
  Dry season onset (Do) [cal week]:      5.2
  Wet season onset (Fo) [cal week]:     18.1
  FP inund onset (FPDo) [cal week]:      N/A
```

APPENDIX A2 : Site 2 : Mucundi

```
--------------------------------------------------
Mucundi Present Day

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/07 11:35:38 AM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                10
Dry Season:
  Ephemeral: Mean Ann Q factor:      0.40
  Perennial: Min Dry Q factor:       5.00
Wet season crossings:
  Mean Ann Q factor:                 1.00
T2:
  Recession rate < (m3/s/d):         1.00
  Rate calculated over (days):         15
Reference thresholds:
  Mean Flood Peak (m3/s):          472.41
  Mean Flood Volume (Mm3):        3863.85
  Dry/T1 threshold (m3/s):          61.61
  T1/Wet threshold (m3/s):         170.47

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                              170.5
Mean flood peak (m3/s)                  472.41
Mean flood vol  (Mm3):                 3863.85

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        31.8
 *Dry season duration (Dd) [days]:        96.0
 *Max 5d flood season Q (Fq) [m3/s]:     429.2
 *Flood volume (Fv) [Mm3]:             3712.45
 *Wet season duration (Fd) [days]:       148.0
 *T2 recession slope (T2s) [m3/s/d]:    -1.658
 *FP area of inundation (FPA) [km2]:       N/A
 *FP inundation dur (FPDi) [days]:         N/A
 *Dry season onset (Do) [cal week]:       31.0
 *Wet season onset (Fo) [cal week]:       26.5
 *FP inund onset (FPDo) [cal week]:        N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         8.1
  Dry season duration (Dd) [days]:        43.0
  Max 5d flood season Q (Fq) [m3/s]:     178.6
  Flood volume (Fv) [Mm3]:             1856.11
  Wet season duration (Fd) [days]:        49.4
  T2 recession slope (T2s) [m3/s/d]:     0.261
  FP area of inundation (FPA) [km2]:       N/A
  FP inundation dur (FPDi) [days]:         N/A
  Dry season onset (Do) [cal week]:        5.1
  Wet season onset (Fo) [cal week]:       23.7
  FP inund onset (FPDo) [cal week]:        N/A
```

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--------------------------------------------------
Mucundi Low Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/07 11:37:55 AM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                10
Dry Season:
  Ephemeral: Mean Ann Q factor:      0.40
  Perennial: Min Dry Q factor:       5.00
Wet season crossings:
  Mean Ann Q factor:                 1.00
T2:
  Recession rate < (m3/s/d):         1.00
  Rate calculated over (days):         15
Reference thresholds:
  Mean Flood Peak (m3/s):          472.41
  Mean Flood Volume (Mm3):        3863.85
  Dry/T1 threshold (m3/s):          61.61
  T1/Wet threshold (m3/s):         170.47

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                            157.7
Mean flood peak (m3/s)                471.18
Mean flood vol  (Mm3):               3607.24

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:      15.5
 *Dry season duration (Dd) [days]:     124.0
 *Max 5d flood season Q (Fq) [m3/s]:   432.4
 *Flood volume (Fv) [Mm3]:           3557.81
 *Wet season duration (Fd) [days]:     135.0
 *T2 recession slope (T2s) [m3/s/d]:  -1.971
 *FP area of inundation (FPA) [km2]:     N/A
 *FP inundation dur (FPDi) [days]:       N/A
 *Dry season onset (Do) [cal week]:     28.0
 *Wet season onset (Fo) [cal week]:      5.0
 *FP inund onset (FPDo) [cal week]:      N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:       6.4
  Dry season duration (Dd) [days]:      42.9
  Max 5d flood season Q (Fq) [m3/s]:   181.5
  Flood volume (Fv) [Mm3]:           1751.55
  Wet season duration (Fd) [days]:      44.8
  T2 recession slope (T2s) [m3/s/d]:   0.273
  FP area of inundation (FPA) [km2]:     N/A
  FP inundation dur (FPDi) [days]:       N/A
  Dry season onset (Do) [cal week]:      5.0
  Wet season onset (Fo) [cal week]:     23.5
  FP inund onset (FPDo) [cal week]:      N/A
```

```
--------------------------------------------------
Mucundi Medium Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/07 11:39:10 AM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        5.00
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.00
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           472.41
  Mean Flood Volume (Mm3):         3863.85
  Dry/T1 threshold (m3/s):           61.61
  T1/Wet threshold (m3/s):          170.47

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                              144.3
Mean flood peak (m3/s)                  475.34
Mean flood vol  (Mm3):                 3287.12

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        11.6
 *Dry season duration (Dd) [days]:       143.0
 *Max 5d flood season Q (Fq) [m3/s]:     434.2
 *Flood volume (Fv) [Mm3]:             3177.74
 *Wet season duration (Fd) [days]:       123.0
 *T2 recession slope (T2s) [m3/s/d]:    -2.169
 *FP area of inundation (FPA) [km2]:       N/A
 *FP inundation dur (FPDi) [days]:         N/A
 *Dry season onset (Do) [cal week]:       27.0
 *Wet season onset (Fo) [cal week]:        4.0
 *FP inund onset (FPDo) [cal week]:        N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         4.7
  Dry season duration (Dd) [days]:        32.4
  Max 5d flood season Q (Fq) [m3/s]:     178.7
  Flood volume (Fv) [Mm3]:             1669.38
  Wet season duration (Fd) [days]:        43.4
  T2 recession slope (T2s) [m3/s/d]:     0.389
  FP area of inundation (FPA) [km2]:       N/A
  FP inundation dur (FPDi) [days]:         N/A
  Dry season onset (Do) [cal week]:        3.6
  Wet season onset (Fo) [cal week]:       19.9
  FP inund onset (FPDo) [cal week]:        N/A
```

```
--------------------------------------------------
Mucundi High Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/07 11:40:21 AM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        5.00
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.00
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           472.41
  Mean Flood Volume (Mm3):         3863.85
  Dry/T1 threshold (m3/s):           61.61
  T1/Wet threshold (m3/s):          170.47

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                              131.9
Mean flood peak (m3/s)                  457.80
Mean flood vol  (Mm3):                 2658.64

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        23.7
 *Dry season duration (Dd) [days]:       152.0
 *Max 5d flood season Q (Fq) [m3/s]:     425.8
 *Flood volume (Fv) [Mm3]:             2531.32
 *Wet season duration (Fd) [days]:       111.0
 *T2 recession slope (T2s) [m3/s/d]:    -2.074
 *FP area of inundation (FPA) [km2]:       N/A
 *FP inundation dur (FPDi) [days]:         N/A
 *Dry season onset (Do) [cal week]:       27.0
 *Wet season onset (Fo) [cal week]:        4.5
 *FP inund onset (FPDo) [cal week]:        N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         7.1
  Dry season duration (Dd) [days]:        43.1
  Max 5d flood season Q (Fq) [m3/s]:     185.3
  Flood volume (Fv) [Mm3]:             1701.93
  Wet season duration (Fd) [days]:        50.8
  T2 recession slope (T2s) [m3/s/d]:     0.265
  FP area of inundation (FPA) [km2]:       N/A
  FP inundation dur (FPDi) [days]:         N/A
  Dry season onset (Do) [cal week]:        3.7
  Wet season onset (Fo) [cal week]:       15.8
  FP inund onset (FPDo) [cal week]:        N/A
```

APPENDIX A3 : Site 3 : Cuito Cuanavale

(Note: The Low, Medium and High scenarios do not include significant development upstream of Cuito Cuanavale, hence only a Present Day summary is provided here).

```
--------------------------------------------------
Cuito Cuanavale Present Day

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/05/07 11:42:00 AM
Software:  v1.02
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        2.00
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.00
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           186.63
  Mean Flood Volume (Mm3):         1990.20
  Dry/T1 threshold (m3/s):          108.44
  T1/Wet threshold (m3/s):          120.57

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                              120.6
Mean flood peak (m3/s)                  186.63
Mean flood vol  (Mm3):                 1990.20

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        80.1
 *Dry season duration (Dd) [days]:       182.0
 *Max 5d flood season Q (Fq) [m3/s]:     163.5
 *Flood volume (Fv) [Mm3]:             1967.56
 *Wet season duration (Fd) [days]:       162.0
 *T2 recession slope (T2s) [m3/s/d]:    -0.700
 *FP area of inundation (FPA) [km2]:      1.07
 *FP inundation dur (FPDi) [days]:       144.0
 *Dry season onset (Do) [cal week]:       25.0
 *Wet season onset (Fo) [cal week]:        8.0
 *FP inund onset (FPDo) [cal week]:        5.0

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:        13.0
  Dry season duration (Dd) [days]:        92.7
  Max 5d flood season Q (Fq) [m3/s]:      66.0
  Flood volume (Fv) [Mm3]:             1331.89
  Wet season duration (Fd) [days]:        87.2
  T2 recession slope (T2s) [m3/s/d]:     1.037
  FP area of inundation (FPA) [km2]:      0.26
  FP inundation dur (FPDi) [days]:        74.2
  Dry season onset (Do) [cal week]:        9.9
  Wet season onset (Fo) [cal week]:       22.1
  FP inund onset (FPDo) [cal week]:       21.5
```

APPENDIX A4 : Site 4 : Kapako

```
--------------------------------------------------
Kapako Present Day

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 03:54:35 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                10
Dry Season:
  Ephemeral: Mean Ann Q factor:      0.40
  Perennial: Min Dry Q factor:       6.00
Wet season crossings:
  Mean Ann Q factor:                 1.00
T2:
  Recession rate < (m3/s/d):         1.00
  Rate calculated over (days):         15
Reference thresholds:
  Mean Flood Peak (m3/s):          518.90
  Mean Flood Volume (Mm3):        3800.52
  Dry/T1 threshold (m3/s):          89.05
  T1/Wet threshold (m3/s):         168.29

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                             168.3
Mean flood peak (m3/s)                 518.90
Mean flood vol  (Mm3):                3800.52

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:       35.0
 *Dry season duration (Dd) [days]:      135.0
 *Max 5d flood season Q (Fq) [m3/s]:    460.6
 *Flood volume (Fv) [Mm3]:            3693.53
 *Wet season duration (Fd) [days]:      154.0
 *T2 recession slope (T2s) [m3/s/d]:   -1.804
 *FP area of inundation (FPA) [km2]:    37.30
 *FP inundation dur (FPDi) [days]:      158.5
 *Dry season onset (Do) [cal week]:      30.0
 *Wet season onset (Fo) [cal week]:       4.0
 *FP inund onset (FPDo) [cal week]:       4.0

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:        8.6
  Dry season duration (Dd) [days]:       46.7
  Max 5d flood season Q (Fq) [m3/s]:    199.0
  Flood volume (Fv) [Mm3]:            1830.29
  Wet season duration (Fd) [days]:       49.1
  T2 recession slope (T2s) [m3/s/d]:    0.372
  FP area of inundation (FPA) [km2]:     3.64
  FP inundation dur (FPDi) [days]:       42.3
  Dry season onset (Do) [cal week]:       4.7
  Wet season onset (Fo) [cal week]:      18.6
  FP inund onset (FPDo) [cal week]:      23.0
```

```
--------------------------------------------------
Kapako Low Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 03:57:36 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        6.00
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.00
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           518.90
  Mean Flood Volume (Mm3):         3800.52
  Dry/T1 threshold (m3/s):           89.05
  T1/Wet threshold (m3/s):          168.29

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                              156.8
Mean flood peak (m3/s)                  514.11
Mean flood vol  (Mm3):                 3588.66

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        20.2
 *Dry season duration (Dd) [days]:       150.0
 *Max 5d flood season Q (Fq) [m3/s]:     455.9
 *Flood volume (Fv) [Mm3]:             3535.06
 *Wet season duration (Fd) [days]:       147.0
 *T2 recession slope (T2s) [m3/s/d]:    -2.207
 *FP area of inundation (FPA) [km2]:     37.25
 *FP inundation dur (FPDi) [days]:       149.5
 *Dry season onset (Do) [cal week]:       28.0
 *Wet season onset (Fo) [cal week]:        4.0
 *FP inund onset (FPDo) [cal week]:        4.0

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         7.3
  Dry season duration (Dd) [days]:        45.2
  Max 5d flood season Q (Fq) [m3/s]:     198.4
  Flood volume (Fv) [Mm3]:             1749.68
  Wet season duration (Fd) [days]:        45.5
  T2 recession slope (T2s) [m3/s/d]:     0.454
  FP area of inundation (FPA) [km2]:      3.72
  FP inundation dur (FPDi) [days]:        40.2
  Dry season onset (Do) [cal week]:        4.9
  Wet season onset (Fo) [cal week]:       15.4
  FP inund onset (FPDo) [cal week]:       22.0
```

```
--------------------------------------------------
Kapako Medium Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 04:00:50 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        6.00
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.00
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           518.90
  Mean Flood Volume (Mm3):         3800.52
  Dry/T1 threshold (m3/s):           89.05
  T1/Wet threshold (m3/s):          168.29

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                             144.8
Mean flood peak (m3/s)                 504.79
Mean flood vol  (Mm3):                3270.22

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:       15.4
 *Dry season duration (Dd) [days]:      168.0
 *Max 5d flood season Q (Fq) [m3/s]:    455.5
 *Flood volume (Fv) [Mm3]:            3209.08
 *Wet season duration (Fd) [days]:      130.0
 *T2 recession slope (T2s) [m3/s/d]:   -2.370
 *FP area of inundation (FPA) [km2]:    37.20
 *FP inundation dur (FPDi) [days]:      134.5
 *Dry season onset (Do) [cal week]:      27.0
 *Wet season onset (Fo) [cal week]:       3.5
 *FP inund onset (FPDo) [cal week]:       4.0

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:        5.5
  Dry season duration (Dd) [days]:       41.4
  Max 5d flood season Q (Fq) [m3/s]:    198.0
  Flood volume (Fv) [Mm3]:            1660.50
  Wet season duration (Fd) [days]:       42.8
  T2 recession slope (T2s) [m3/s/d]:    0.515
  FP area of inundation (FPA) [km2]:     3.86
  FP inundation dur (FPDi) [days]:       38.6
  Dry season onset (Do) [cal week]:       4.6
  Wet season onset (Fo) [cal week]:      11.8
  FP inund onset (FPDo) [cal week]:      15.4
```

```
--------------------------------------------------
Kapako High Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 04:05:14 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                  10
Dry Season:
  Ephemeral: Mean Ann Q factor:        0.40
  Perennial: Min Dry Q factor:         6.00
Wet season crossings:
  Mean Ann Q factor:                   1.00
T2:
  Recession rate < (m3/s/d):           1.00
  Rate calculated over (days):           15
Reference thresholds:
  Mean Flood Peak (m3/s):            518.90
  Mean Flood Volume (Mm3):          3800.52
  Dry/T1 threshold (m3/s):            89.05
  T1/Wet threshold (m3/s):           168.29

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                               135.0
Mean flood peak (m3/s)                   491.90
Mean flood vol  (Mm3):                  2704.10

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        19.1
 *Dry season duration (Dd) [days]:       176.0
 *Max 5d flood season Q (Fq) [m3/s]:     441.6
 *Flood volume (Fv) [Mm3]:             2580.08
 *Wet season duration (Fd) [days]:       117.0
 *T2 recession slope (T2s) [m3/s/d]:    -2.143
 *FP area of inundation (FPA) [km2]:     36.04
 *FP inundation dur (FPDi) [days]:       120.5
 *Dry season onset (Do) [cal week]:       27.0
 *Wet season onset (Fo) [cal week]:        5.0
 *FP inund onset (FPDo) [cal week]:        4.0

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         8.7
  Dry season duration (Dd) [days]:        47.1
  Max 5d flood season Q (Fq) [m3/s]:     200.7
  Flood volume (Fv) [Mm3]:             1727.04
  Wet season duration (Fd) [days]:        52.1
  T2 recession slope (T2s) [m3/s/d]:     0.594
  FP area of inundation (FPA) [km2]:      4.22
  FP inundation dur (FPDi) [days]:        50.5
  Dry season onset (Do) [cal week]:        5.1
  Wet season onset (Fo) [cal week]:       12.0
  FP inund onset (FPDo) [cal week]:       12.0
```

APPENDIX A5 : Sites 5 an 6 : Popa Falls and Panhandle

```
--------------------------------------------------
Popa Present Day

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 04:23:14 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        2.10
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.20
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           697.89
  Mean Flood Volume (Mm3):         5737.14
  Dry/T1 threshold (m3/s):          167.79
  T1/Wet threshold (m3/s):          289.09

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                              289.1
Mean flood peak (m3/s)                  697.89
Mean flood vol  (Mm3):                 5737.14

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:       113.9
 *Dry season duration (Dd) [days]:       115.0
 *Max 5d flood season Q (Fq) [m3/s]:     624.8
 *Flood volume (Fv) [Mm3]:             5269.15
 *Wet season duration (Fd) [days]:       150.0
 *T2 recession slope (T2s) [m3/s/d]:    -1.877
 *FP area of inundation (FPA) [km2]:       N/A
 *FP inundation dur (FPDi) [days]:         N/A
 *Dry season onset (Do) [cal week]:       33.0
 *Wet season onset (Fo) [cal week]:        3.0
 *FP inund onset (FPDo) [cal week]:        N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:        18.5
  Dry season duration (Dd) [days]:        42.1
  Max 5d flood season Q (Fq) [m3/s]:     255.9
  Flood volume (Fv) [Mm3]:             2750.45
  Wet season duration (Fd) [days]:        47.5
  T2 recession slope (T2s) [m3/s/d]:     0.260
  FP area of inundation (FPA) [km2]:       N/A
  FP inundation dur (FPDi) [days]:         N/A
  Dry season onset (Do) [cal week]:        3.9
  Wet season onset (Fo) [cal week]:       13.7
  FP inund onset (FPDo) [cal week]:        N/A
```

```
--------------------------------------------------
Popa Low Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 04:30:57 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                  10
Dry Season:
  Ephemeral: Mean Ann Q factor:        0.40
  Perennial: Min Dry Q factor:         2.10
Wet season crossings:
  Mean Ann Q factor:                   1.00
T2:
  Recession rate < (m3/s/d):           1.20
  Rate calculated over (days):           15
Reference thresholds:
  Mean Flood Peak (m3/s):            697.89
  Mean Flood Volume (Mm3):          5737.14
  Dry/T1 threshold (m3/s):           167.79
  T1/Wet threshold (m3/s):           289.09

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                               278.2
Mean flood peak (m3/s)                   693.61
Mean flood vol  (Mm3):                  5498.58

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:        101.3
 *Dry season duration (Dd) [days]:        130.0
 *Max 5d flood season Q (Fq) [m3/s]:      622.8
 *Flood volume (Fv) [Mm3]:              4980.77
 *Wet season duration (Fd) [days]:        143.0
 *T2 recession slope (T2s) [m3/s/d]:     -2.112
 *FP area of inundation (FPA) [km2]:        N/A
 *FP inundation dur (FPDi) [days]:          N/A
 *Dry season onset (Do) [cal week]:        31.0
 *Wet season onset (Fo) [cal week]:         3.5
 *FP inund onset (FPDo) [cal week]:         N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         17.1
  Dry season duration (Dd) [days]:         41.2
  Max 5d flood season Q (Fq) [m3/s]:      256.0
  Flood volume (Fv) [Mm3]:              2679.00
  Wet season duration (Fd) [days]:         45.7
  T2 recession slope (T2s) [m3/s/d]:      0.313
  FP area of inundation (FPA) [km2]:        N/A
  FP inundation dur (FPDi) [days]:          N/A
  Dry season onset (Do) [cal week]:         4.3
  Wet season onset (Fo) [cal week]:        13.6
  FP inund onset (FPDo) [cal week]:         N/A
```

```
--------------------------------------------------
Popa Medium Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 04:33:53 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                  10
Dry Season:
  Ephemeral: Mean Ann Q factor:        0.40
  Perennial: Min Dry Q factor:         2.10
Wet season crossings:
  Mean Ann Q factor:                   1.00
T2:
  Recession rate < (m3/s/d):           1.20
  Rate calculated over (days):           15
Reference thresholds:
  Mean Flood Peak (m3/s):            697.89
  Mean Flood Volume (Mm3):          5737.14
  Dry/T1 threshold (m3/s):           167.79
  T1/Wet threshold (m3/s):           289.09

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                               263.0
Mean flood peak (m3/s)                   681.27
Mean flood vol  (Mm3):                  5012.48

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:         92.5
 *Dry season duration (Dd) [days]:        145.0
 *Max 5d flood season Q (Fq) [m3/s]:      613.3
 *Flood volume (Fv) [Mm3]:              4450.10
 *Wet season duration (Fd) [days]:        129.0
 *T2 recession slope (T2s) [m3/s/d]:     -2.149
 *FP area of inundation (FPA) [km2]:        N/A
 *FP inundation dur (FPDi) [days]:          N/A
 *Dry season onset (Do) [cal week]:        30.0
 *Wet season onset (Fo) [cal week]:         4.0
 *FP inund onset (FPDo) [cal week]:         N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:         15.3
  Dry season duration (Dd) [days]:         42.7
  Max 5d flood season Q (Fq) [m3/s]:      256.0
  Flood volume (Fv) [Mm3]:              2618.76
  Wet season duration (Fd) [days]:         45.8
  T2 recession slope (T2s) [m3/s/d]:      0.536
  FP area of inundation (FPA) [km2]:        N/A
  FP inundation dur (FPDi) [days]:          N/A
  Dry season onset (Do) [cal week]:         4.6
  Wet season onset (Fo) [cal week]:        11.7
  FP inund onset (FPDo) [cal week]:         N/A
```

```
--------------------------------------------------
Popa High Development

SUMMARY HYDROLOGICAL DATA

--------------------------------------------------
DateTime:  2009/06/04 04:36:31 PM
Software:  v1.03
--------------------------------------------------

PARAMETERS:

Hydro year start month:                 10
Dry Season:
  Ephemeral: Mean Ann Q factor:       0.40
  Perennial: Min Dry Q factor:        2.10
Wet season crossings:
  Mean Ann Q factor:                  1.00
T2:
  Recession rate < (m3/s/d):          1.20
  Rate calculated over (days):          15
Reference thresholds:
  Mean Flood Peak (m3/s):           697.89
  Mean Flood Volume (Mm3):         5737.14
  Dry/T1 threshold (m3/s):          167.79
  T1/Wet threshold (m3/s):          289.09

--------------------------------------------------

SUMMARY STATISTICS:

--------------------------------------------------

Do: Dry Season Onset (cal week)

MAR (m3/s):                             203.4
Mean flood peak (m3/s)                 648.66
Mean flood vol  (Mm3):                3809.54

Median(*) / Mode(+) values:
 *Min 5d dry season Q (Dq) [m3/s]:       21.1
 *Dry season duration (Dd) [days]:      193.0
 *Max 5d flood season Q (Fq) [m3/s]:    578.0
 *Flood volume (Fv) [Mm3]:            3294.28
 *Wet season duration (Fd) [days]:      103.0
 *T2 recession slope (T2s) [m3/s/d]:   -3.171
 *FP area of inundation (FPA) [km2]:      N/A
 *FP inundation dur (FPDi) [days]:        N/A
 *Dry season onset (Do) [cal week]:      26.0
 *Wet season onset (Fo) [cal week]:       5.0
 *FP inund onset (FPDo) [cal week]:       N/A

Standard deviations:
  Min 5d dry season Q (Dq) [m3/s]:       11.9
  Dry season duration (Dd) [days]:       42.9
  Max 5d flood season Q (Fq) [m3/s]:    263.0
  Flood volume (Fv) [Mm3]:            2486.67
  Wet season duration (Fd) [days]:       46.5
  T2 recession slope (T2s) [m3/s/d]:    1.058
  FP area of inundation (FPA) [km2]:      N/A
  FP inundation dur (FPDi) [days]:        N/A
  Dry season onset (Do) [cal week]:       5.0
  Wet season onset (Fo) [cal week]:      12.4
  FP inund onset (FPDo) [cal week]:       N/A
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The Okavango River Basin Transboundary Diagnostic Analysis Technical Reports

In 1994, the three riparian countries of the Okavango River Basin – Angola, Botswana and Namibia – agreed to plan for collaborative management of the natural resources of the Okavango, forming the Permanent Okavango River Basin Water Commission (OKACOM). In 2003, with funding from the Global Environment Facility, OKACOM launched the Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project to coordinate development and to anticipate and address threats to the river and the associated communities and environment. Implemented by the United Nations Development Program and executed by the United Nations Food and Agriculture Organization, the project produced the Transboundary Diagnostic Analysis to establish a base of available scientific evidence to guide future decision making. The study, created from inputs from multi-disciplinary teams in each country, with specialists in hydrology, hydraulics, channel form, water quality, vegetation, aquatic invertebrates, fish, birds, river-dependent terrestrial wildlife, resource economics and socio-cultural issues, was coordinated and managed by a group of specialists from the southern African region in 2008 and 2009.

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

Final Study Reports	***Reports integrating findings from all country and background reports, and covering the entire basin.***		
		Aylward, B.	*Economic Valuation of Basin Resources: Final Report to EPSMO Project of the UN Food & Agriculture Organization as an Input to the Okavango River Basin Transboundary Diagnostic Analysis*
		Barnes, J. et al.	*Okavango River Basin Transboundary Diagnostic Analysis: Socio-Economic Assessment Final Report*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Project Initiation Report (Report No: 01/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment EFA Process Report (Report No: 02/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Guidelines for Data Collection, Analysis and Scenario Creation (Report No: 03/2009)*
		Bethune, S. Mazvimavi, D. and Quintino, M.	*Okavango River Basin Environmental Flow Assessment Delineation Report (Report No: 04/2009)*
		Beuster, H.	*Okavango River Basin Environmental Flow Assessment Hydrology Report: Data And Models(Report No: 05/2009)*
		Beuster, H.	*Okavango River Basin Environmental Flow Assessment Scenario Report : Hydrology (Report No: 06/2009)*
		Jones, M.J.	*The Groundwater Hydrology of The Okavango Basin (FAO Internal Report, April 2010)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 1 of 4)(Report No. 07/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 2 of 4: Indicator results) (Report No. 07/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions: Climate Change Scenarios (Volume 3 of 4) (Report No. 07/2009)*
		King, J., Brown, C.A., Joubert, A.R. and Barnes, J.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Biophysical Predictions (Volume 4 of 4: Climate Change Indicator Results) (Report No: 07/2009)*
		King, J., Brown, C.A. and Barnes, J.	*Okavango River Basin Environmental Flow Assessment Project Final Report (Report No: 08/2009)*
		Malzbender, D.	*Environmental Protection And Sustainable Management Of The Okavango River Basin (EPSMO): Governance Review*
		Vanderpost, C. and Dhliwayo, M.	*Database and GIS design for an expanded Okavango Basin Information System (OBIS)*
		Veríssimo, Luis	*GIS Database for the Environment Protection and Sustainable Management of the Okavango River Basin Project*

		Wolski, P.	*Assessment of hydrological effects of climate change in the Okavango Basin*
Country Reports Biophysical Series	***Angola***	*Andrade e Sousa, Helder André de*	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Sedimentologia & Geomorfologia*
		Gomes, Amândio	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Vegetação*
		Gomes, Amândio	*Análise Técnica, Biofísica e Socio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final:Vegetação da Parte Angolana da Bacia Hidrográfica Do Rio Cubango*
		Livramento, Filomena	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina:Macroinvertebrados*
		Miguel, Gabriel Luís	*Análise Técnica, Biofísica E Sócio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Subsídio Para o Conhecimento Hidrogeológico Relatório de Hidrogeologia*
		Morais, Miguel	*Análise Diagnóstica Transfronteiriça da Bacia do Análise Rio Cubango (Okavango): Módulo da Avaliação do Caudal Ambiental: Relatório do Especialista País: Angola Disciplina: Ictiofauna*
		Morais, Miguel	*Análise Técnica, Bióфisica e Sócio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final: Peixes e Pesca Fluvial da Bacia do Okavango em Angola*
		Pereira, Maria João	*Qualidade da Água, no Lado Angolano da Bacia Hidrográfica do Rio Cubango*
		Santos, Carmen Ivelize Van-Dúnem S. N.	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório de Especialidade: Angola: Vida Selvagem*
		Santos, Carmen Ivelize Van-Dúnem S.N.	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango:Módulo Avaliação do Caudal Ambiental: Relatório de Especialidade: Angola: Aves*
	Botswana	*Bonyongo, M.C.*	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Wildlife*
		Hancock, P.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report: Country: Botswana: Discipline: Birds*
		Mosepele, K.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Fish*
		Mosepele, B. and Dallas, Helen	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Aquatic Macro Invertebrates*
	Namibia	*Collin Christian & Associates CC*	*Okavango River Basin: Transboundary Diagnostic Analysis Project: Environmental Flow Assessment Module: Geomorphology*
		Curtis, B.A.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report Country: Namibia Discipline: Vegetation*
		Bethune, S.	*Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO): Transboundary Diagnostic Analysis: Basin Ecosystems Report*
		Nakanwe, S.N.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Aquatic Macro Invertebrates*
		Paxton, M.	*Okavango River Basin Transboundary Diagnostic Analysis: Environmental Flow Module: Specialist Report:Country:Namibia: Discipline: Birds (Avifauna)*
		Roberts, K.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Wildlife*
		Waal, B.V.	*Okavango River Basin Technical Diagnostic Analysis:*

			Environmental Flow Module: Specialist Report: Country: Namibia:Discipline: Fish Life
Country Reports Socioeconomic Series	***Angola***	*Gomes, Joaquim Duarte*	*Análise Técnica dos Aspectos Relacionados com o Potencial de Irrigação no Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final*
		Mendelsohn, .J.	*Land use in Kavango: Past, Present and Future*
		Pereira, Maria João	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Qualidade da Água*
		Saraiva, Rute et al.	*Diagnóstico Transfronteiriço Bacia do Okavango: Análise Socioeconómica Angola*
	Botswana	*Chimbari, M. and Magole, Lapologang*	*Okavango River Basin Trans-Boundary Diagnostic Assessment (TDA): Botswana Component: Partial Report: Key Public Health Issues in the Okavango Basin, Botswana*
		Magole, Lapologang	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Land Use Planning*
		Magole, Lapologang	*Transboundary Diagnostic Analysis (TDA) of the Botswana p Portion of the Okavango River Basin: Stakeholder Involvement in the ODMP and its Relevance to the TDA Process*
		Masamba, W.R.	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Output 4: Water Supply and Sanitation*
		Masamba,W.R.	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Irrigation Development*
		Mbaiwa.J.E.	*Transboundary Diagnostic Analysis of the Okavango River Basin: the Status of Tourism Development in the Okavango Delta: Botswana*
		Mbaiwa.J.E. & Mmopelwa, G.	*Assessing the Impact of Climate Change on Tourism Activities and their Economic Benefits in the Okavango Delta*
		Mmopelwa, G.	*Okavango River Basin Trans-boundary Diagnostic Assessment: Botswana Component: Output 5: Socio-Economic Profile*
		Ngwenya, B.N.	*Final Report: A Socio-Economic Profile of River Resources and HIV and AIDS in the Okavango Basin: Botswana*
		Vanderpost, C.	*Assessment of Existing Social Services and Projected Growth in the Context of the Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin*
	Namibia	*Barnes, J and Wamunyima, D*	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Socio-economics*
		Collin Christian & Associates CC	*Technical Report on Hydro-electric Power Development in the Namibian Section of the Okavango River Basin*
		Liebenberg, J.P.	*Technical Report on Irrigation Development in the Namibia Section of the Okavango River Basin*
		Ortmann, Cynthia L.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report Country: Namibia: discipline: Water Quality*
		Nashipili, Ndinomwaameni	*Okavango River Basin Technical Diagnostic Analysis: Specialist Report: Country: Namibia: Discipline: Water Supply and Sanitation*
		Paxton, C.	*Transboundary Diagnostic Analysis: Specialist Report: Discipline: Water Quality Requirements For Human Health in the Okavango River Basin: Country: Namibia*

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Environmental protection and sustainable management of the Okavango River Basin

EPSMO

Boteti River shoreline, Botswana

Republic of Botswana

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