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OKACOM

The Permanent Okavango River Basin Water Commission

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List of reports in report series

Report 01/2009: Project Initiation Report
Report 02/2009: Process Report
Report 03/2009: Guidelines for data collection, analysis and scenario creation
Report 04/2009: Delineation Report
Report 05/2009: Hydrology Report: Data and models
Report 06/2009: Scenario Report: Hydrology (2 volumes)
Report 07/2009: Scenario Report: Ecological and social predictions (4 volumes)
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EXECUTIVE SUMMARY

The Okavango River Basin Commission, OKACOM, initiated a project titled the Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO). This was approved by the United Nations Development Program (UNDP), to be executed by the United Nations Food and Agriculture Organization (FAO). The standard UNDP process is a Transboundary Diagnostic Analysis followed by a Strategic Action Programme of joint management to address threats to the basin's linked land and water systems. Because of the pristine nature of the Okavango River, this approach was modified to include an Environmental Flow Assessment (EFA). To complete the EFA, EPSMO collaborated with the BIOKAVANGO Project at the Harry Oppenheimer Okavango Research Centre of the University of Botswana, in 2008 to conduct a basin-wide EFA for the Okavango River system.

This is report number 8 in the report series for the EFA. It outlines the full project and summarises the main hydrological, biophysical, social and macroeconomic findings, including those linked to climate change.

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Acronyms and abbreviations

DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
EFA	Environmental Flow Assessment
EPSMO	Environmental Protection and Sustainable Management of the Okavango River Basin
Ha	hectare
HOORC	Harry Oppenheimer Okavango Research Centre
IFA	Integrated Flow Assessment
IUA	Integrated Units of Analysis
MAR	Mean Annual Runoff
Mcm	Millions of cubic metres
OBSC	Okavango Basic Steering Committee
OKACOM	Okavango River Basin Water Commission
PD	Present day
SADC	Southern African Development Community
SAP	Strategic Action Programme
TDA	Transboundary Diagnostic Analysis

1. Background

The riparian countries to the Okavango River Basin, Angola, Botswana and Namibia, formed the Permanent Okavango River Basin Water Commission (OKACOM) in 1994. OKACOM was required to develop criteria for conservation, equitable allocation and sustainable utilisation of water within this basin. The environment is now regarded as a legitimate water user and therefore OKACOM needs information on the water needs for maintenance of the river ecosystems when preparing criteria for conservation, equitable allocation and sustainable utilization of water. The Southern African Development Community (SADC), of which the three riparian countries are members, adopted a SADC Water Policy that calls upon member countries to allocate adequate water for maintaining ecosystem integrity. The Revised SADC Protocol on Shared Watercourse Systems requires that member countries should aim to achieve a balance between water development and protection of the environment. Future developments within the Okavango River Basin have the potential to affect the integrity of the river ecosystem as well as human livelihoods and wellbeing that are supported by this river. Therefore, the three riparian countries require information about the links between basin development and ecosystem health to aid their discussions on acceptable future development pathways.

An Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project is being implemented, with one of the activities being to carry out a Transboundary Diagnostic Analysis (TDA) for the purpose of developing a Strategic Action Programme. The TDA is an analysis of current and future possible causes of transboundary problems. The Okavango Basic Steering Committee (OBSC) of OKACOM noted during the March 2008 meeting in Windhoek, Namibia, that future transboundary problems 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 possible future developments. This meeting recommended that an Environmental Flow Assessment (EFA) be carried out to provide information about the effects of possible future developments on the flow regime of the Okavango River and on the related physico-chemical, ecological and socioeconomic attributes of the system. In this project, the EFA was upgraded into an Integrated Flow Assessment (IFA), which aims to develop a comprehensive set of descriptions of the potential impacts of water-resource development. IFAs reflect more recent thinking on the role of such work in water-resource planning (King and Brown in press) and the term is used throughout this document.

The Biokavango Project, whose goal is to mainstream biodiversity management into the three main production sectors of water management, tourism and fishery, is being implemented on the Okavango Delta. An IFA will improve an understanding of hydro-ecological relationships in the Delta, which is necessary for biodiversity management. The EPSMO and Biokavango Projects are therefore cooperating in carrying out an IFA for the Okavango River basin. The aim of the IFA is to provide predictions of ecological, social and economic change resulting from potential water-resource developments in the basin, as a basis for intra- and inter-country discussions on a future basin development pathway.

This is the final report in the IFA series of reports.

2. The IFA process

The IFA team comprised of:

- The Project Managers from EPSMO and BIOKAVANGO
- The Team Coordinators for Angola, Namibia and Botswana
- Hydrological, biophysical and social specialists from each country
- An international EF process management team
- Support staff for, for instance, GIS.

The full team is listed at the beginning of all documents and the national specialists responsible for each discipline are shown in Table 2.1.

Table 2.1 Specialists responsible for each discipline in the IFA

Discipline	Specialist
Geomorphology	Angola: Helder André de Andrade e Sousa Namibia: Colin Christian Botswana: none
Water quality	Angola: Maria João M. Pereira Namibia: Cynthia Ortmann Botswana: Wellington R.L. Masamba
Vegetation	Angola: Amândio Gomes Namibia: Barbara Curtis Botswana: Casper Bonyongo
Aquatic invertebrates	Angola: Filomena Livramento Namibia: Shishani Namutenya Nakanwe Botswana: Belda Q. Mosepele
Fish	Angola: Miguel Morais Namibia: Ben van der Waal Botswana: Keta Mosepele
Water birds	Angola: Carmen Ivelize Van-Dúnem S.N. Santos Namibia: Mark Paxton Botswana: Pete Hancock
Terrestrial wildlife	Angola: Carmen Ivelize Van-Dúnem S.N. Santos Namibia: Kevin Roberts Botswana: Casper Bonyongo
Social/resource economics	Angola: Rute Saraiva Namibia: Dorothy Wamunyima Botswana: Goitseope Mmopelwa

There were five main aims to the IFA:

1. synthesise present knowledge on the river ecosystem;
2. synthesise present knowledge on how people use the river;
3. predict how the river could change with water-resource development
4. predict how these river changes could affect people and countries
5. predict how climate change could affect items 3 and 4.

To achieve these aims, 12 main activities were completed over the period July 2008 to October 2009 (Table 2.2), in five main streams of activities. These activities are reported on in detail in the IFA series of reports and described briefly below. A set of meetings brought various parts of the team together at key points in the process (Table 2.3).

Table 2.2 The 12 main activities of the IFA as detailed in the IFA report series

IFA activity	Comment
Appoint teams	A full multi-disciplinary team was appointed in each country, with specialists in hydrology, hydraulics, channel form, water quality, vegetation, aquatic invertebrates, fish, water birds, river-dependent terrestrial wildlife, resource economics, and social and cultural issues. An international team managed the IFA process.
Delineate basin	The basin was divided into homogenous units (Integrated Units of Analysis – IUAs) so that data and knowledge for any one site could be extrapolated over a wider area.
Collate and synthesis hydrological data	The known hydrological data for the basin were gathered as calibration data for the hydrological models.
Identify scenarios	The three governments decided on which three water-resource development scenarios they wished to consider: low, medium and high water-use.
Select representative sites	A representative site was chosen in each of the eight most important IUAs as the focal point for data collection and interpretation.
Select discipline indicators	Biophysical indicators (river attributes that could change with flow change) and socio-economic indicators (social attributes that could change with river change) were jointly chosen by the country teams.
Collect data	The country teams collected and synthesised all known data on the indicators, working in basin-wide discipline groups, and carried out new research as the project allowed.
Write specialist reports and review	The specialists wrote reports of their findings and described the flow-river ecosystem relationships, and the river-social wellbeing relationships.
Set-up, populate and calibrate the Decision Support System (DSS)	These relationships were captured in a custom-built Decision Support System (DSS).
Analyse scenarios and write Scenario Report	The hydrological team simulated the changes in flow at the eight representative sites under each scenario. The DSS was then queried to predict how these flow changes would impact the indicators chosen to represent the river ecosystem and the peoples' social structures. The predictions were assessed and approved by the full EF team.
Climate change assessment	As an addendum to the project, four climate change (CC) scenarios were developed showing predicted impacts of the driest and wettest CC model predictions on the low and medium scenarios.
Integrate findings in TDA Report.	All of these predictions formed part of the TDA report.

The first stream of activities involved the specialist biophysical and social teams. After appointment, they participated in a joint activity to divide the basin into homogeneous biophysical and social units; harmonise these into a short series of Integrated Units of Analysis; and choose a representative study site/area in each to be used as the focus in the investigations and analyses (Table 2.4; Figure 2.1). The specialists then worked in discipline groups to identify a number of indicators that represented variables that they felt could change with flow changes. These indicators formed the focus for site visits, data collection, literature reviews and analysis over the time period October 2008 to March 2009, culminating in the writing of specialist reports: one per discipline per country, with each specialist focusing on the representative sites/areas in her/his country.

Table 2.3 Key meetings and other team activities in the IFA

Date	Meeting	Location
July 2008	Planning Meeting	Pretoria, South Africa
September 2008	Delineation Workshop	Maun, Botswana
October 2008	Field trip to each of the eight EF sites	Angola, Namibia, Botswana
November 2008	EPSMO and OBSC planning meeting	Maun, Botswana
December 2008	Hydrological Model familiarisation and training	Maun, Botswana
January 2009	Basin hydrological modelling	Maun, Botswana
February 2009	Liaison meeting with Angolan specialists: TDA meeting	Luanda, Angola
March/April 2009	Knowledge Capture Workshop	Windhoek, Namibia
April 2009	Okavango Delta Modelling Workshop	Gaborone, Botswana
June 2009	Scenario Workshop	Cape Town, South Africa
August 2009	IFA output incorporated into TDA document	Gobabeb, Namibia
October 2009	Climate change scenarios added	Cape Town, South Africa

Table 2.4 The eight sites chosen for the IFA

IFA Site No	Country	River	Location	Coordinates
1	Angola	Cuebe	Capico	15° 33’ 05” S 17° 34’ 00” E
2	Angola	Cubango	Mucundi	16° 13’ 05” S 17° 41’ 00” E
3	Angola	Cutio	Cuito Cuanavale	15° 10’ 11” S 19° 10’ 06” E
4	Namibia	Okavango	Kapako	17° 49’ 07” S 19° 11’ 44” E
5	Namibia	Okavango	Popa Falls	18° 07’ 02” S 21° 35’ 03” E
6	Botswana	Okavango	Panhandle at Shakawe	18° 21’ 16” S 21° 50’ 13” E
7	Botswana	Khwai	Xakanaka in Delta	19° 11’ 09” S 23° 24’ 48” E
8	Botswana	Boteti	Chanoga (road bridge)	20° 12’ 51” S 24° 07’ 37” E

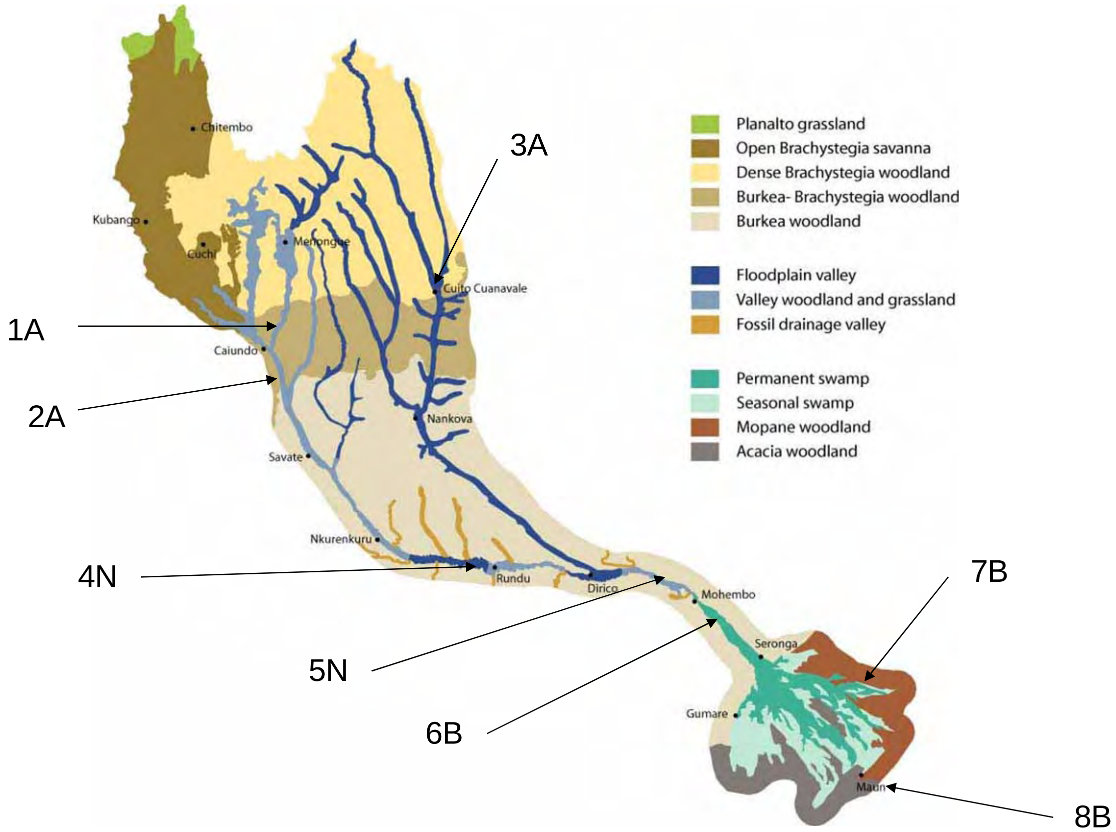

Figure 2.1 Location of the eight representative sites for the IFA: three in Angola (marked A), two in Namibia (N) and three in Botswana (B).

The second stream of activities consisted of discussions between the countries, project members and OKACOM on what development scenarios should be used in the study, and whether they should describe increasing levels of overall water-use or each focus on a sector (e.g. maximising agriculture; maximising hydropower generation, and so on). The discussions resulted in agreement that three scenarios of increasing water use would be chosen – called in this project Low, Medium and High Water-use Development – plus a fourth scenario representing present-day conditions.

The third stream of activities involved a hydrological team consisting of the International basin hydrologist and hydrologists from each of the three riparian countries. They collated and synthesised hydrological data for the whole basin and assessed hydrological models in terms of their suitability for use in the project. They then set up the models and simulated flow regimes at the chosen sites for the chosen development scenarios (Report 06 volume 1).

The fourth stream of activities was the development and configuration of the Decision Support System (DSS) software and the capturing of specialists' knowledge. After the database was prepared, simulated flow regimes prepared by the hydrological team were entered into the DSS, which used its knowledge base (from the specialists) to output predictions of ecosystem change and social impact (Report 07 volumes 1 and 2). These predictions of change were assessed and approved by the full IFA team in a Scenario Meeting in June 2009 (Table 2.3).

The fifth stream of activities, addressing climate change, was added to the project later. Dr Piotr Wolski of HOORC used widely recognised climate-change models to provide a series of predictions of possible climate change. Mr Hans Beuster, the basin hydrologist on the team, used the wettest and driest predictions to create for four new flow regimes that formed the basis of four new scenarios:

1. Low water-resource development under driest CC predictions
2. Low water-resource development under wettest CC predictions
3. Medium water-resource development under driest CC predictions
4. Medium water-resource development under wettest CC predictions.

This process and the resulting simulated hydrological data for these four scenarios are described in Report 06 (volume 2). The DSS team in Cape Town inputted these hydrological predictions into the DSS to produce predictions of the social and ecological impacts of climate change (Report 07 volumes 3 and 4).

The full suite of IFA Process Reports (Table 2.5) and the national specialist reports (Table 2.1) are housed on the project ftp site.

Table 2.5 The IFA Process series of reports, including those dealing with climate change, and other deliverables for the Okavango Basin TDA. CC = climate change

Report No. and Name	Title
Report 01/2009	Project Initiation Report
Report 02/2009	Process Report
Report 03/2009	Guidelines for data collection, analysis and scenario creation
Report 04/2009	Delineation Report
Report 05/2009	Hydrology Report: Data and models
Report 06/2009	Scenario Report: Hydrology (1 volume + 1 CC volume)
Report 07/2009	Scenario Report: Ecological and social predictions (2 volumes + 2 CC volumes)
Report 08/2009	Final Report
DSS Software	DSS for the EPSMO-Biokavango Integrated Flow Assessment
PowerPoint files	Process Management Team presentations

In summary, the original scenario predictions produced by the DSS and approved by the team were written up as Reports 06 (volume 1) and 07 (volumes 1 and 2) in the IFA Report series (Table 2.5). The climate change predictions are detailed in Reports 06 (volume 2) and 07 (volumes 3 and 4). The main scenario findings are summarised in Sections 3 and 4 of this report.

The DSS outputs described the largely negative impacts of water-resource development on the river ecosystem and its subsistence users. Development also brings positive impacts, perhaps in terms of national economies or peoples' incomes and health. In order to provide a balanced prediction of the outcome of water-resource development, a parallel macro-economic assessment of the three development scenarios was completed and is reported on in the TDA. Together, the IFA and macro-economic assessments outline the predicted consequences of development in terms of the three pillars of sustainable development: ecological integrity, economic wealth and social justice (Figure 2.2).

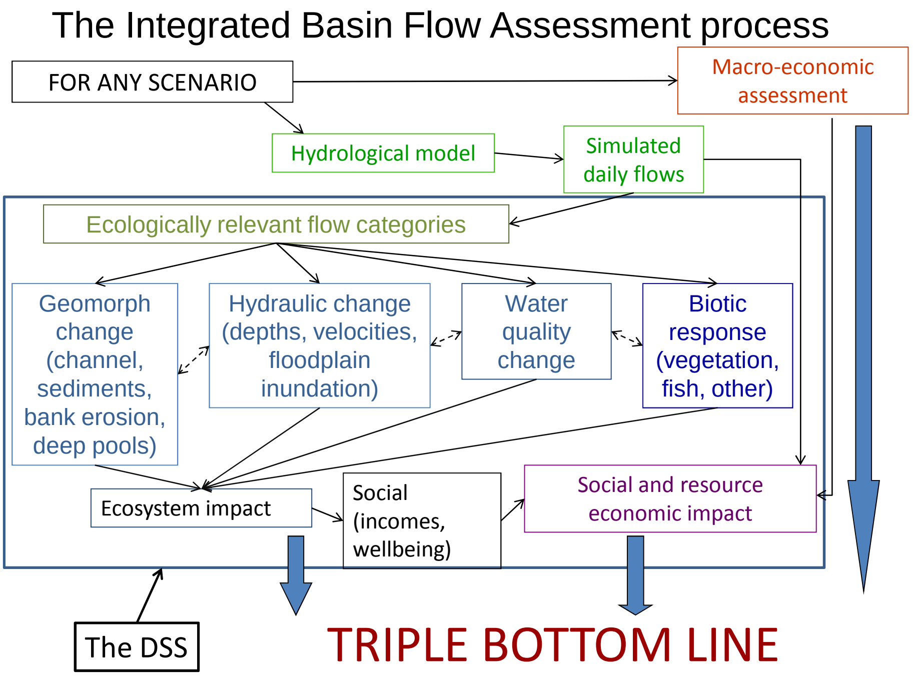

Figure 2.2 **The IFA process showing the outputs and the linked macro-economic assessment that together provide three streams of information representing the three pillars of sustainable development.**

3. Preparing the scenarios – flow analyses

The water-use development and accompanying climate-change scenarios chosen (Table 2.2) formed the basis of the IFA analysis of how the flow regime of the Okavango River could change, and the consequences that this could have. These scenarios do not describe a future that will happen, but rather capture a range of possible futures based on present trends in the basin and in climate. These hypothetical pathways into the future are created by a) inserting possible water-resource developments and climate change (e.g. dams, irrigation schemes) into the basin hydrological model, b) simulating the changes that these would cause to the river's flow regime, c) converting these simulated data into ecologically-useful summary statistics and inputting these into the Okavango Basin DSS, d) using the DSS to predict the ecological and social consequences, and e) linking these to the macro-economic analyses for each scenario. These steps are explained further below.

3.1. The developments inserted into the hydrological models

The hypothetical developments inserted into the basin hydrological model are summarised in Table 4.1 of Report 07 (volume 1) in the EFlows Report Series (Scenario Report: Ecological and social predictions). In summary, a limited number of dams, irrigation and hydropower schemes and a low increase in urban and other water demands were included in the Low Scenario, approximately representing the present 5-7 year plans of the three governments. All of these interventions, plus more that represented possible 10-15 year plans were included in the Medium Scenario. The High Scenario added a further layer of interventions, some of which are probably not realistic. The main purpose of this final scenario was to 'push' the ecosystem as far as possible in terms of development interventions, to assess if there would be significant ecological and social impacts.

Finally, climate change overlaid its own set of impacts on the Low and Medium Scenarios.

3.2. Simulating the flow regimes

The hydrological team simulated the flow regimes for each site under each scenario. The process is described in Report 06 (volumes 1 and 2) in the IFA Report Series (Scenario Report: Hydrology).

3.3. Converting the simulated data into summary flow statistics

The data were summarised as ecologically-relevant statistics for each site (Table 3.1), with the full suite of data in Report 07 (volumes 1 and 3) of the IFA Report Series. These statistics were input values into the DSS.

Site 3 on the Cuito was excluded from the initial analysis because it is located upstream of development. The scenarios and the developments that they would include were agreed some months after site selection and by chance all developments chosen for the Cuito were downstream of Site 3 and so they do not affect Site 3's flow regime. Developments in the lower Cuito are reflected in changing flow patterns at Site 5 onwards, after the Cuito joins the Cubango (Figure 2.1).

3.3.1 Without Climate Change

The picture of flow change shown (Table 3.1) is discussed in Section 3.4.

Table 3.1 Median values of the ecologically-relevant summary statistics for each scenario for relevant river sites. PD = Present Day

a) Mean Annual Runoff (Mcm)

IFA Site	PD	Low	Medium	High	Comment
1	22	14	14	13	All Scenarios similar and about 64% lower than PD
2	166	155	140	128	Gradual decline to 93%, 85%, 77% of PD
4	164	152	140	129	Progressive decline to 93%, 85%, 79% of PD
5/6	270	261	245	186	Progressive decline: 97%, 91%, 69% of PD

b) Dry season onset

IFA Site	PD	Low	Medium	High	Comment
1	Aug	May	May	May	All Scenarios similar and 11 wk earlier than PD
2	July	July	July	July	All Scenarios similar. Onset 2-3 wk earlier than PD.
4	July	July	July	July	Approx same throughout
5/6	Aug	July	July	June	Progressively earlier: 1, 3, and 7 wk than PD

c) Dry season duration (days)

IFA Site	PD	Low	Medium	High	Comment
1	86	212	212	213	All Scenarios similar and approx 18 wk longer than PD
2	96	124	143	152	Progressively longer than PD by 4, 7 and 8 wk
4	135	150	168	176	Progressively longer than PD by 2, 5 and 6 wk
5/6	115	130	145	193	Progressively longer than PD by 2, 4 and11 wk

d) Dry season minimum flow (m^3s^{-1})

IFA Site	PD	Low	Medium	High	Comment
1	12	0.4	0.3	0.3	All Scenarios similar. Drastic drop from PD
2	32	16	12	24	Min Q drops to 50% (L), 38% (M) of PD and then under H increases to 75% because of dam releases in dry season
4	35	20	15	19	Decline through L and M to 43% of PD then increase for H to 54%
5/6	114	101	93	21	Progressive decline from PD to very large drop for H: 89%, 82%, 18%

e) Flood season onset

IFA Site	PD	Low	Medium	High	Comment
1	Dec	Jan	Jan	Jan	All Scenarios similar: delay by about 7 wk compared to PD
2	Jan	Jan	Jan	Jan	Progressive delay from PD by 2-3 wk
4	Jan	Jan	Jan	Feb	Slight delay by about 2 wk from PD in H
5/6	Jan	Jan	Jan	Feb	Slight delay by 1 wk (M) and 2 wk (H)

f) Flood season peak (m^3s^{-1})

IFA Site	PD	Low	Medium	High	Comment
1	38	35	35	35	All Scenarios similar with slightly smaller peak than PD
2	429	430	429	401	Peak not affected until (H), when drops to 93% of PD
4	452	446	453	433	Medium about same as PD; L slightly lower at 99% and H at 96% of PD
5/6	620	618	611	573	Progressive very slight decline: 99%, 98, 92% of PD

g) Flood season volume (Mcm)

IFA Site	PD	Low	Medium	High	Comment
1	456	231	231	230	All Scenarios similar and half of PD

2	3713	3558	3178	2531	Progressive decline to 96%, 86%, 68% of PD
4	3694	3535	3209	2580	Progressive decline to 96%, 87%, 70% of PD
5/6	5269	4980	4450	3294	Progressive decline to 96%, 84%, 63% of PD

h) Flood season duration (days)

IFA Site	PD	Low	Medium	High	Comment
1	197	97	97	97	All Scenarios similar and approx 14 wk shorter than PD
2	148	135	123	111	Progressive shortening of flood season: 2, 3, 5 wk less than PD
4	154	147	130	117	Progressive shortening of flood season: 1, 4, 6 wk less than PD
5/6	150	143	129	103	Progressive shortening of flood season: 1, 3, 7 wk less than PD

3.3.2 With Climate Change

The future climate change signal for the Okavango system has been derived from the ensemble of global circulation models using statistical downscaling procedures. This has been done only for one scenario of greenhouse gas emissions – SRESA2, but for near future (2025-2045) the differences between various emission scenarios are not strongly pronounced. Accuracy of the projections hinges heavily on the quality of models and procedures used in the process, but these used here represent current state-of-the-art.

There is a lack of consistency between various GCMs, members of the analysed ensemble, in terms of magnitude of prognosed change in rainfall, but the prognoses of change in temperature are relatively consistent between them. It is projected that the temperatures in the basin will increase by 2.2-3.2 ^{o}C compared to the reference period of 1960-1990. The increase in the north of the basin (headwaters) will be slightly smaller than that in the south (Delta). There is a slightly stronger increase projected for September-November and a weaker one for March-May.

In terms of rainfall, differences between results from various models are strongly pronounced. In general, an increase in total annual rainfall is projected for the basin, ranging from 5-20% compared to the reference period of 1960-1990. Smaller increases are expected in the north, and larger increase in the south. The strongest increase is projected to occur in March-May and the weakest in September-November, which translates to a slight shift in the seasonal distribution of rains. The increase in rainfall is projected to occur through the increase in number of rain days. As a result, the duration of dry spells is projected to reduce. No increase in intensities of rainfall events is projected. Also, the inter-annual variability of rains is projected not to change.

The resulting expected flow changes are shown for the four new climate change scenarios in Table 3.2 and discussed in Section 3.4. Site 3 is now included because although no development was included for this site, climate change will affect the flow regime.

Table 3.2 Median values of the ecologically-relevant summary statistics for each climate-change scenario for relevant river sites. PD = Present Day. CC = climate change. CCD = driest climate change prediction. CCW = wettest climate change prediction.

a) Mean Annual Runoff (Mcm)

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	22	14	14	14	14	14	14	No change from No CC.
2	166	155	166	204	140	152	188	CCD mitigates development and CCW goes further, increasing MAR to 13-23% more than PD.
3	119	119	130	147	119	130	147	Increase of 9-24% above PD
4	164	152	167	204	140	154	190	CCD mitigates development and CCW goes further, increasing MAR to 2-16% more than PD
5/6	270	261	287	341	245	270	324	CCD mitigates development and CCW goes further, increasing MAR to 20-26% more than PD

b) Dry season onset

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	Aug	May	June	June	May	June	June	Onset later than for No CC: slight mitigation of development
2	July	July	July	July	July	July	July	No change.
3	July	July	July	July	July	July	July	No change.
4	July	July	July	July	July	July	July	No change.
5/6	Aug	July	Aug	Aug	July	July	Aug	CC mitigates development, with onset as PD.

c) Dry season duration (days)

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	86	212	200	200	212	200	200	Virtually no mitigation of development by CC; dry season duration still more than double PD.
2	86	124	113	95	143	136	113	Some mitigation to shorter dry season, especially by CCW.
3	182	182	121	48	182	121	48	CCW shortens dry season by about 70% compared to PD
4	135	150	138	109	168	158	132	CCD partially (Medium) or completely (Low) mitigates development and CCW goes further, shortening the dry season by up to 20% of PD
5/6	115	130	110	71	145	133	92	CCD partially (Medium) or completely (Low) mitigates development and CCW goes further, shortening the dry season by up to 38% of PD

d) Dry season minimum flow (m^3s^{-1})

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	12	0.4	0.4	0.4	0.3	0.4	0.4	No change from No CC.
2	32	16	22	28	12	16	22	CCD and CCW increasingly mitigate development but do not return minimum flows to PD levels
3	80	80	93	94	80	93	94	Minimum flows up to 18% higher than PD
4	35	20	31	40	15	23	30	CCD and CCW partially or completely mitigate development
5/6	114	101	113	125	93	107	122	CCD and CCW partially or completely mitigate development

e) Flood season onset

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	Dec	Jan	Jan	Jan	Jan	Jan	Jan	No change.
2	Jan	Jan	Jan	Dec	Jan	Jan	Dec	Flood season slightly earlier than PD under CCW.
3	Jan	Jan	Dec	Nov	Jan	Dec	Nov	Onset 1 month earlier in CCD and 2 months earlier in CCW.
4	Jan	Jan	Jan	Jan	Jan	Jan	Jan	No change.
5/6	Jan	Jan	Jan	Dec	Jan	Jan	Jan	No change.

f) Flood season peak (m^3s^{-1})

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	38	35	38	38	35	38	38	Peak returns to PD magnitude mitigating development
2	429	430	446	562	429	449	563	4% increase in peak over PD under CCD and 30% under CCW
3	163	163	173	195	163	173	195	CCD and CCW higher than PD by 6% and 20% respectively.
4	452	446	400	497	453	394	483	Reduction of PD peak to 88% in CCD but increase by 10% over PD in CCW.
5/6	620	618	528	649	611	519	635	Reduction to 84% of PD in CCD and increase by up to 4% in CCW.

g) Flood season volume (Mcm)

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	456	231	242	242	231	242	242	Mild mitigation of development but still about half PD.
2	3713	3558	3817	5123	3178	3466	4355	Under CCD volume moves back toward or just above PD, and in CCW show a large increase to 17-38% above PD
3	1968	1968	2617	3436	1968	2617	3436	Volumes 33% (CCD) to 75% (CCW) higher than PD
4	3694	3535	3885	5188	3209	3523	4711	Under CCD volume moves back toward or just above PD, and in CCW show a large increase to 28-40% above PD
5/6	5269	4980	5587	7882	4450	5038	7236	Under CCD volume moves back toward or just above PD, and in CCW show a large increase to 37-50% above PD

h) Flood season duration (days)

IFA site	PD	Low			Medium			Comment
		No CC	CCD	CCW	No CC	CCD	CCW	
1	197	97	103	103	97	103	103	Mild mitigation of development but all CC scenarios still about half PD
2	148	135	143	183	123	128	150	Under CCD volume moves back toward PD. In CCW, flood duration expands beyond PD, most noticeably in the low scenario where it is 24% longer
3	162	162	205	263	162	205	263	Duration 27% (CCD) to 62% (CCW) longer than PD
4	154	147	154	186	130	144	167	Under CCD duration moves back toward or equals PD, and in CCW is longer than PD by 8-21%
5/6	150	143	158	190	129	141	178	Under CCD duration moves back toward or slightly longer than PD, and in CCW is longer than PD by 19-27%

3.4. Summarising potential development-driven changes in the flow regime

It is re-emphasised that the following discussion on the flow changes summarised in Table 3.1 and Table 3.2 is not of changes that WILL happen but of ones that WOULD happen if the developments chosen for inclusion in the scenarios were implemented. Changing the assumptions of location, design or operation of developments within the models could change the resulting flow regimes. These flow predictions are thus indicative of the kinds of changes that could occur and allow early warning of where significant change could be expected. Climate change, as an overlay on the Low and Medium Scenarios could mitigate some of these impacts and could increase the severity of others.

The main characteristics of the present-day hydrological regime are the great difference between the two headwater tributaries, the Cubango and the Cuito, and the massive storage capacity for floods in the floodplains along the system. The Cubango exhibits a flashy hydrograph with sharp increases in flow after rain events, receding quickly to low base flow levels. The Cuito exhibits a smoother rise and fall, more characteristic of large monsoonal systems, because of the combined effects of groundwater contributions to baseflow and wet-season storage of floodwaters in vast floodplains and their drainage back into the river in the dry season. The Okavango River system as a whole is a floodplain-driven system, with floodplains throughout but most prominently on the Cuito in Angola, on the Okavango along the Angola/Namibia border, and the Okavango Delta in Botswana. These floodplains sustain the river in the dry season and also store floodwaters that would otherwise increase flooding downstream.

The following summary of predicted flow changes first addresses Sites 1,2,4,5 and 6 (the river sites), and then Sites 7 and 8 the Delta and outflow sites, where consideration of changes in inundation are more appropriate. In each case the situation with and without climate change is presented.

3.4.1 The river sites

Without climate change

At the river sites (Table 3.1), the present-day (PD) flow regime is close to natural and although the overall amount of water in the river system would decline a little through the development levels this does not represent the major changes to the flow regime. For instance, at Sites 1,2,3,5 and 6 Mean Annual Runoff (MAR) declines to 93-97% of PD under the Low Scenario, 85-91% under the Medium Scenario and 69-79% under the High Scenario. The lowest percentages are under the High Scenario and at the most downstream sites, indicating a modest erosion of MAR along the system, mostly through diversions for agriculture and urban areas.

The flood season, as defined by flood onset, flood peak, flood volume and flood-season duration, shows significant impact in two main areas: Site 1 on the Cuebe River and Sites 4-6 on the Okavango. The impact at Site 1 is mainly due to inclusion in the basin model of run-of-river irrigation schemes that continuously abstract a significant proportion of the flow from the river. These developments, all included in the Low Scenario and not expanded in the other two scenarios, delay the onset of the flood season by up to 7 weeks, reduce the duration of the flood season by up to 14 weeks and half the flood volume.

The impact on the flood season at Sites 4-6 is through the general accumulation of interventions along the system, which are felt most at the downstream end. There is an overall very slight delay of up to 3 weeks in the onset of the flood season and a very mild reduction to 92-99% of the flood peak. There are major changes in the other two flood indicators, however. Flood volume declines progressively through the scenarios to a lowest value of 63% of PD at Sites 5 and 6 under High Development. Flood-season duration is shortened by up to 7 weeks, again with a progressive shortening through the scenarios with Sites 5 and 6 under High Scenario most impacted.

By far the most noticeable of the flow impacts is on the dry-season flows. Again, Site 1 on the Cuebe is heavily impacted, with the dry season starting about 11 weeks earlier, lasting up to 18 weeks longer and with a minimum flow that drops drastically to about 3% of PD. The impacts of these developments are also felt at Site 2 but much less so.

The impact on the dry season at Sites 4-6 is again the end result of the series of interventions along the whole system, with Sites 5 and 6 showing the biggest flow changes. There is little change in the onset of the dry season at Site 4, but at Sites 5 and 6 it starts 1 week earlier under the Low Scenario increasing to 7 weeks earlier under the High Scenario. The change in the duration of the dry season is again most obvious at Sites 5 and 6, and under the High Scenario, when it is 11 weeks longer. The dry-season minimum flows show a mixed pattern, with flow levels declining under the Low and Medium Scenario at Sites 2 and

4, but increasing slightly under the High Scenario due to additional dams storing flood waters and releasing them in the dry season. These sites, both on the Cubango upstream of the confluence with the Cuito, fall below 50% of PD dry season flows under the Medium Scenario and then increase again to 54% to 75% under the High Scenario. Sites 5 and 6, downstream of the confluence, show a different pattern, with flows remaining quite high until the High Scenario, when they fall to 18% of PD.

The overall trend in flow changes is for run-of-river abstractions to be reducing flows throughout the year, with the effect being particularly noticeable in the dry season. Dry-season flows tend to be lower, start earlier and last longer than PD, with the effect greatest at Sites 1, 5 and 6. Flood volumes become progressively smaller, the flood season progressively shorter and its onset a little later. Again, Sites 1, 5 and 6 show the greatest impact. Flood peaks are not reduced significantly and there is not a marked transfer of water from the flood season to the dry season, as with many developed basins, because there are not enough dams with sufficient storage to affect this.

With climate change

Apart from Site 1, climate change under the driest scenario reverses the loss of MAR brought about by development and under the wettest scenario increases MAR by up to 20% above PD even under the Medium Scenario.

The flood season starts about the same time with climate change, except in the Cuito where it is up to two months earlier. It also lasts up to three months longer, with the most extreme case again being the Cuito. In the upper basin (sites 2 and 3) flood peaks increase slightly under the driest climate change scenario and are up to 30% higher in the wettest scenario, but in the lower basin (sites 4,5,6) there is a 12-16% reduction in peak under the driest scenario and a very low increase under the wettest. Flood volumes move back toward PD values in the driest scenario, ameliorating development, and greatly exceed PD by up to 50% in the wettest. The overall picture is of the flood season starting a little earlier, lasting longer, having higher flood peaks and providing more water than PD, particularly in the wettest scenario and the upper basin. The Cuito shows the most extreme response, with flooding starting up to two months earlier, peaks up to 20% higher, flood volumes up to 75% higher and the flood season being up to 62% longer.

The dry season is predicted to begin at about the same time as PD or slightly later and to become shorter at all sites except Capico (Site 1). Climate change partially or completely returns minimum flows to PD levels even under Medium development. Again, the most dramatic changes are for the Cuito, where the dry season could be up to 19 weeks shorter with minimum flows up to 18% higher.

3.4.2 The Delta

Without climate change

Site 7, Xakanaxa in the Delta, receives essentially the same amount of water as Site 6, in the same pattern of flows described above. This manifests as changes in inundation patterns in the Delta, with an expected development-driven decrease under the High Scenario in all major types of permanent swamp (open channels, lagoons and backswamps) and an increase in seasonal swamps (seasonal pools, seasonal sedgeland, seasonal grassland) as well as in dry-floodplain savanna (Table 3.3 and Table 3.4). For all vegetation types, the High Scenario shows a much greater change than the other scenarios, with various types of permanent swamp decreasing to about 22% of PD and seasonal swamp types increasing to 104-178% of PD. Savanna shows the largest change, increasing more than four-fold over the PD level in the High Scenario. These shifts represent a progressive drying-out of the Delta.

Table 3.3 Vegetation types in the Delta

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

Table 3.4 Mean percentage of cover for vegetation types in the area of the Delta represented by Site 7, for simulated present-day conditions, and for the low, medium and high scenarios.

Inflow scenarios	CH-ps	L-ps	BS-ps	SP-sf	Sed-sf	Gr-sf	S-sf
	Mean percentage cover						
Present-day	0.49	0.98	47.58	0.89	27.27	16.32	6.47
Low	0.46	0.92	44.62	0.94	27.84	18.08	7.13
Medium	0.43	0.867	41.67	0.98	26.28	21.51	8.29
High	0.11	0.23	11.02	1.18	28.59	29.12	29.74

With climate change

Under the wettest climate change scenarios, the proportions of the various Delta vegetation groups revert partially (Medium development) or completely (Low development) back to present day levels.

Under the driest climate change scenarios, the drying out of the Delta continues, with a moderate shift from permanent swamps to seasonal swamps and savanna under the Low CC Scenario and a more severe shift under the Medium CC Scenario to the same conditions predicted for the original High Scenario.

Table 3.5 Mean percentage of cover for vegetation types in the area of the Delta represented by Site 7, for simulated present-day conditions, and for the present day, and for the low and medium scenarios with two levels of climate change. C = climate change. CCD = driest climate change prediction. CCW = wettest climate change prediction.

Inflows		CH-ps	L-ps	BS-ps	SP-sf	Sed-sf	Gr-sf	S-sf
		Mean percentage cover						
Present-day		0.49	0.98	47.58	0.89	27.27	16.32	6.47
Low	No CC	0.46	0.92	44.62	0.94	27.84	18.08	7.13
	CCD	0.21	0.41	20.02	1.18	34.44	23.60	20.13
	CCW	0.49	0.99	47.95	0.94	29.74	16.12	3.77
Medium	No CC	0.43	0.87	41.67	0.98	26.28	21.51	8.29
	CCD	0.11	0.22	10.64	1.29	31.50	31.70	24.55
	CCW	0.44	0.88	42.51	1.03	29.71	20.80	4.64

3.4.3 The outflow: Boteti River

Without climate change

Site 8, representing the outflowing Boteti River that normally exhibits dry and wet cycles of years, would be similarly impacted with a progressive decline in the number of years when it contains water. In the High Scenario it would be completely dry for most of the time, holding water only in the wettest years (Figure 3.1; Figure 3.2; Figure 3.3; Figure 3.4). Details of the model used to provide these data are given in Report 05/2009: Hydrology Report: Data and models.

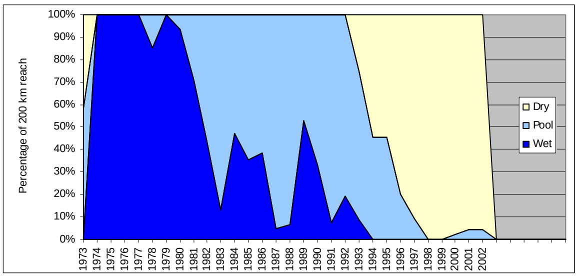

Figure 3.1 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the present-day simulated conditions given climatic conditions that prevailed from 1973-2002.**

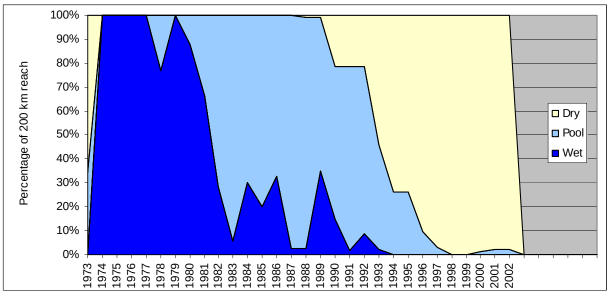

Figure 3.2 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the Low Scenario given climatic conditions that prevailed from 1973-2002.**

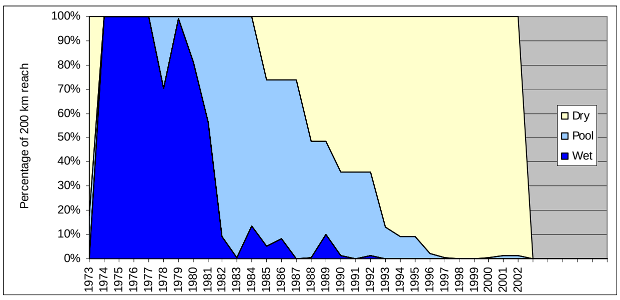

Figure 3.3 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the Medium Scenario given climatic conditions that prevailed from 1973-2002.**

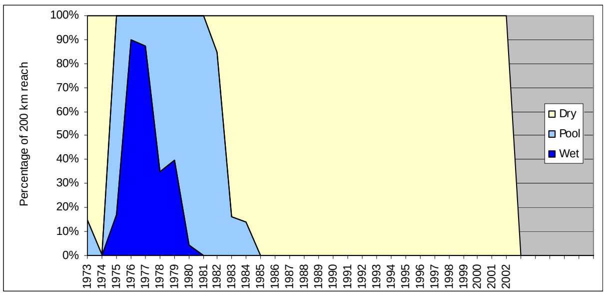

Figure 3.4 Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the High Scenario given climatic conditions that prevailed from 1973-2002.

With climate change

Climate change is predicted to reverse some of the impacts of development (Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8). Under the wetter scenarios, inundation conditions will be very similar to present day even with Low and Medium development included. Under the drier conditions, the Low CC Scenario would resemble the original Medium one, while the Medium CC Scenario would represent a condition half way between the original Medium and High Scenarios.

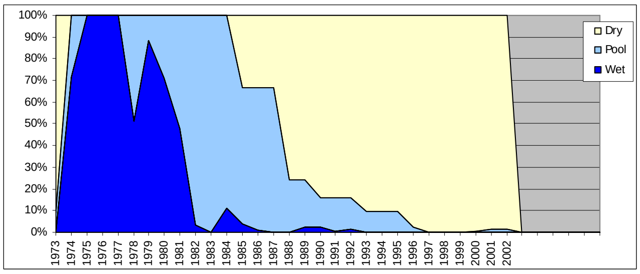

Figure 3.5 Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the low scenario with the driest Climatic Change (CCD) imposed on 1973-2002.

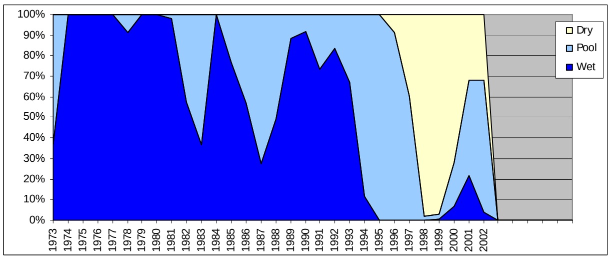

Figure 3.6 Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the low scenario with the wettest Climatic Change (CCW) imposed on 1973-2002.

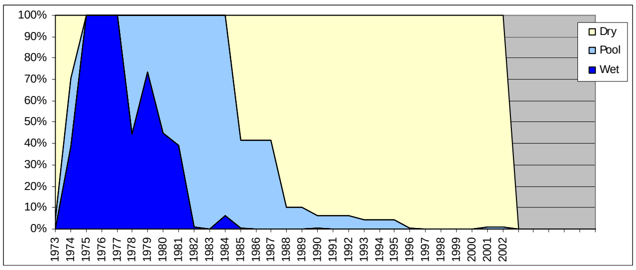

Figure 3.7 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the medium scenario with the driest Climatic Change (CCD) imposed on 1973-2002.**

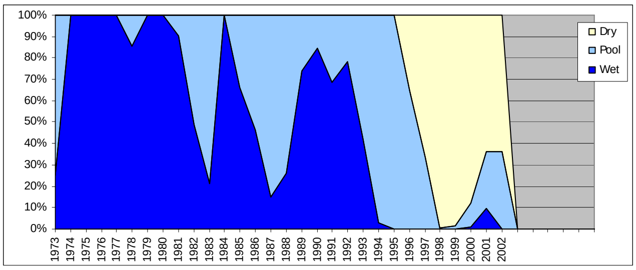

Figure 3.8 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the medium scenario with the wettest Climatic Change (CCW) imposed on 1973-2002.**

3.5. Conclusion on potential flow changes

The Okavango River system is a floodplain-driven system, with floodplains that sustain the river in the dry season and store floodwaters that would otherwise increase flooding downstream. The Cuito River is key to the functioning of the whole lower river system, because of its strong year-round flow, its wet-season storage of floodwaters on vast floodplains and the gradual release of water back into the river in the dry season. The riverine ecosystems and associated social structures of people along the lower Okavango River, the Okavango Delta and the outflowing Thalamakana and Boteti Rivers are sustained mostly by the annual flow regime of the Cuito. If these areas are of concern at the basin level, then water-resource development along the Cuito, or intervention in the functioning of its floodplains, should be modest and undertaken with extreme caution.

Without climate change, the severe impacts linked to Site 1 could be mitigated by opting for a less intrusive series of developments on the Cuebe River. Any development that does take place on this tributary is likely to have impacts that are largely limited to the Angolan part of the basin. The severe impacts described for Sites 5-8 are less easily mitigated as they would result from many developments along the whole system. Increasing the number and nature of the developments, as one moves from the Low to the High Scenario, will inevitably extend the impacts from localised to transboundary and push the river ecosystem into significant degradation. Mitigation could realistically only be addressed by planning and managing at the basin level.

With climate change, considerable mitigation occurs anyway in the upper basin under the wettest CC scenario. The most severe impacts are predicted for the Delta and Boteti under the driest CC conditions.

4. Predicting the ecological and social consequences

The above potential flow changes become the input for the DSS, which then produces an output consisting of the predictions of river ecosystem and social impacts (Report 07 volumes 1-4 in the EFlows Report Series).

4.1. Impacts on the river ecosystem

International experience has shown that five main attributes of the natural flow regime are paramount in supporting the healthy functioning of river ecosystems: the magnitude of flows, their frequency, timing and duration, and the overall variability of flows on every scale from daily to decadal. The flow changes described above impact on all these aspects of the flow regime, with consequences for the health and integrity of the river ecosystem.

These consequences are described as predicted changes in 70 biophysical indicators (Table 3.1 in Report 07 in the EFlows Report Series). The indicators cover the major parts of the ecosystem: channel form, water quality, vegetation, aquatic invertebrates, fish, river-dependent terrestrial wildlife and water birds. Their present status and predicted changes at each site under each scenario are described in the four volumes of Report 07 and summarised below in Table 4.1.

Table 4.1 Abbreviated summary of predictions of ecosystem change under the three development scenarios. PD = Present Day. For full predictions see Report 07.

Ecosystem component	Predicted impact without climate change	Predicted impact with climate change
Channel	There will be a trend towards stabilisation and narrowing of the main channels, possibly accompanied by a deepening of the channel and thus some drying out of the floodplains. Lack of data on sediment dynamics of the system means that predicted changes could be seriously underestimated.	In the upper catchment the flow-related impacts of development would be largely mitigated by CC but this effect weakens with distance downstream.
Water quality	The water quality of the Okavango system is good, and in the Low and Medium Scenarios all indicators should remain mostly within their natural range of variability. Most indicators will noticeably move away from PD values with the High Scenario, particularly from Site 4 downstream. Only flow-related changes were addressed, and water-use developments will likely cause additional water-quality changes because of increased effluents from urban areas, agricultural return flows with their loads of pesticides and fertilisers, and changed oxygen and temperature levels caused by storage dams.	The situation remains similar in the upper catchment, where water quality is expected to be fairly natural. In the lower catchment, the driest climate change predictions are expected to result in poor water quality in the Delta and Boteti.
Vegetation	Aquatic and semi-aquatic vegetation will be negatively affected at Sites 1, 2, 5, 6 and 8, where abstraction will seriously reduce low flows, particularly in the dry season. Riparian trees and shrubs will be less affected, but once impacted will take a long time to recover, if recovery is in fact possible. In some parts of the	The climate change predictions for the upper catchment slightly reduce the expected impact of the Low and Medium developments at Sites 1, 2 and 4, but this is mainly in the floodplains in response to expected increases in flood peak and duration. In the delta and at Boteti, under the driest climate change, the flow-related

Ecosystem component	Predicted impact without climate change	Predicted impact with climate change
	system, floodplain grasses will increase in area because of general terrestrialisation of the system.	impacts of development will be more marked, and there will be a significant increase in savanna habitats, and gradual terrestrialisation of the Delta. This would be exacerbated by water-resource developments in the upper catchment. The wettest predicted climate change, even with Low and Medium development, will result in a wetter Delta than present day, with the proportions of permanent swamp plants increasing.

Ecosystem component	Predicted impact without climate change	Predicted impact with climate change
Aquatic invertebrates	With the exception of Site 1, the Low and Medium Scenarios are expected to have a low to negligible impact. The High Scenario could cause significant declines in some indicators, mostly at Sites 5, 6, 7 and 8, whilst inhabitants of woodland pools are expected to increase several fold in the Delta as *mopane* woodlands expand.	In the upper catchment at Sites 1 and 2, the climate change predictions result in little or no change from the original lLw and Medium scenarios. In the middle and lower catchment, Sites 4, 5, 6, 7, and 8, the wettest scenario will result in an increase in floodplain invertebrates. In the lower catchment, however, the driest climate change predictions will drive terrestrialisation and exacerbate the flow - elated impacts of development.
Fish	At Site 1 fish losses are expected to be high for all three scenarios because of run-of-river abstraction during the low-flow season. Elsewhere the fish assemblages are expected to cope fairly well with the Low Scenario, and slightly less well with the Medium Scenario. Under the High Scenario, fish in the lower part of the catchment, e.g., Sites 4, 5, 6, 7 and 8 will be severely and negatively impacted, and local extinctions are highly likely, particularly from Popa Falls (Site 5) downstream to the Boteti (Site 8).	In the upper catchment (with the exception of Site 1), the flow impacts of water-resource developments under the Low and Medium scenarios are significantly mitigated under both the driest and the wettest CC predictions. In the lower catchment, however, their impacts are significantly greater under the drier climate change predictions, and somewhat reduced with wetter climate change.
Wildlife	Abundances of wildlife are predicted to decline progressively through the scenarios, with the High Scenario having a severe impact. Some species at some sites could permanently decline to as low as 5% of PD values. The notable exception to this is the Delta, where one group of wildlife - the large grazers - would benefit from the scenarios as permanent swamps gave way to seasonal floodplains, but even they may show an eventual decline as wetlands give way to savanna.	In the upper catchment, these patterns would be reversed for both sets of CC predictions (drier and wetter). In the lower catchment, specifically in the Delta and Boteti, the trends shown for the Low and Medium scenarios would be exacerbated under the drier climate change predictions, as the increased evaporation would lead to the Delta becoming drier than present. Under the wetter climate change predictions, some of the flow reductions as a result of development would be offset by higher flows in the rivers, and thus a higher inflow into the Delta and Boteti.

Ecosystem component	Predicted impact without climate change	Predicted impact with climate change
Birds	Moderate declines in abundance of some bird groups could occur at Sites 1, 2, 4, 6 and 8, especially under the High Scenario, with some local extinctions. Site 7, conversely, would have mild to moderate increases in several indicators as open water and permanent swamp give way to seasonal grass and sedge lands. Birds are highly mobile and soon arrive when conditions become favourable or leave when they are unfavourable. This implies that there are other areas for them to arrive from or depart to. Development in the Okavango Basin, however, will probably be mirrored by that in other nearby basins such as that of the Zambezi River, and it cannot be assumed that there will always be suitable habitat elsewhere. The Okavango River is a vital part of the southern African mosaic of wetlands that supports both resident and migrant birds, and would need to maintain that status to ensure their long-term viability.	The increased flows in the upper catchment with climate change have an ameliorating effect on the flow-related impacts of the Low and Medium scenarios, with the exception of Site 1 (Capico), where the effect is minimal. The same is true for the wettest climate change predictions in the lower parts of the catchment. However, this is probably insufficient to prevent local extinctions at Site 2 (Mucundi). The drier climate change predictions at Site 7 (Delta), conversely, show mild to moderate increases in several indicators as open water and permanent swamp give way to seasonal grass and sedge lands.

Combining all ecosystem attributes, the overall picture of predicted change is depicted in two ways: overall ecosystem integrity and status of river zones.

4.1.1 Overall ecosystem integrity

River ecosystems can be judged in terms of their overall integrity, that is, the extent to which they still have their natural attributes and functioning. We have used a scoring system from A to F whereby A represents a natural, unmodified system and F represents a critically modified system that has essentially lost all its natural attributes and has little value for people (Table 6.1 in Report 07). A general aim among countries using such a system would be to not let rivers fall below a D category. The Okavango River system was estimated in 2008 to be at a level B throughout, which translates as ***Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.***

The DSS predicted how the overall integrity status of the system could change under the development and climate change scenarios.

Without climate change

In the ecosystem integrity plot the eight sites are shown along the horizontal axis and the value for integrity is shown along the vertical axis (Figure 6.8 in Report 07 and Figure 4.1 below). The fuzzy horizontal lines indicate the approximate integrity values where the ecosystem moves from one class to the next. The fuzzy blue line, for instance, shows that ecosystem integrity drops from a B to a C at an integrity value of about -0.5. Present-day integrity is valued at 0, and the thin black line indicates that all sites are presently sitting above the B to C transition, i.e. in a B condition.

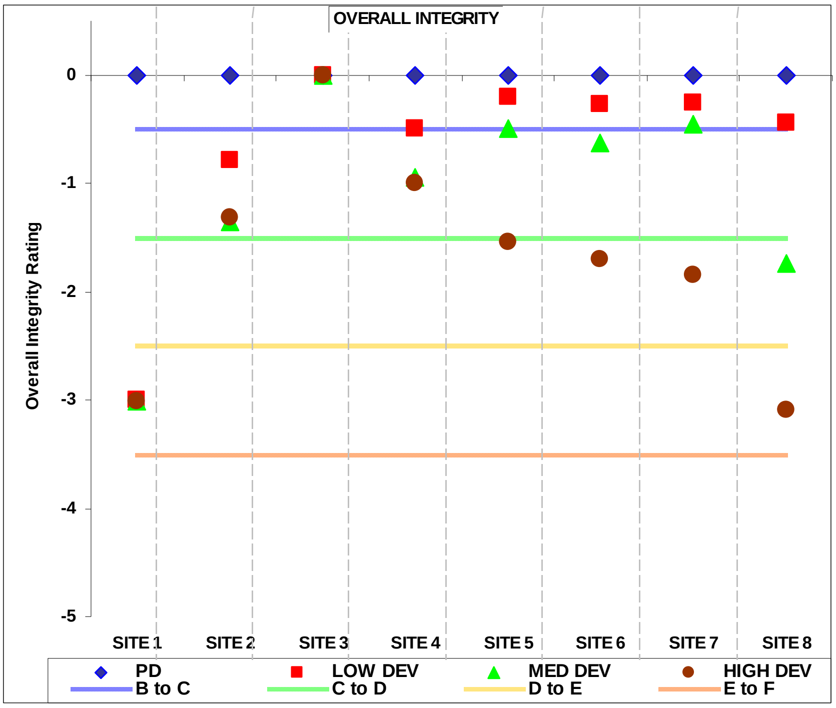

Figure 4.1 **Overall ecosystem integrity for the three scenarios at each of the study sites, showing the integrity value of each site under each development scenario and the shifts to lower integrity classes**

It is predicted that with water-resource development, ecosystem integrity will decline, that is, no sites will improve to an A, and so only negative integrity values are shown on the plot. The overall picture is that:

1. There will be no change at Site 3, because it is upstream of development, as explained earlier.
2. Site 1 (Capico) will be heavily impacted by all scenarios, dropping to an E condition, mainly because of the loss of dry-season flows.
3. The remaining sites (2,4,5,6,7,8) show a mild loss of integrity under the Low Scenario, mostly remaining in a (slightly lower) B or upper C condition.
4. The same sites show a moderate loss of integrity under the Medium Scenario, declining to a C condition and, for Site 8, to an upper D.
5. The same sites show a severe decline under the High Scenario, dropping to a D condition, and, for Site 8, to an E.
6. Ecosystem integrity generally declines with distance downstream, under all scenarios.

With climate change

Figure 4.1 is repeated in Figure 4.2, with the climate change scenarios added and the High Scenario omitted. Integrity scores greater than 0 may denote an improvement back towards natural conditions, but more likely denote a change in the overall ecosystem towards one that is wetter than ‘recent natural’.

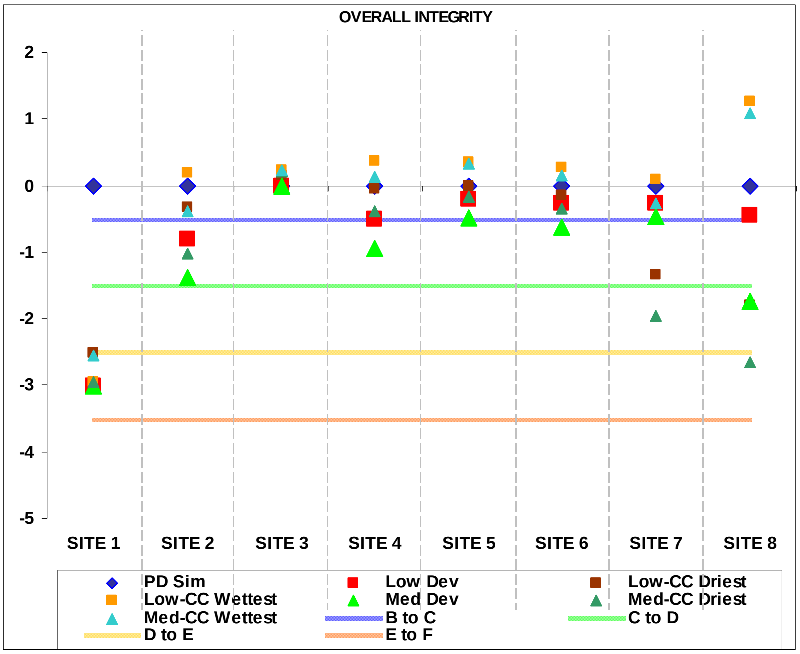

Figure 4.2 **Overall ecosystem integrity for the Low and Medium scenarios, with and without climate change, at each of the study sites**

The impacts of climate change are predicted to be as follows:

Site 1: The drop of three categories to a E-category under the Medium and Low scenarios, was reduced slightly to a D/E-category under the wettest CC conditions, but there was no significant improvement under the drier CC conditions.

Site 2: Under the Low and Medium scenarios the condition of the system dropped from a B-category to a C-category. Under the Low scenario both CC conditions result in a return to a B-category. For the Medium scenario, there is no significant change in overal condition under the driest CC, but there is an improvement to a B-category under the wettest CC.

Site 3: No change.

Site 4: The flow-related impacts of the Low Scenario developments will be mitigated by both CC conditions. Under the Medium Scenario and the driest CC, the ecosystem will decline from a B category to a C, whilst it will remain at C under the wettest CC

Site 5: The flow-related impacts of Low and Medium development will be mitigated by both CC conditions.

Site 6: The flow-related impacts of Low and Medium development will be mitigated by both CC conditions.

Site 7: The flow-related impacts of Low and Medium development will be mitigated by the wettest CC condition. The driest CC condition will result in a significant decline in condition because of the drying out of the Delta.

Site 8: As for the Delta, i.e., the driest CC condition will exacerbate the impacts of water-resource development on the Boteti. The wettest CC condition will mitigate these impacts.

The most striking aspect is the possible exacerbation of flow-related impacts in the Delta and Boteti under the drier CC conditions. These impacts would be particularly acute under the Medium Scenario, with the condition of the Delta and Boteti dropping two and three categories lower than at present, respectively. Under the same scenario, the Boteti could cease to flow in most years in a forty-year sequence, and there would be considerable terrestrialisation of the Delta, approximating the predicted impacts for the High Scenario without climate change (see Volume 1).

4.1.2 Status of river zones

The impacts predicted for the representative sites can be translated to expected impacts over the whole river network.

Without climate change

In the basin graphic of ecosystem health (Figure 6.9 in Report 07 and Figure 4.3 below) rivers depicted in black had no representative sites and so were not included in the assessment. . Those coloured blue were predicted to retain their present-day B status, whilst the remainder declined to a C (green), D (orange) or E (red). The sections most under threat are shown with red flags, because they would be unable to sustain present beneficial uses of the system.

Three main predicted trends are clear.

A progressive decline in condition of the river ecosystem would occur from the Low to High Scenarios, with the High Scenario rendering large parts of the system unable to sustain present beneficial uses and causing significant terrestrialisation within the Delta.

A severe impact in an upper-basin tributary would be localised around Capico (Low Scenario) until it, together with further downstream developments, triggered a widespread decline in the middle reaches to condition C (Medium Scenario).

Transboundary impacts would be felt first and most severely in the lower basin.

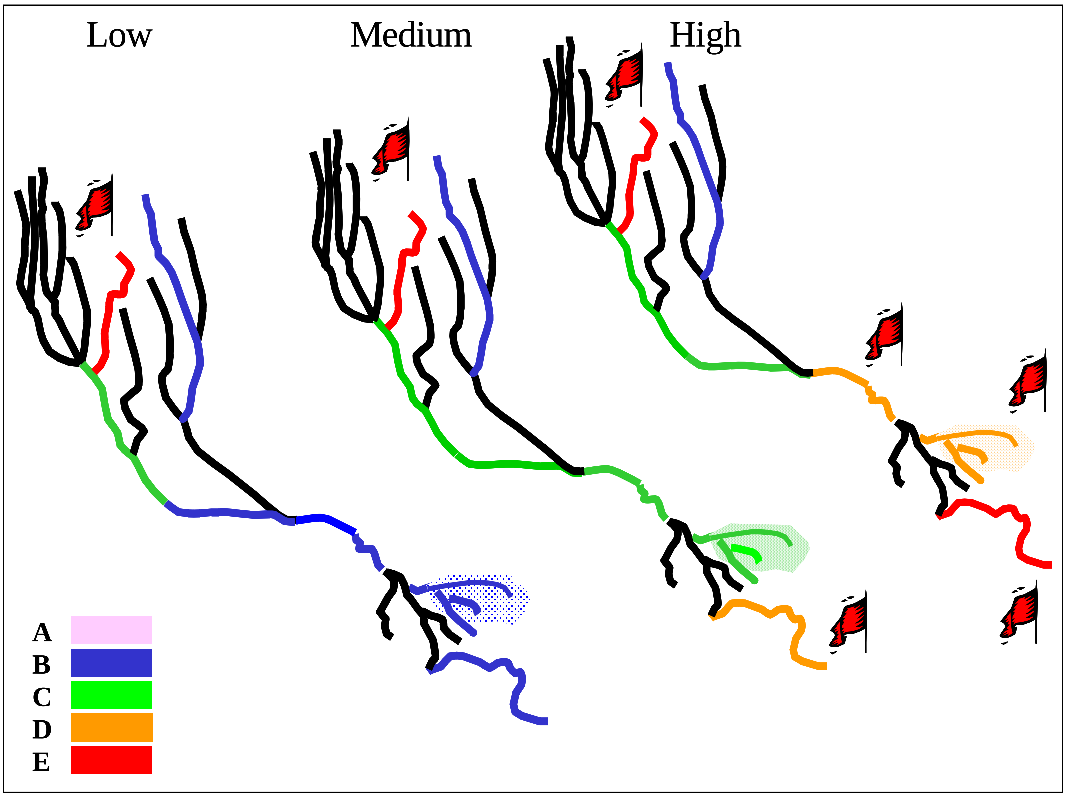

Figure 4.3 Summary of expected changes in ecosystem integrity for the Low, Medium and High Scenarios. Present-day conditions are estimated as B-category.

With climate change

The impacts at Capico are reflected throughout the graphic, and essentially reflect the result such a development would have on any of the Cubango headwater streams (Figure 4.4). Developments on the lower Cuito are not included as the IFA site was upstream of any potential ones (lower Cuito therefore designated black). Focusing on the remainder of the basin, the wettest CC condition would substantially mitigate development even in the vulnerable Delta and Boteti areas. The driest CC condition under Medium development would for the most part have the same outcome as the original High Scenario, with significant drying out and loss of ecosystem integrity of the vulnerable Delta and Boteti.

It should be remembered that these predictions of change are conservative as they only address the direct impacts of changes in the flow regime. Infrastructure such as dams also fragments the river ecosystem affecting, for instance, fish and other migrations, gene pools, seed dispersal and sediment transport. In addition, other impacts of development, such as population movement, agricultural runoff with toxins, urban waste waters and more will add to the impact on the ecosystem in ways not explored here.

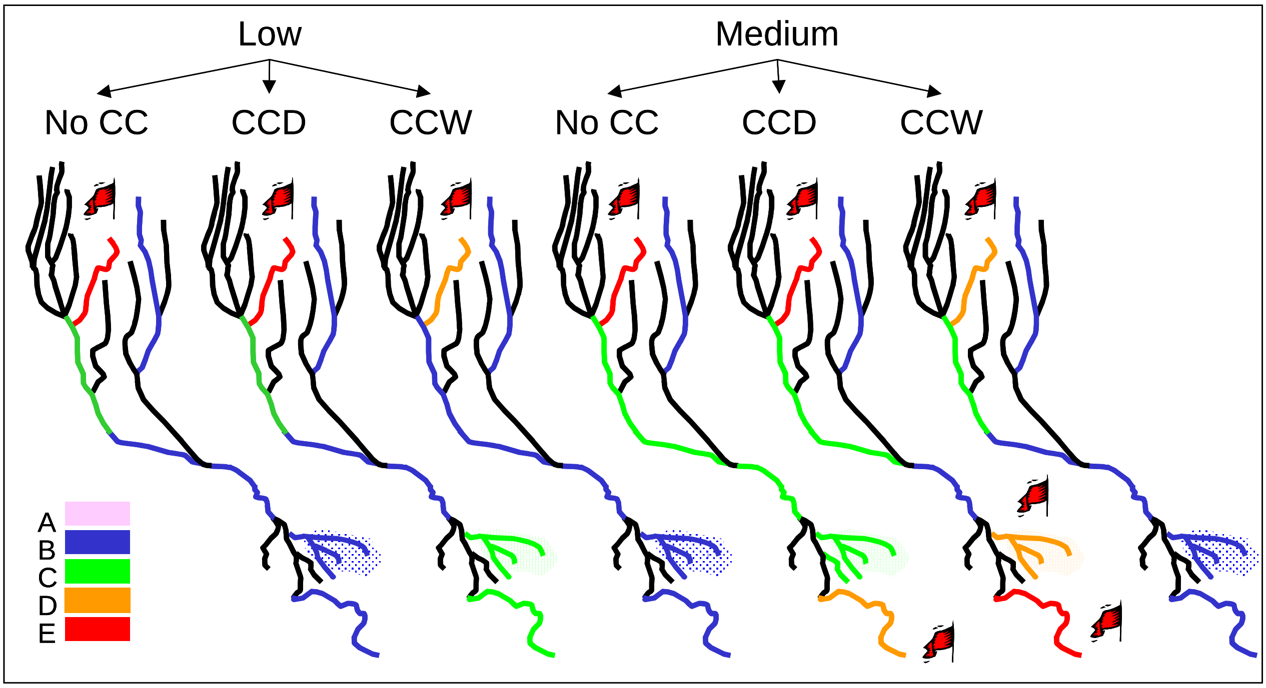

Figure 4.4 **Summary of expected changes in ecosystem integrity for the Low and Medium scenarios under the two levels of climate change. Present-day conditions are estimated as B-category. No CC = without climate change; CCD = driest climate change predictions; CCW = wettest climate change predictions.**

4.1.3 Conclusion on biophysical impacts

All of the predicted impacts are likely to have been underestimated because the localised impacts of construction, the longitudinal impacts of fragmentation of the system, and the impacts of increasing human numbers have not been factored in.

It is clear that the level of development represented by the High Scenario would have a significant impact on this river system, and severely reduce the services it presently provides. This situation would be mirrored by the Medium Scenario under the driest CC condition. Until there is more certainty regarding CC predictions, it cannot be assumed that the river ecosystem will continue to support present beneficial uses beyond the Low level of development described in this project. If the wettest CC condition manifests, then development could proceed to the Medium levels used without an overall loss of ecosystem function.

4.2. Social impacts

Many of the impacts of flow change on the river ecosystem as described above translate into impacts on the livelihoods and economic welfare of the basin's people and economies through changes in abundance and availability of natural-resource products used in the basin. These changes in natural resources were applied to enterprise models that measure private net incomes (livelihoods) and economic national income (economic contribution), and which were developed for use in the natural-resource context.

Without climate change

Figure 4.5 and Figure 4.6 show the aggregate short-term responses to flow change due to the water-use scenarios, in terms of livelihoods and the direct economic contribution to national income.

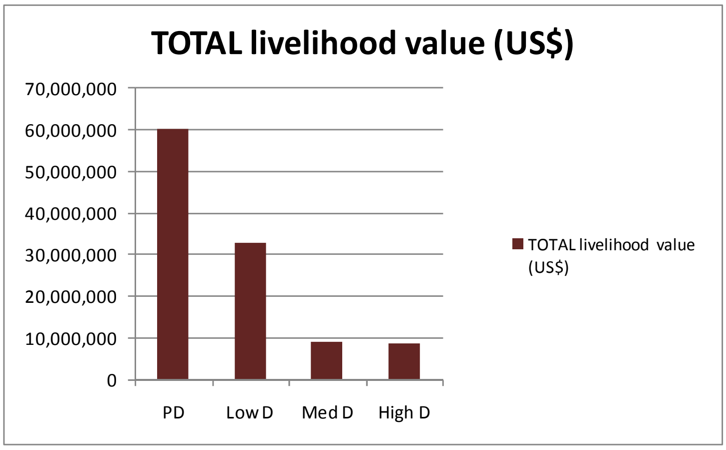

Figure 4.5 The short-term implications for livelihoods in the Okavango River Basin with present day (PD), Low development (Low Dev), Medium development (Med Dev) and High development (High Dev) water-use scenarios as a result of changing river resources (US$, 2008)

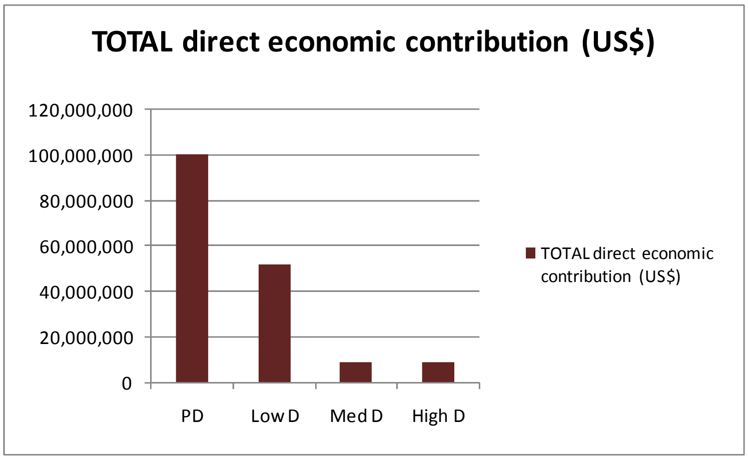

Figure 4.6 The short-term implications for direct economic income in the Okavango River Basin with present day (PD), Low development (Low Dev), Medium development (Med Dev) and High development (High Dev) water-use scenarios as a result of changing river resources (US$ 2008)

Both livelihoods and national income are predicted to decline in the scenarios, with the Medium and High Scenarios showing a massive decline. This is primarily as a result of a predicted decline in tourism. Tourism has a high value in the lower parts of the basin and the development scenarios are predicted to heavily impact this. Because of the very strong significance of the finding, a supplementary survey was carried out among Okavango delta tourism operators to determine their perceptions regarding the likely impacts of flow and flood change on their operations. The survey indicated a complex short term response (Figure 4.7), with turnover dropping by up to 15% if changes in the flood regime were to make the delta significantly wetter or drier. This information was combined with data on two delta aspects that influence tourism: channel low-flow levels, and wildlife abundance. Then responses were applied to the tourism enterprise model to measure changes in occupancy levels and consequent effects on net incomes (livelihoods) and value added (economic contribution). The results confirmed the initial findings. Relatively small, sustained reductions in tourism demand would severely reduce these values.

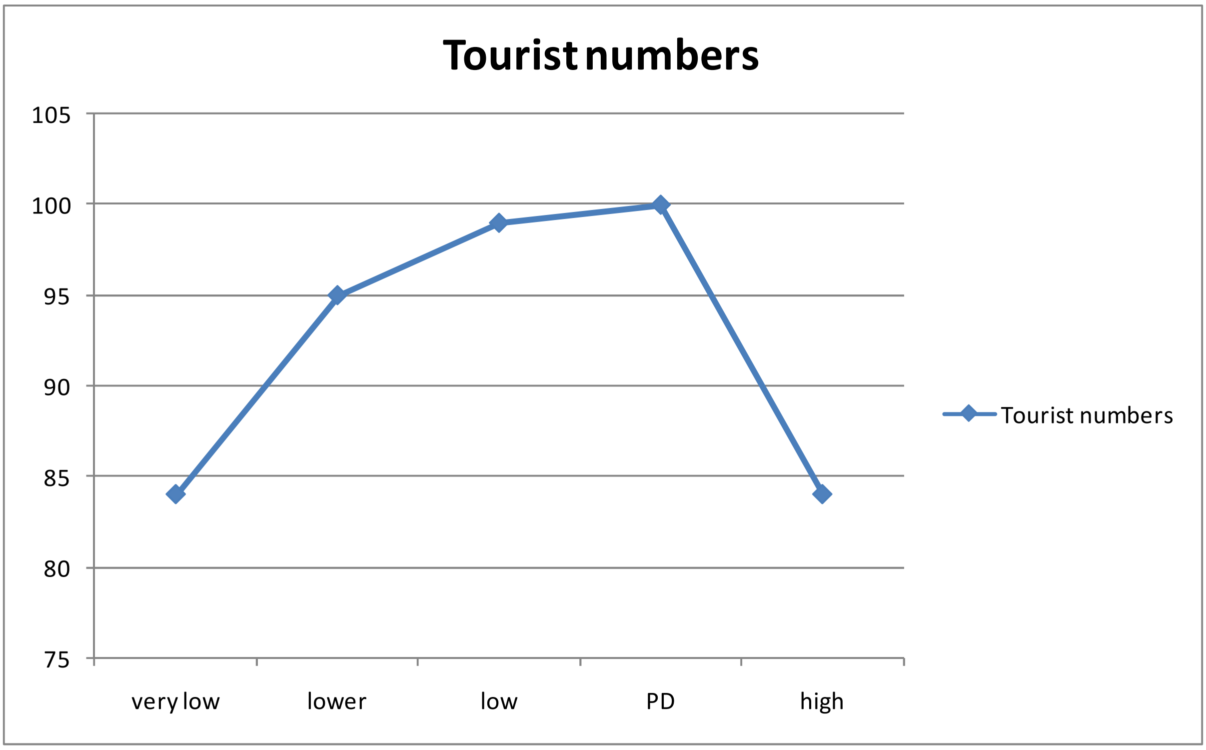

Figure 4.7 **The expected short term changes in tourist numbers predicted by tourism operators in Botswana (% of present day (PD), which equal 100%), in the face of four different changes to average flooding levels (2008)**

By its nature the EFA socio-economic model determined only short term impacts on livelihoods and economies, and did not consider medium and long-term long adaptation in the basin tourism sector, or changes such as those expected from human population growth and tourism demand growth. These were incorporated into the next stage of the analysis, which was done outside the IFA and is reported upon in the TDA.

4.3. Macro-economic impacts

These are reported in the TDA Report.

5. The way forward

At the final meeting of the basin-wide IFA team, recommendations were lodged for research to provide the kinds of data that would most have improved the confidence in their predictions of ecosystem changes in response to flow changes. Discussions also took place on desirable features of a follow-up, research-based IFA.

5.1. Further research

In the IFA, some new data were collected but the major dependence was on expert opinion from specialists. They developed their understanding of the system through visiting the eight sites, and by reviewing existing data and knowledge of the Okavango and similar river systems. The basin-wide IFA team unanimously stressed that the exercise should be seen as a data-poor first estimate of the changes likely with development and that focused research on specific topics is essential to ratify their predictions of development-driven change (Table 5.1).

Table 5.1 Recommended research to refine predictions of development-driven ecosystem and social change

a) Hydrology and hydraulics

Research Need	Detail
Groundwater data	1. Upgrade present stations and install more 2. Develop a structured programme for monitoring water levels in wells 3. Establish groundwater-surface water relationships
Floodplain inundation	1. Obtain satellite images of dry and wet seasons 2. Monitor the extent of inundation, linked to flow 3. Take weekly water-level readings at pump stations such as Popa Rapids 4. Complete topographic surveys of all major floodplains and produce DTMs 5. Develop flow-inundation relationships for all major floodplains
Map	Create a geohydrological map (1:250 000) of the complete Okavango Basin
Training	Develop and run appropriate modelling training courses
Autographic stations	Botswana: improvement and monitoring

b) Fluvial geomorphology

Research Need	Detail
Sediment dynamics	1. Obtain data on sediment contributions of all tributaries to lower river and particularly to the Delta 2. Ascertain composition of sediments by grain size
Rates of change	Scroll bars are old river courses: need to know their age and when/why new channels form
Rare habitat	Angolan border to Popa Rapids: middle river reaches with rocky-bed islands, rare riverine forests and rare rocky-pool habitat. Needs study and to be represented in any further IFA work

c) Water quality

Research Need	Detail
Monitor surface waters	1. Monthly coordinated sampling programme for 12 sites per country 2. Basin-wide standardised sampling and analysis protocol, including methods for analysing the very low nutrient levels that have biological implications
Monitor groundwater	Water quality analysis of all wells
Establish laboratories	Angola: 1 national lab; strengthen existing labs; 5 field labs Namibia: 1 field lab Botswana: 1 field lab
Training and literature	Sampling and analysis procedures; water-quality management
Equipment	Funds needed for acquiring and maintaining boats, vehicles, field equipment, consumables
Flow-quality relationships	In-depth research of daily flows and water quality to establish how the various chemical constituents change with flow changes

d) Vegetation

Research Need	Detail
Survey	Coarse-level basin-wide survey of abundance and spatial distribution of riverine vegetation, to be undertaken by joint basin-wide team
Inundation	Relationship between composition of the various vegetation communities and depth, frequency and timing of inundation
Relation to groundwater	Research on the relationships between riverine vegetation and groundwater
Resource use	Research on the impacts of use on natural river resources, and sustainability levels
Chemical and sediment links	Establish the links between riverine vegetation communities, water chemistry and sediments

e) Aquatic invertebrates

Research Need	Detail
Basin-wide monitoring	1. Coordinated sampling programmes across the basin, at sites used for water-quality monitoring at key times in annual flow cycle 2. All samples linked to discharge and local hydraulic conditions (depth, velocity, substratum particle size) 3. Identify and include in monitoring potential disease-bearing species for people, livestock and wildlife
Habitats and life cycles	Research on habitat needs and life cycle attributes of important rare species, pest species and major food species for fish and birds

f) Fish

Research Need	Detail
Fish communities	Basin-wide coordinated survey of fish species, in terms of abundances and distribution
Fish migration	Establish natural migratory patterns along the river system and laterally onto floodplains, and links with flow regime
Fish life cycles	Habitat use and partitioning throughout life cycles of important fish species, and links with flow regime
Floodplain dependence	Specific study of relationship between floodplain flooding, food availability and fish population dynamics; major focus on small floodplain fish species, which are critical part of food chain
Fisheries	Fish harvesting by subsistence and commercial fishers

g) Birds

Research Need	Comment
Refine list of suitable indicators	Some bird species do not show a marked predicted response to flow changes. Need to refine list of indicator groups to include only those that are sensitive to flow changes
Bird counts	Repeat counts at points along the system but especially in Angola, linked to flow regime
Data analysis	Where count data are available, analyse in terms of links to flow regime and other environmental variables. Coordinate throughout basin, as birds are very mobile.
Food chains	Research food sources of key species in each indicator group, and links with flow regime and life cycles

h) Wildlife

Research Need	Comment
Links to flow regime	Response of major indicator groups to different parts of the flow regime; and links between migrations and the timing, duration and intensity of flooding
Links to vegetation	Seasonal changes of major indicator groups in habitat use and food sources
Interdisciplinary research	Coordinated basin research for hydrologists, vegetation and wildlife specialists, for better interpretation of results and production of predictions
Small mammals and herpetofauna	Any research on abundances, distribution, habitat use and links to flow regime

i) Data sharing, literature and economics

Research Need	Comment
Data sharing	Need basin-wide data-sharing agreement and protocol
Accessibility	Need programme to promote communication of technical knowledge to governments and non-technical stakeholders
Library	Need a shared library and database with a dedicated secretariat so that research and monitoring data are quickly accessible for planned studies
Indicators	With understanding gained in the present project, all specialists wish to re-visit their lists of indicators in a joint workshop environment, to refine them preparatory to further coordinated research
Networking	Need a means for basin river specialists to keep in touch and plan joint research
Value of water	Comparative study of the different values of $1m^3$ of water used for, by example, irrigation, urban areas, livestock, industry and tourism

5.2. Recommendations for a comprehensive follow-up IFA

The IFA has provided insights into possible water-resource development trajectories and their consequences. It is limited by being based primarily on existing knowledge, and having been done by national teams with no prior knowledge of this technical field of work and, for some people, no prior knowledge of the river and its basin. The basin team has gained a substantial understanding and capacity in this branch of technical work now, and is in a position to prioritise the work that needs to be done in order to refine predictions and plan a programme of activities for OKACOM to approve and take forward to seek funding. Some of the basic features of this next desired stage that they recommended are:

- maintain the same basin team, and allow for other specialists as required
- establish a networking facility for specialists to share ideas, attend joint field work and share data
- allow time for basic research, as outlined above – this should be of the order of 3-5 years if possible, and should be carefully focused by experienced IFA specialists in order to produce the kinds of data needed
- plan an early basin-wide team meeting to re-visit the indicator lists for each discipline, so that research is focused on suitable species and river features
- arrange that team members visit the sites in all three countries, not just those in their own country, so that they develop a basin-wide understanding of the river system and its users
- increase the number of sites, adding, for instance, one at the confluence of the Cuito and Cubango
- include the two transitional flow seasons between the wet and dry seasons, as the rapidity of the transition dictates, *inter alia*, the composition of the floodplain vegetation communities.

5.3. Dissemination of IFA

The IFA done for the Okavango system used an internationally recognised, structured and advanced process to produce results that can inform stakeholder discussions and government decisions on sectoral water allocations. The project outputs prove the ability of OKACOM and BIOKAVANGO to produce relevant and informative results, and form a substantial foundation upon which to seek further funding. They are of interest not only in the Okavango basin, but also regionally and internationally, and so it is strongly recommended that an early agreement be reached as to how this work should be disseminated in the international literature.

6. Conclusion

The developments included in this analysis have the potential to lead to transboundary ecological and social impacts. Basin-wide planning can address this, leading to truly sustainable water-resource development. The concept of 'development space' (King and Brown in press) can aid such basin-wide discussions on a way forward (Figure 6.1). Development Space is defined as the difference between current conditions in the basin and the furthest level of development found acceptable to governments and other stakeholders through consideration of the scenarios. Beyond this point, the costs in terms of ecosystem degradation could be perceived by at least some stakeholders and governments as outweighing the benefits of development. Negotiations could apportion the recognized Development Space among countries in an agreed way that leads to a basin development plan. Countries could then be free to develop their water resources within the limits defined by the plan, or to reserve that right for the future, or to develop in ways that do not impact the ecosystem.

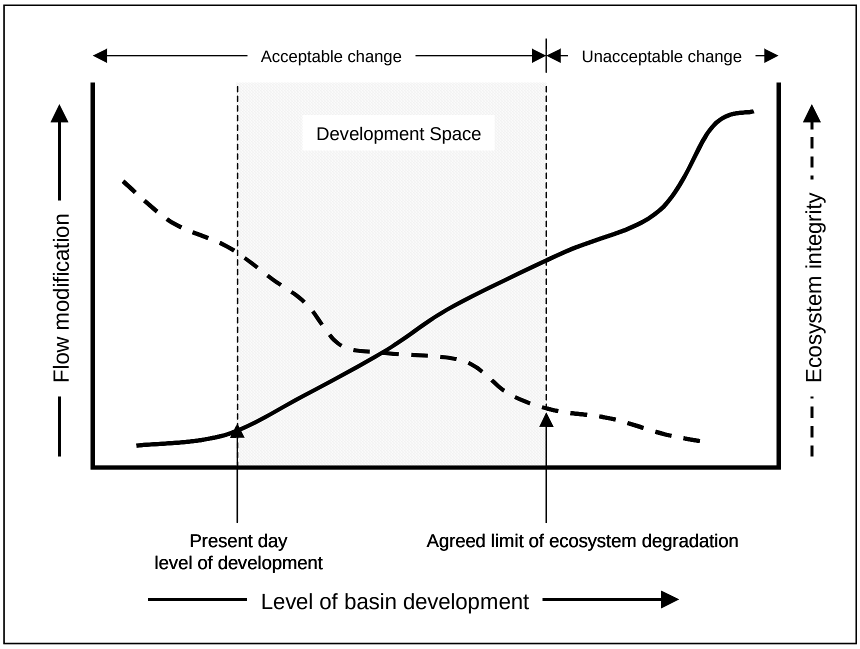

Figure 6.1 The concept of Development Space, which is defined by Present Day conditions and the negotiated limit of ecosystem degradation as basin development proceeds.

Defining the Development Space is essentially a political exercise that searches for a trade-off between costs and benefits, based on the ecological impacts, impacts on rural users of the river, and overall national interests. The concept promotes a new perspective on water-resource development that consists of first identifying the limit of socially-acceptable degradation of an inland water ecosystem and then devising ways of living and developing within that limit. This is the opposite of the historical practice in basins worldwide where transboundary conflict over water is now arising (Pearce 2006). In such historical situations, a need is identified and then development proceeds, and then another need and another development, and so on, with no overall plan for managing change and thus no control over the ability of the ecosystem to sustain valued services.

7. References

King, J.M. and Brown, C.A. 2009 (in press). Integrated Basin Flow Assessments: concepts and method development in Africa and South-east Asia. Special Issue of Freshwater Biology.

Pearce F. 2006. When the rivers run dry: water - the defining crisis of the twenty-first century. Beacon Press, Boston. 368 pp.

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*
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