Okavango River Basin Transboundary Diagnostic Analysis Technical Report

OKACOM

The Permanent Okavango River Basin Water Commission

Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 1 of 4) Report No: 07/2009

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Environmental protection and sustainable management of the Okavango River Basin

EPSMO

ENVIRONMENTAL FLOW ASSESSMENT SERIES

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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 7 (Volume 1) in the report series for the EFA. It details the three water-resource development scenarios chosen for the project; the sites along the system; and the 70 indicators chosen to describe change. It then describes the predicted hydrological change at each site under each scenario, and the response of the river under seven main groups of biophysical indicators: channel geomorphology, water quality, vegetation, aquatic invertebrates, fish, birds and wildlife. These river changes are then interpreted as impacts to users of the river, using 12 indicators in four main groups: household incomes, wellbeing, macro-economics and ecological services. It concludes with a discussion of important aspects of the scenarios.

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All photographs that are not acknowledged in the text are by J.M. King and C.A. Brown.

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Acronyms and abbreviations

DWAF	Department of Water Affairs and Forestry
EFA	Environmental Flow Assessment
EPSMO	Environmental Protection and Sustainable Management of the Okavango River Basin
Ha	hectare
HOORC	Harry Oppenheimer Okavango Research Centre
IUA	Integrated Units of Analysis
PD	Present Day
SAP	Strategic Action Programme
TDA	Transboundary Diagnostic Analysis

1. INTRODUCTION

1.1. Project background

The origin of the project is described in Report 01/2009: Project Initiation Report. Essentially, an OKACOM initiative titled the Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) project was approved by the United Nations Development Program (UNDP), to be executed by the United Nations Food and Agriculture Organization (FAO). In 2008 it collaborated with the Biokavango Project at the Harry Oppenheimer Okavango Research Centre (HOORC) of the University of Botswana, to conduct a basin-wide Environmental Flows Assessment (EFA) for the Okavango River system. This would be a major part of a standard UNDP process: a Transboundary Diagnostic Analysis (TDA) followed by a Strategic Action Programme (SAP) of joint management to address threats to the basin's linked land and water systems. In the case of the Okavango Basin, the standard approach, designed for rehabilitating degraded rivers, would be modified because of the near-pristine nature of the river ecosystem.

The EFA began with a Planning Meeting in July 2008 and was finalised in June 2009. It used mainly existing knowledge and understanding of the river ecosystem and its users. It was generally acknowledged that this was a first, low-confidence, trial run of an EFA for this system, which should be followed by a more comprehensive and long-term exercise where important missing data and knowledge could be addressed to provide higher-confidence predictions.

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. Recap of process and earlier reports

The EFA ran over 12 months, from July 2008 to June 2009. The principal features and their timing were:

- a Planning Meeting (July 2008)
- a Basin Delineation Workshop (September 2008)
- a basin field trip (October 2008)
- a series of hydrological team meetings (September 2008 to May 2009)
- specialist discipline studies and report writing (November 2008 to May 2009)
- development of Decision Support System (DSS) software to capture the specialists' knowledge (November 2008 to May 2009)
- a Knowledge Capture Workshop (April 2009)
- a Scenario Workshop (May 2009).

The full report series produced by the EFA is listed at the beginning of this report, with a summary of the contents of each detailed below.

1.3.1 Report 01/2009: Project Initiation Report

Details the origin of the project, including the July 2008 Planning Meeting and the agreed work plan.

1.3.2 Report 02/2009: Process Report

Describes the technical process followed in the EFA, including the division of the basin into homogeneous units and choosing of representative sites, the data collection and knowledge capture exercises, the hydrological modeling, the choice of indicators with which to describe expected development-driven change, and the nature of the DSS.

1.3.3 Report 03/2009: Guidelines for data collection, analysis and scenario creation

A set of guidelines for basin delineation; site selection, estimating ecological condition of the sites, scenario selection, indicator selection, data collection, Response Curves construction (these describe the flow-ecosystem and ecosystem-social impact relationships), and report writing.

1.3.4 Report 04/2009: Delineation Report

The results of the September 2008 workshop, containing the following: basin location and characteristics; river zonation; delta zonation; socio-economic zonation; Integrated Units of Analysis; and selected study sites/zones. Eight representative sites were chosen along the system: three in Angola, two in Namibia and three in Botswana. Each would be linked to specific socio-economic areas so that the predictions of river change could be interpreted as predictions of social impact.

1.3.5 Report 05/2009: Hydrology Report: Data and models

The initial work of the three-country hydrological team and the international basin hydrologist, including choosing and setting up the hydrological and hydraulic models, field data collection, hydrological and geohydrological data and information, water-resource development information, and data and information sharing arrangements.

1.3.6 Report 06/2009: Scenario Report: Hydrology

Details the initial part of the scenario descriptions, including the scenarios chosen, and the hydrological outcomes for all eight sites along the system.

1.3.7 Report 07/2009: Scenario Report: Ecological and social predictions

This report.

1.3.8 Report 08/2009: Final Report

A short report of the project for contractual purposes.

1.4. The scenarios

Through a process of government consultation, three scenarios of increasing water-use were chosen for the EFA. The details are provided in Report 06/2009: Scenario Report: Hydrology, and in Chapter 3 of this report.

1.5. Limitations

The project faced financial, time and knowledge constraints that influenced its outputs. The major of these limitations were as follows:

- A limited budget, which resulted in various important parts of the process having to be excluded, such as training exercises at key points in the process, in-depth review of the specialist reports and production of a glossy information brochure in accessible language for water managers and decision makers.
- Limited warning of the project beginning, which meant that all team members were over-committed throughout the project.
- Limited time to complete the work, which meant that the project ran on available data and general expert knowledge of the system; virtually no new data were collected, even where uncertainty was extremely high.

Despite this, the project stimulated a very strong and constructive team spirit and an inter-basin collaboration that appears set to continue long after it ends.

1.6. Presentation of the results

1.6.1 Rivers and delta

For each scenario, the predicted changes in the river and delta are evaluated in three ways:

1. time-series of abundance, area or concentration of key indicators (see list in Chapter 2.7) under the flow regime resulting from each scenario (Appendix 2);
2. estimated mean percentage changes from present day in the abundance, area or concentration of key indicators (Appendix 2, with a summary in Chapter 4);
3. estimated change in discipline-specific integrity, relative to present day (Section 5.4)
4. estimated change in overall ecological integrity, relative to present day (Section 5.5.

1.6.2 Societal wellbeing

The impact on local communities is assessed in terms of changes in wellbeing as a result of the changes in tangible and intangible benefits derived from the use of water and aquatic ecosystem resources. These changes are expressed as:

- Change in household income from agricultural activities likely to be affected by change in water flow,
- Change in household income from natural resources use likely to be affected by water flow.

These values include own consumption of products and cash income. They include the net incomes (profits) derived by community members while using natural resources, as well as wages and salaries derived by them from employment in natural resource use, e.g., tourism. These values are summed to estimate overall change income, and reflect the contribution made by river/wetland resources to livelihoods in the basin. Then the impact of water use scenarios on these values is measured, using the EFA model, for each IUA in the basin, for each of the three countries, and for the basin as a whole.

All livelihood values are expressed as the aggregate for all households in the affected area. The overall value is expressed as a percentage change in overall household income, taking all other sources of household income into account. Note that the percentage change might not apply to individual households, since this value might be shared by more households under an expanded population.

Other measures of societal well being are those that impact on the broader society in each country. These include the impact of the natural resources use described above in the national income, including income not just for community members, but also for all other stakeholders in society. National income change is a macroeconomic measure as linking up with the economic values in 1.7, below. Other broader measures for societal wellbeing which were assessed include indirect use values derived from ecosystem services in the wetlands. These include the value derived from carbon storage, water purification, core wildlife refuge values, and so on. Intangible impacts as reflected in existence value and cultural value are expressed as the percentage change in overall recreational and spiritual wellbeing, taking other intangible sources of wellbeing into account.

1.7. Economic value

In a separate exercise, the same three development scenarios were assessed in terms of their development benefits. This involved assessment of the macroeconomic impacts of water use developments in the scenarios, including those of hydropower, irrigation, and water extraction for domestic and urban use. These macroeconomic benefits as measured in change to the national income, were assessed in comparison to the losses in national income from flow related river/wetland natural resource uses as measured in the EFA model.

1.8. Layout of the report

Chapter 1: Introduction
Chapter 2: Location and description of the EF sites
Chapter 3: A listing and explanation of the indicators
Chapter 4: A description of the chosen scenarios in terms of the location and specifications of each chosen water-resource development, a summary of the changes in the flow regime under each scenario at each site
Chapter 5: The predictions of biophysical change per scenario
Chapter 6: The predictions of overall change in ecosystem integrity, per scenario
Chapter 7: The predictions of socio-economic change
Chapter 8: Conclusions

2. The EF sites/reaches and IUAs

2.1. The location of the ecological sites and links with IUAs

The number, and to some extent the position, of the eight biophysical sites was dictated by financial, time and safety constraints, and they did not represent the entire basin. The locations of the eight sites, chosen in an exercise described in Report 04/2009: Delineation Report, are given in Table 2.1 and Figure 2.1. These sites are described in Section 2.2.

Each biophysical site corresponded to a wider, socio-economic Integrated Unit of Analysis (IUA), where it was used to represent the predicted river changes that would affect people. These IUAs are described in Section 2.3.

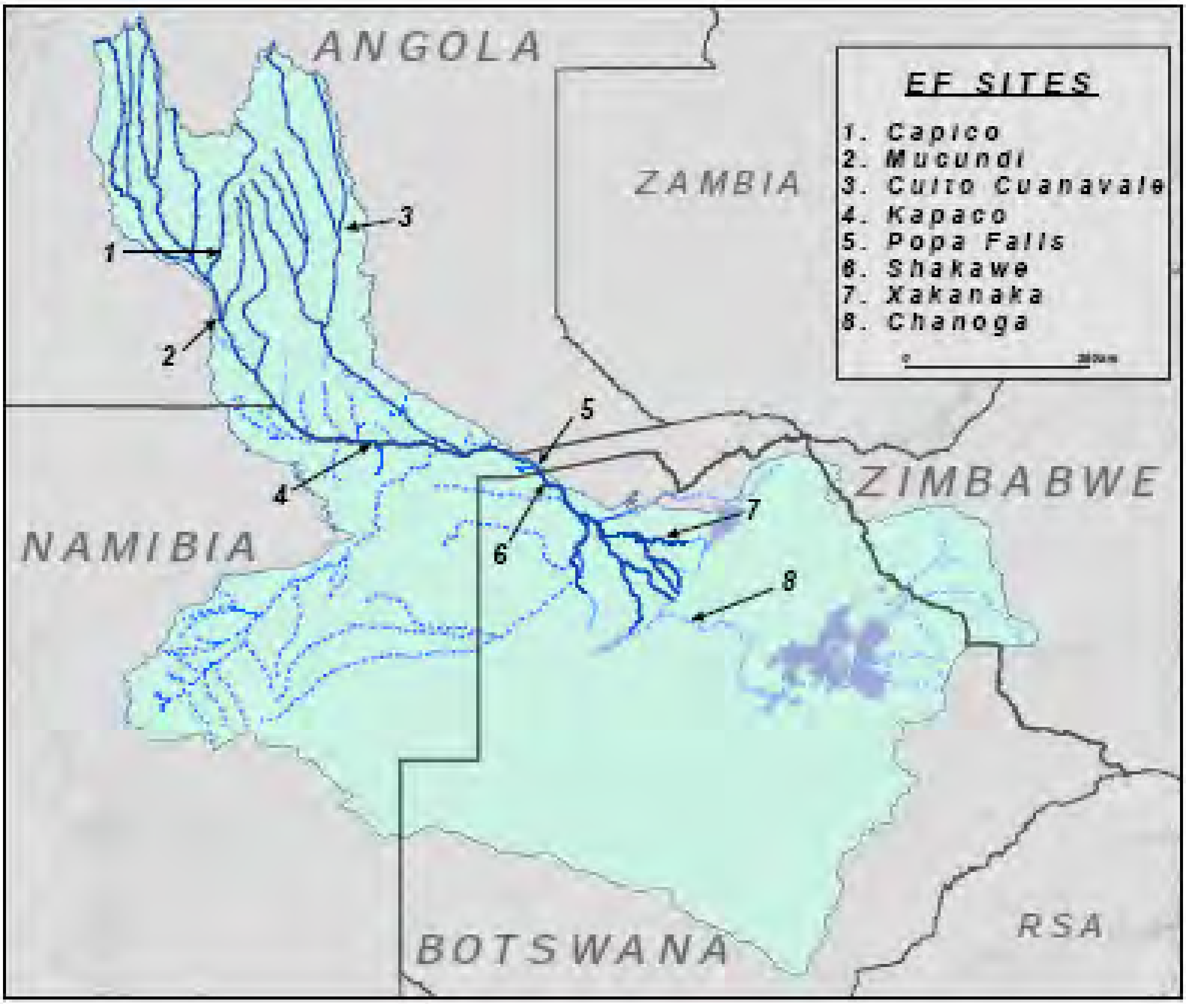

Figure 2.1 **Map showing site locations**

Table 2.1 The Environmental Flow (EF) sites and their corresponding socio-economic Integrated Unit of Analysis (IUA)

EF Site	EF Site name	Coordinates	Socio-economic IUA
1	Cuebe @ Capico	15° 33' 05" S 17° 34' 00" E	3
2	Cubango @ Mucundi	16° 13' 05" S 17° 41' 00" E	2
3	Cuito @ Cuito Cuanavale	15° 10' 11" S 19° 10' 06" E	6
4	Okavango @ Kapako	17° 49' 07" S 19° 11' 44" E	8
5	Okavango @ Popa Falls	18° 07' 02" S 21° 35' 03" E	9
6	Okavango @ Panhandle	18° 21' 16" S 21° 50' 13" E	10
7	Okavango Delta @ Xaxanaka	19° 11' 09" S 23° 24' 48" E	11
8	Boteti	20° 12' 51" S 24° 07' 37" E	12

The location of the study sites resulted in portions of the catchment for which no predictions were possible in this study. These are indicated in Figure 2.2.

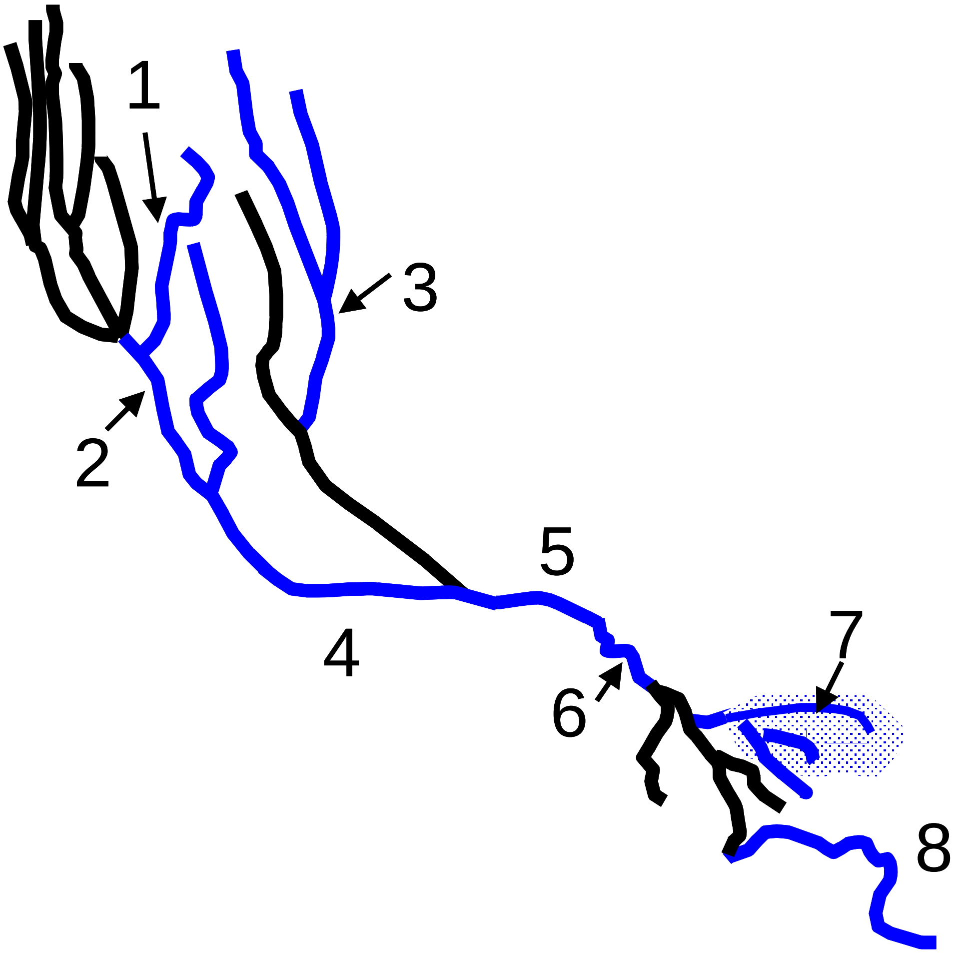

Figure 2.2 Sketch map of the main channels in the Okavango Basin and the location of the study sites. Channels not represented in the study are shown in black, and those represented are in blue.

2.2. Biophysical sites

2.2.1 Site 1: Cuebe River at Capico, ANGOLA

Location: At Capico on the Cuebe River, Angola.
River reach: Cuebe River from downstream of Menongue to the confluence with the Cubango River.
Photographs: Figure 2.3 - Figure 2.5.

Figure 2.3 Site 1: Cuebe River at Capico during the lowflow season (October 2008)

Figure 2.4 Site 1: Cuebe River at Capico showing the gauging weir in the lowflow season (October 2008)

Figure 2.5 **Site 1: Cuebe River at Capico in the flood season (March 2008). Note the top of the gauging weir in the middle of the picture. (Photo Helder André de Andrade e Sousa)**

2.2.2 Site 2: Cubango River at Mucundi, ANGOLA

Location: At Mucundi on the Cubango River, Angola.
River reach: Cubango River from downstream of confluence with the Cuebe River to the Namibian border.
Photographs: Figure 2.6 - Figure 2.8.

Figure 2.6 **Site 2: Cubango River at Mucundi in the lowflow season (October 2008)**

Figure 2.7 Site 2 Cubango River at Mucundi in the lowflow season (October 2008)

Figure 2.8 Site 2: Cubango River at Mucundi in the flood season (March 2009; Photo Helder André de Andrade e Sousa)

2.2.3 Site 3: Cuito River at Cuito Cuanavale, ANGOLA

Location: At Cuito Cuanavale on the Cuito River.
River reach: Cuito River from downstream of confluence with the Cuanavale River to downstream of Cuito Cuanavale.
Photographs: Figure 2.9 and Figure 2.10.

Figure 2.9 **Site 3: Cuito River at Cuito Cuanavale in the lowflow season (November 2007; Photo Manuel Quintino).**

Figure 2.10 **Site 3: Cuito River at Cuito Cuanavale in the lowflow season (October 2008)**

2.2.4 Site 4: Okavango River at Kapako, NAMIBIA

Location: At Kapako on the Okavango River, Namibia.
River reach: Okavango River from Kitwetwe to Rundu.
Photographs: Figure 2.11 and Figure 2.12

Figure 2.11 Site 4: Okavango River at Kapako in the lowflow season (October 2008).

Figure 2.12 Cattle grazing on the floodplain at Site 4: Kapako in the lowflow season (October 2008).

2.2.5 Site 5: Okavango River at Popa Falls, NAMIBIA

Location: At Popa Falls on the Okavango River, Namibia.
River reach: Okavango River at Popa Falls.
Photographs: Figure 2.13 and Figure 2.14.

Figure 2.13 Site 5: Okavango River at Popa Falls in the lowflow season (October 2008)

Figure 2.14 Aerial view of Site 5: Okavango River at Popa Falls in the lowflow season, showing the whole reach. Flow direction is from right to left. (Photo: Colin Christian)

2.3. Site 6: Okavango River at the Panhandle, BOTSWANA

Location:	At Drotsky's Fishing Camp in the Panhandle, Botswana.
River reach:	Okavango River at the Panhandle.
Photographs:	Figure 2.15 to Figure 2.17.

Figure 2.15 Site 6: Okavango River - erosion on bends in the Panhandle in the lowflow season (October 2008)

Figure 2.16 Site 6: Marginal vegetation along the Okavango River in the Panhandle in the lowflow season (October 2008)

Figure 2.17 Site 6: Ungrazed floodplain along the Okavango River in the Panhandle (October 2008)

2.4. Site 7: Okavango Delta at Xaxanaka, BOTSWANA

Location: At Xakanaka in the western portion of the Okavango Delta, Botswana
River reach: Western portion of the Okavango Delta.
Photographs: Figure 2.18 to Figure 2.21.

Figure 2.18 The Okavango Delta (Photo: Colin Christian)

Figure 2.19 Site 6: Okavango Delta at Xaxanaka in the lowflow season (October 2008)

Figure 2.20 Site 6: Backwater in the Okavango Delta at Xaxanaka in the lowflow season (October 2008)

Figure 2.21 Site 6: Heronry in the Okavango Delta at Xaxanaka in the lowflow season (October 2008)

2.5. Site 8: Boteti River, BOTSWANA

Location: Boteti River, Botswana.
River reach: Boteti River from the confluence with the Talamakane River for 200 km downstream.
Photographs: Figure 2.22 - Figure 2.24.

Figure 2.22 Site 8: Boteti River, Okavango during the lowflow season (October 2008).

Figure 2.23 Site 8: Lagoon on the Boteti River, Okavango during the lowflow season (October 2008).

Figure 2.24 Site 8: Boteti River, Okavango, with animals, during the lowflow season (October 2008).

2.6. Social IUAs

The delineation report (04/2009) describes the process of delineation of IUAs after consideration of all biophysical and socio-economic features of the basin. The final delineation can be described in terms of the socio-economic characteristics as the socio-economic impacts generally come last and effectively tie up the results of the EFA model. Figure 2.25 shows the 12 IUAs schematically.

Angolan IUAs 1 to 4 were delineated in the Cubango arm of the basin. In the Cubango arm, floodplains are rare and river courses are relatively incised. The basement geology has mostly been exposed, leaving little Kalahari sand cover. The IUAs here were delineated on the basis of topography, ecology, population density, urbanisation and the future likely water use developments. Thus, IUA 1 covered the high rainfall, high altitude upper reaches where parallel tributaries drain an open upland savanna, the soils are medium textured, and there is a high density of people. Rainfed crop production with maize is the most important land use. IUA 2, including the town of Cuchi, was similar but lower, less incised, slightly drier, slightly less densely settled and it contains small areas of Kalahari sand woodlands. It contained field study site 2, at Mucundi. IUA 3 was specific to the Cuebe River catchment and included the city of Menongue. Here the situation was similar to that of IUA 2 but there were some water quality issues surrounding the city, and there was some irrigation of crops and plans for much more. The field study site 1 at Capico was included here.

Angolan IUAs 5 to 7 were delineated for the Cuito arm of the basin. These were relatively uninhabited, pristine, and occupied by Kalahari sand woodlands. Floodplains were more significant here than in the Cubango arm, and water flow variation was much more seasonally stable. The three IUAs here were separated on the grounds of rainfall (from humid to semi-arid), on the basis of crops grown (cassava is the main crop grown in the upper part), the presence of an urban area (Cuito Cuanavale) and on the basis of future water use developments (likely to be in the lower reaches). Field study site 3 at Cuito, was situated in IUA 6.

Two IUAs, each with two subdivisions, were defined for Namibia, based on the presence or absence of a floodplain, flooding regime, and whether or not there was a human population. IUA 8 covered the river along the Angolan border, where human population density was high and a moderate floodplain was present. It contained the urban area of Rundu, and field study site 4 at Kapako. It was subdivided between the parts above and below the Cuito junction, which differed slightly in terms of seasonal flow regime. IUA 9 covered the river below Mukwe, where a floodplain was mostly absent and some rocky exposures occurred in the river bed. IUA 9 was subdivided into that section with a resident human population and that which was protected as Bwabwata National Park. It contained field study site 5 at Popa.

Three IUAs were defined for the Botswana part of the basin, based primarily of flooding patterns. IUA 10 formed the panhandle with a fairly wide, mostly permanently flooded plain and a moderately dense, relatively ethnically distinct human population. It contained field study site 6 at Mohembo. Fishing, and non-floodplain crops were characteristic. IUA 11 covered most of the Delta with a complex pattern of seasonal, permanent, frequent, and occasional flooding. It contained two subdivisions; moderately dense human settlement in the west, and natural protected areas used mostly for tourism in the north east. Field study site 7 at Xakanaka was in the latter subdivision. IUA 12 covered the most distal part of the active basin and as such contained ephemeral channels and more restricted, less commonly flooded floodplain. Fairly dense human settlement was present here including the urban centre of Maun. It contained field study site 8 at Boteti. Five additional IUAs, numbers 13 to 17 were classified to refer to larger urban areas, in case these could be of use in the EFA process. These were embedded within the other IUAs and not delineated spatially.

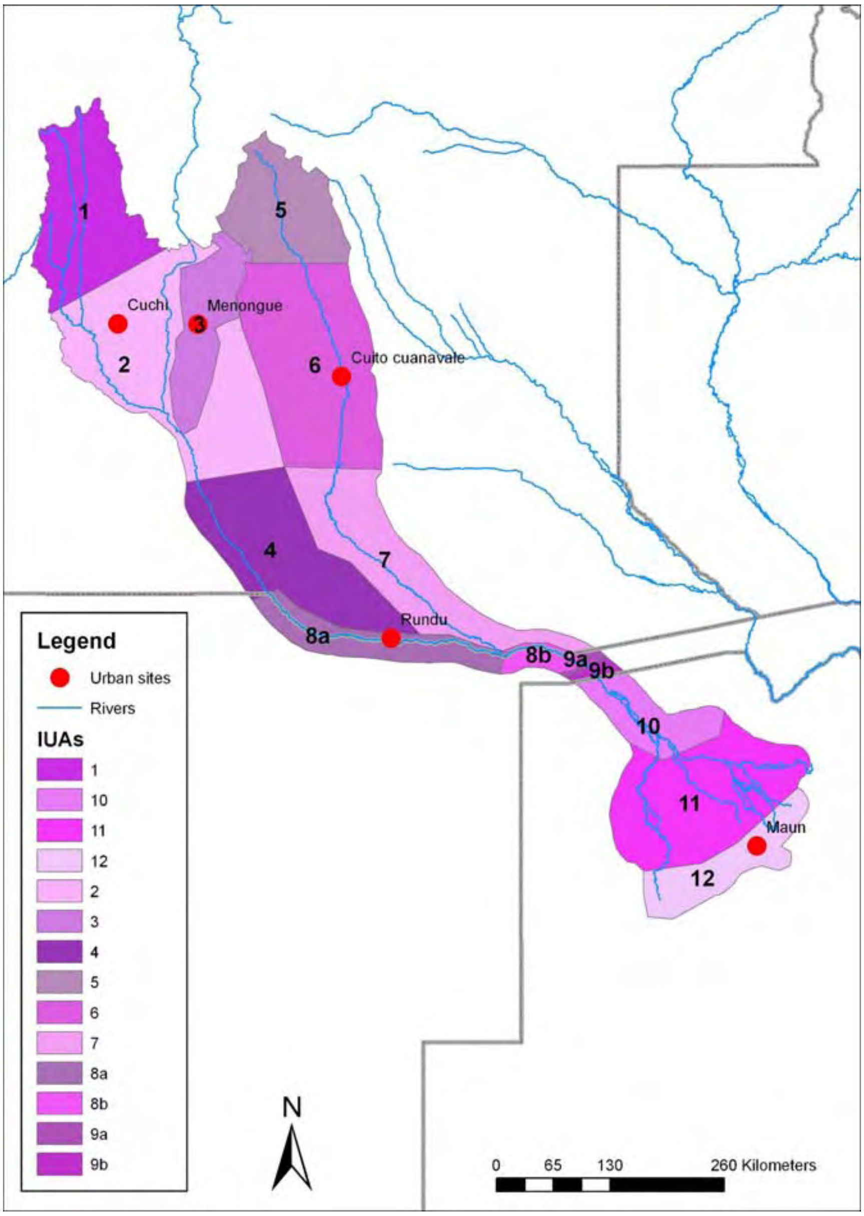

Figure 0.15 Sketch map of the IUAs delineated in the Okavango Basin

2.7. Indicators

2.7.1 The nature and purpose of indicators

In this EFA two kinds of indicators are used: biophysical and socioeconomic. They represent attributes of the ecological and social system that are thought to be either directly or indirectly linked to the river and its flow regime. Their predicted changes as flows change provide a composite picture of the ecological and social impacts of the chosen water-resource developments.

2.7.2 Biophysical indicators

Biophysical indicators are attributes of the river ecosystem that can be described in terms of abundance (e.g. number of elephants), area (e.g. area of exposed sand banks), concentration (e.g. nitrates, conductivity) or cover (e.g. vegetation communities.

Those chosen by the biophysical team for use in this project are listed in Table 0.1.

Table 0.1 Biophysical indicators used in the EPSMO/BIOKAVANGO EF process

Discipline	Sites	Indicators used
Geomorphology	1-6	Extent - exposed Rocky Habitat
		Extent - Coarse Sediments
		Cross Sectional Area of Channel
		Extent of Backwaters
		Extent of Vegetated Islands
		Sand Bars at low flow
		Percentage Clays on Floodplain
		Extent of inundated floodplain
		Inundated Pools and Pans
		Extent of Cut Banks
	7	Carbon sequestration
Water Quality	1-8	pH
		Conductivity
		Temperature
		Turbidity
		Dissolved oxygen
		Total nitrogen
		Total phosphorus
		Chlorophyll a
Vegetation	1-6	Channel macrophytes
		Lower Wet Bank (hippo grass, papyrus)
		Upper Wet Bank 1 (reeds)
		Upper Wet Bank 2 (trees, shrubs)
		River Dry Bank
		Floodplain Dry Bank
		Floodplain residual pools
		Lower floodplain
		Middle floodplain (grasses)
		Upper floodplain (trees,)
	7	Open waters
		Permanent swamps
		Lower floodplain
		Upper floodplain
		Occasionally flooded grassland
		Sporobolus islands
		Riparian woodland, trees
		Savanna and scrub

Discipline	Sites	Indicators used
	8	Open water
		Riparian woodland, trees
Macroinvertebrates	1-8	Channel-submerged vegetation
		Channel-marginal vegetation
		Channel-fine sediments
		Channel-cobbles, boulders
		Channel rapid, fast flowing
		Channel-pools
		Floodplain-marginal vegetation
		Floodplain-pools, backwaters
	Plus for 7	Mopane woodland-pools
Fish	1-8	Fish resident in river
		Migrate floodplain small fish
		Migrate floodplain large fish
		Fish-sandbank dweller
		Fish-rock dweller
		Fish-marginal vegetation
		Fish in backwaters
Wildlife	1-8	Semi Aquatics (hippos, crocodiles)
		Frogs, river snakes
		Lower floodplain grazers
		Middle floodplain grazers
		Outer floodplain grazers
Birds	1-8	Piscivores - open water
		Piscivores - shallow water
		Piscivores and invertebrate feeders
		Specialists - floodplains
		Specialists - water lilies
		Specialists - fruit trees
		Breeders - reedbeds, floodplains
		Breeders - overhanging trees
		Breeders - banks
		Breeders - rocks, sandbars

In the EFA process (Report 02/2009: Process Report), specialists draw Response Curves that describe the relationship between each indicator and each relevant part of the flow regime (Section 3.3).

2.7.3 Social indicators

The economic activities in the basin were identified and described. They were then examined and assessed to select those that might exhibit measurable value change if the river/wetland system would be subjected to flow change. These were then used as the socio-economic indicators in the EFA process. Figure 2.26 shows the full list of socio-economic indicators. Most indicators are applicable to all of the eight field study sites and 12 IUAs in the basin. The exceptions apply where, for example, there is no floodplain of significance, and thus no floodplain grazing or floodplain crop production, or where, for example, there are no resident people.

It is important to stress that the indicators selected are limited to values that are expected to change under differing water use scenarios. Some natural resource uses associated with the riverine environment provide livelihood and economic value but are unlikely to change with flow change. An example is use of riparian tree fruits, and another is irrigated commercial agricultural production. Some 2,600 hectares are irrigated in this way in the Namibian basin, contributing significant income and employment for local residents. But irrigated crop production draws water regardless of flow change. New irrigation will also form part of water use development scenarios, itself affecting water flow.

Figure 2.26: List of socio-economic indicators used in the EFA and their links to the broader economy

Possible indicators affecting human wellbeing are those related to health and disease, such as malaria, bilharzia and diarrhoea, were examined. Although their incidence is linked to the aquatic environment these were found to not be affected specifically by flow change. Other possible indicators included natural resource uses such as water lily use (*Nymphaea* sp.) for food, and use of the sedge (*Cyperus papyrus*) for mat making, were rejected as indicators either because they were considered of small import or because in some sites their use was unlikely to be affected by flow changes. Further, not all indicators have been assigned values. Where data are unavailable some relatively minor resources have been treated only in discussion, despite being recognised as possibly responsive to flow change.

The indicators in Figure 2.26 are divided firstly into those affecting both local household income, or livelihoods (indicators 1 to 8) and the broader economy, and secondly those impacting directly on the broader economy or on societal well-being (9.1 to 9.4). The table shows how these all contribute ultimately to overall social and economic wellbeing.

3. Water-use Scenarios

Three scenarios were selected for analysis, each representing an hypothetical level of water-resource development in the Okavango Basin: low, medium or high.

The process for scenario selection is described in Report 02/2009: Process Report. Water-use scenarios are not situations that will happen; rather, they are combinations of possible future water-resource developments that can be explored in terms of their implications, as an aid to planning and decision-making.

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.

3.1. Summary of the water-resource developments/abstractions that formed part of each water-use scenario

The hypothetical water-resource developments/abstractions that formed part of each water-use scenario are summarised in Table 3.1 and displayed in Figure 3.1 and Figure 3.2.

Table 3.1 The hypothetical water-resource developments included in each scenario

<table>
<tr><td rowspan="2">Site</td><td rowspan="2">Present</td><td rowspan="2">Low</td><td>Medium</td><td>High</td></tr>
<tr><td>Low schemes plus:</td><td>High schemes plus:</td></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>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>
</table>

Site	Present	Low	Medium	High
			Low schemes plus:	High schemes plus:
			HEP: Cuito Cuanavale (13 km u/s confluence). Diversion, Run-of-river. H = 7m, Qmax = 90 m3/s	
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 Calais 45 000 ha, pump intake on river bank
Site 5&6 Popa and Panhandle	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 Carrier (ENC) for water supply from Kavango to Namibia, Tower on right bank, 17 Mm3/a	Eastern National Carrier (ENC) 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

Site	Present	Low	Medium	High
			Low schemes plus:	High schemes plus:
				HEP: Cuito – Chamavera (d/s M'Pupa). Run-of-river. H = 6m, Qmax = 100 m3/s
Site 7 Khwai	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 MCM/a)

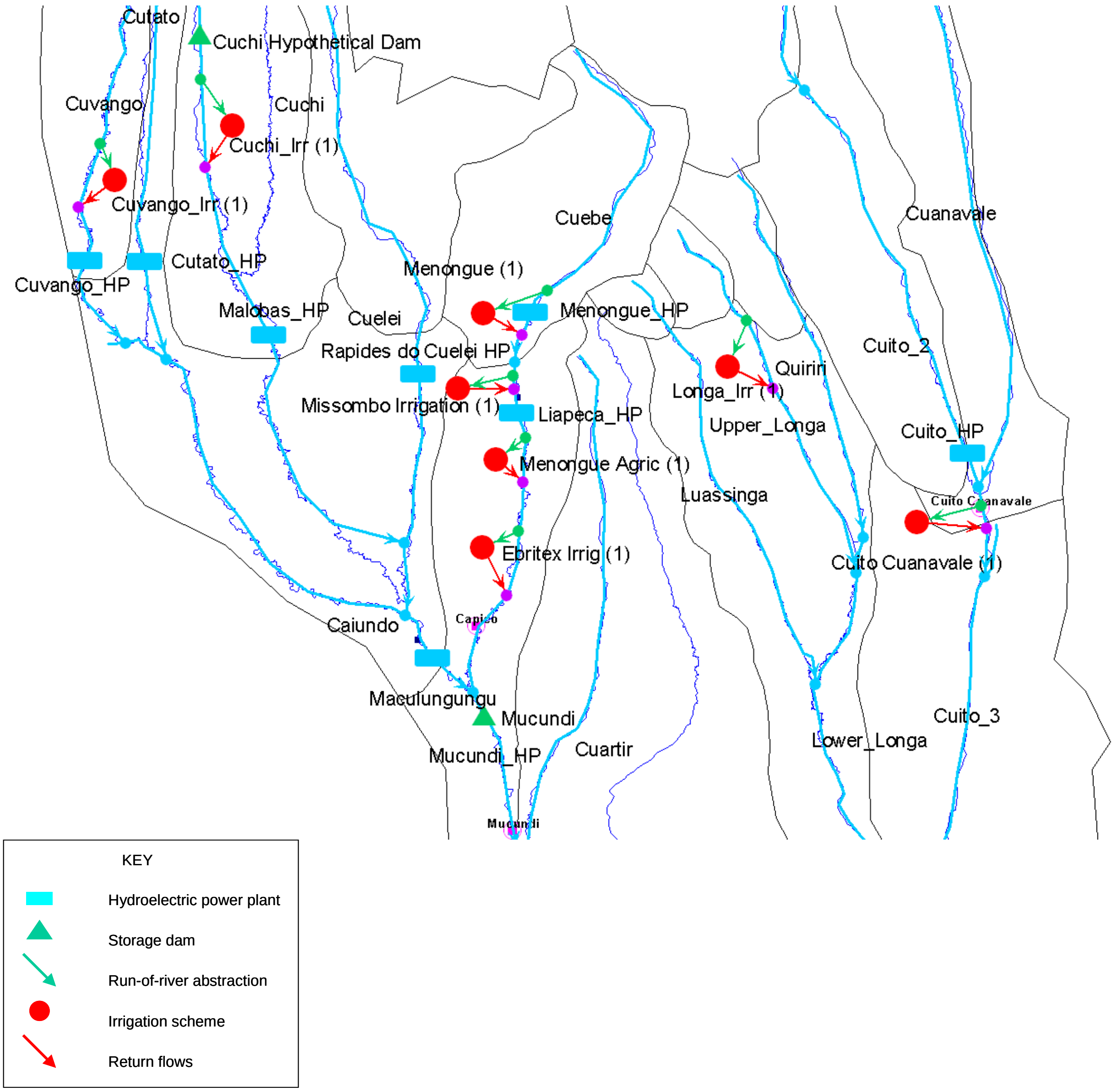

Figure 3.1 Position of water-resource developments included in the water-use scenarios in the upper portion of the catchment.

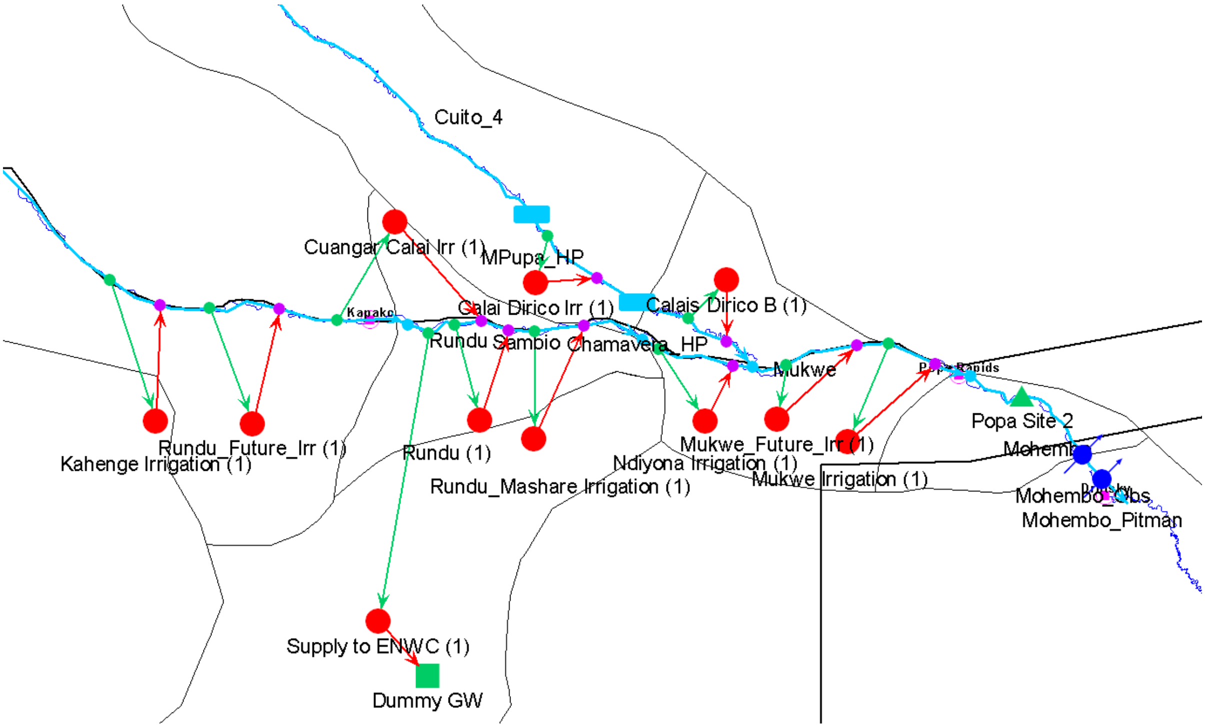

Figure 3.2 Position of water-resource developments included in the water-use scenarios in the lower portion of the catchment.

Details of the water-resource development included and the modeling thereof for inclusion in the three scenarios are provided in Report 06/2009: Scenario Report: Hydrology.

3.2. Hydrological data generated for the scenarios

The hydrological modelling for the three scenario yielded times series of daily 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 3.1 was imposed on the full hydrological period.

It is important to emphasise that the base hydrological for the period used, 1959-2001, show a declining trend in mean annual runoff (e.g., Figure 3.3). This trend was primarily driven by climatic conditions, as was borne out by a reversal of the trend in 2004-2009. Unfortunately, these more recent data were not available for the modelling exercise. They were, however, made available for certain sites during the Knowledge Capture Workshop. This meant that the biophysical specialists could calibrate their response curves using the more recent data. For the hydrological modelling of the scenarios, however, 'present-day' was represented by a simulated record for 1959-2001.

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.

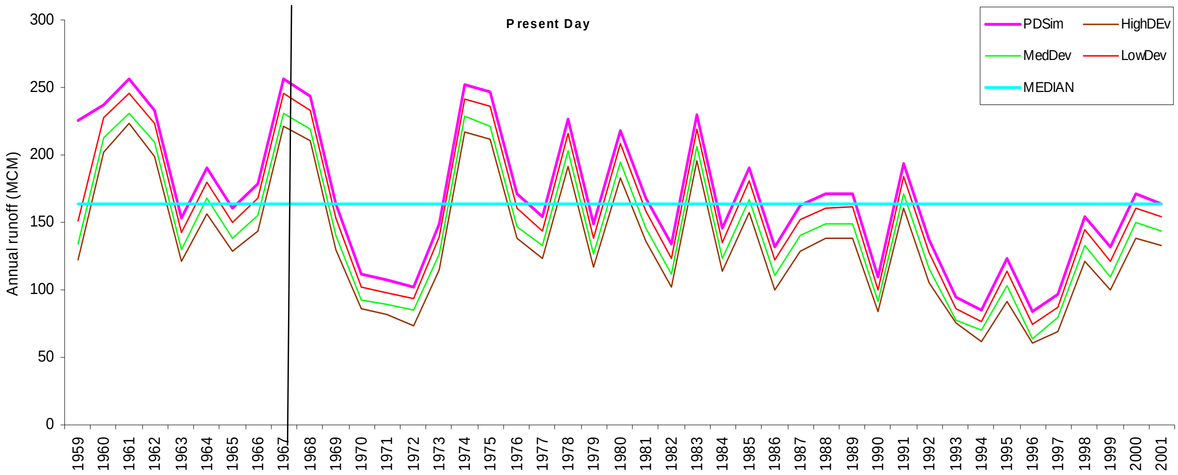

Figure 3.3 Annual runoff data for Site 4: Kapako (1959-2001).

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.

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. For instance, the high scenario at Site 4: Kapako, comprises the 1959-2003 period and assumes that all of the upstream developments envisaged in the high scenario would be in place for the entire time.

3.3. The ecologically-relevant summary statistics for the river sites (Sites 1-6)

The time series of daily flows were analysed using set of hydrological rules to generate the following ecologically-relevant summary statistics for each year of record:

1. Dry season onset in weeks
2. Dry season minimum 5-day discharge in m^3s^{-1}
3. Dry season duration in days
4. Flood season onset in weeks
5. Flood type (0-6)
6. Flood season duration in days.

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 and Report 06/2009:Scenario Report: Hydrology.

The annual statistics are stored in the DSS, and their median values for each scenario at each site, with comments where relevant, are provided in Table 3.2 to Table 3.6. The statistics for flood season peak 5-day magnitude and flood season volume are presented separately in Table 3.2 to Table 3.6. These were later combined to provide Flood Type (0-6).

Table 3.2 Median values for the ecologically-relevant summary statistics for each scenario for Site 1: Capico. PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario.

Flow category	PD	Low	Medium	High	Comment
MAR (McM)	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 (m^3s^{-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 (m^3s^{-1})	38	35	35	35	All Scs similar and slightly smaller than PD
Flood season volume (Mcm)	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

Table 3.3 Median values for the ecologically-relevant summary statistics for each scenario for Site 2: Mucundi. PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario.

Flow category	PD	Low	Medium	High	Comment
MAR (McM)	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 (Mcm)	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

Table 3.4 Median values for the ecologically-relevant summary statistics for each scenario for Site 3: Cuito Cuanavale. PD = simulated present day flow regime.

Flow category	PD	Low	Medium	High	Comment
MAR (McM)	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 (Mcm)	1968	1968	1968	1968	About half of Mucundi
Flood season duration (days)	162	162	162	162	Within range of other Angolan sites

Table 3.5 Median values for the ecologically-relevant summary statistics for each scenario for Site 4: Kapako. PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario.

Flow category	PD	Low	Medium	High	Comment
MAR (McM)	164	152	140	129	Progressive decline to 93%, 85%, 79% of PD
Dry season onset (wk)	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 (Mcm)	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

Table 3.6 **Median values for the ecologically-relevant summary statistics for each scenario for Site 5: Popa Falls and Site 6: Panhandle. PD = simulated present day flow regime. L = low scenario; M = medium scenario; and H = high scenario.**

Flow category	PD	Low	Medium	High	Comment
MAR (McM)	270	261	245	186	Progressive decline: 97%, 91%, 69% of PD
Dry season onset	Aug	July	July	June	Progressively earlier: 1, 3, and 7 weeks earlier than PD
Dry season duration (days)	115	130	145	193	Progressively longer dry season: 2, 4,11 weeks more than PD
Dry season minimum flow (m^3s^{-1})	114	101	93	21	Progressive decline to very large drop for H: 89%, 82%, 18% of PD
Flood season onset	Jan	Jan	Jan	Feb	Slightly delayed by 1 wk (M) and 2 wks (H)
Flood season peak (m^3s^{-1})	620	618	611	573	Progressive very slight decline: 99%, 98, 92% of PD
Flood season volume (Mcm)	5269	4980	4450	3294	Progressive decline: 96%, 84%, 63% of PD
Flood season duration (days)	150	143	129	103	Progressive shortening of flood season by 1, 3, 7 weeks

3.4. Summary statistics for Site 7: Xaxanaka

Hydrological data per se are not particularly useful in the analysis of the Okavango Delta, as areas of inundation vary year on year with climate. 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 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: Xaxanaka. The output of the model is a series of vegetation types/habitat based on duration and frequency of inundation (Table 3.7).

Table 3.7 **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

Mean percentage over for these vegetation types for simulated present-day inflows between 1983-2002 is shown in Table 3.8.

Table 3.8 **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.**

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	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

Details of the model used are provided in Report 05/2009: Hydrology Report: Data and models.

3.5. Summary statistics for Site 8: Boteti

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 3.4, Figure 3.5, Figure 3.6 and Figure 3.7, respectively.

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

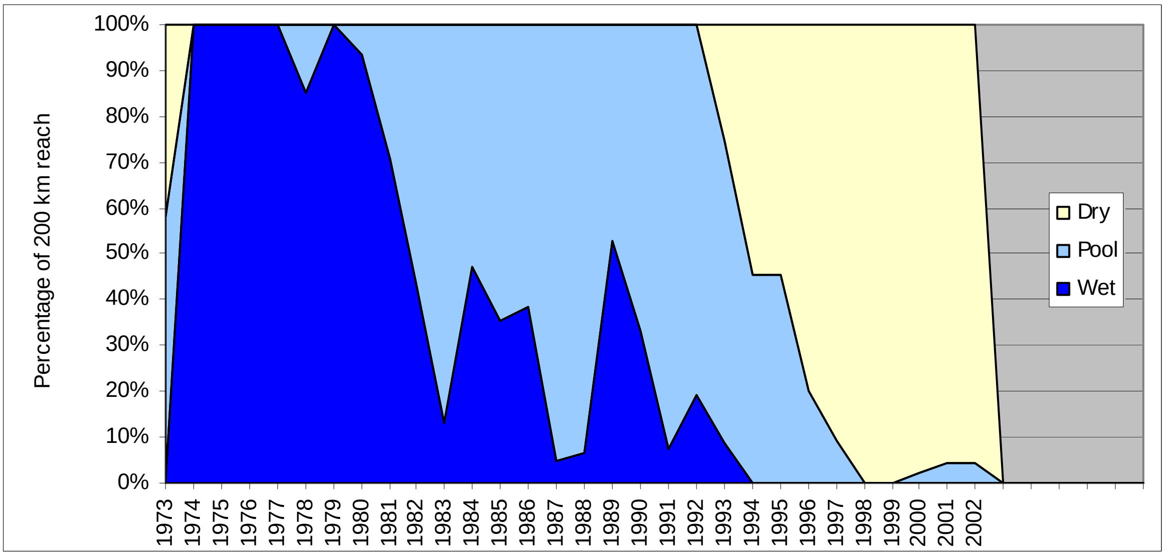

Figure 3.4 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the present-day simulated conditions given climatic conditions that prevailed from 1973-2002.**

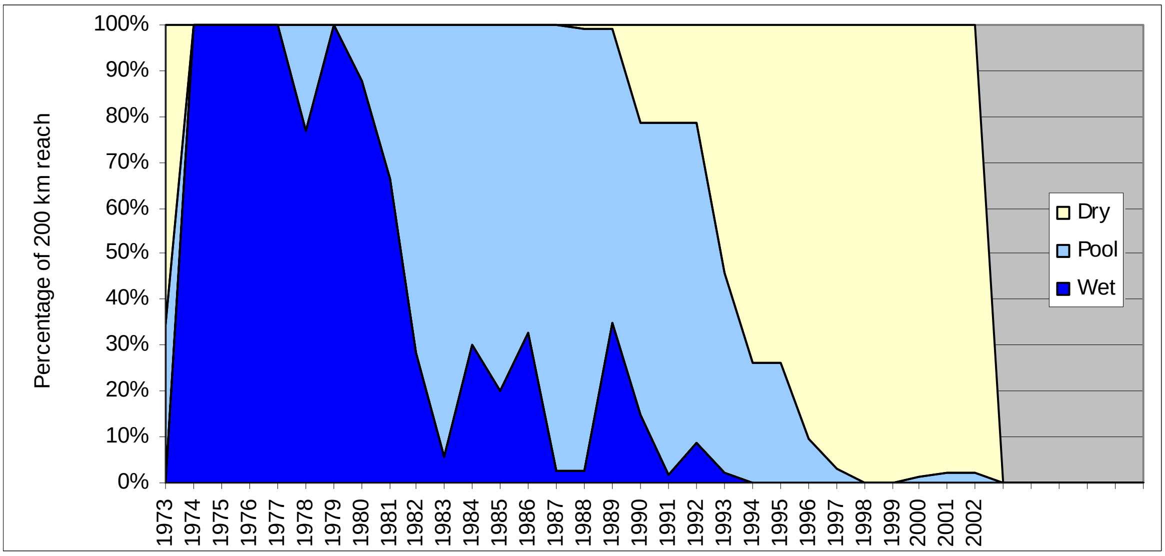

Figure 3.5 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the low scenario given climatic conditions that prevailed from 1973-2002.**

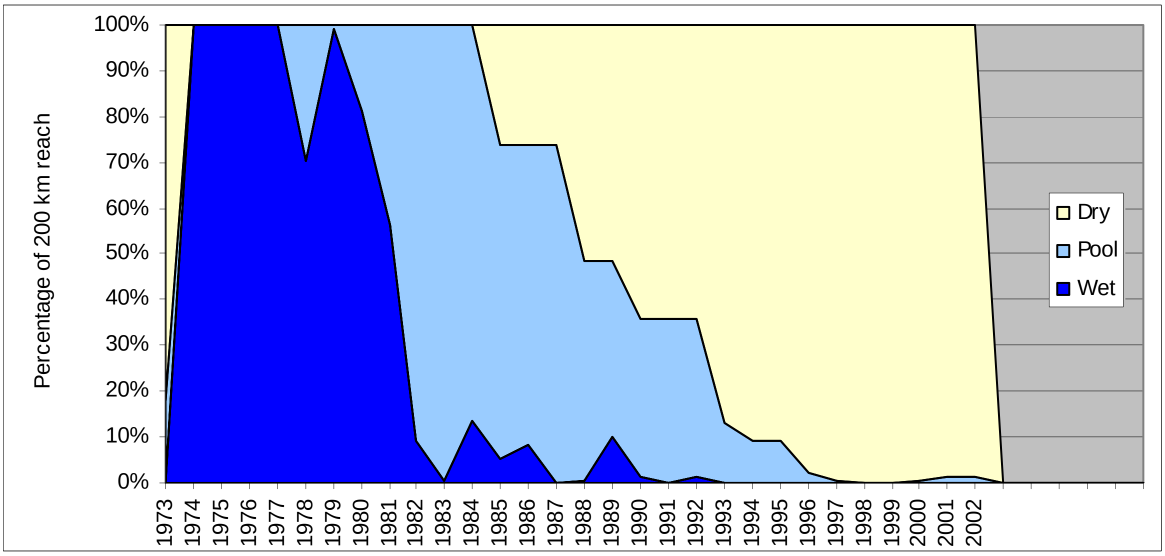

Figure 3.6 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the medium scenario given climatic conditions that prevailed from 1973-2002.**

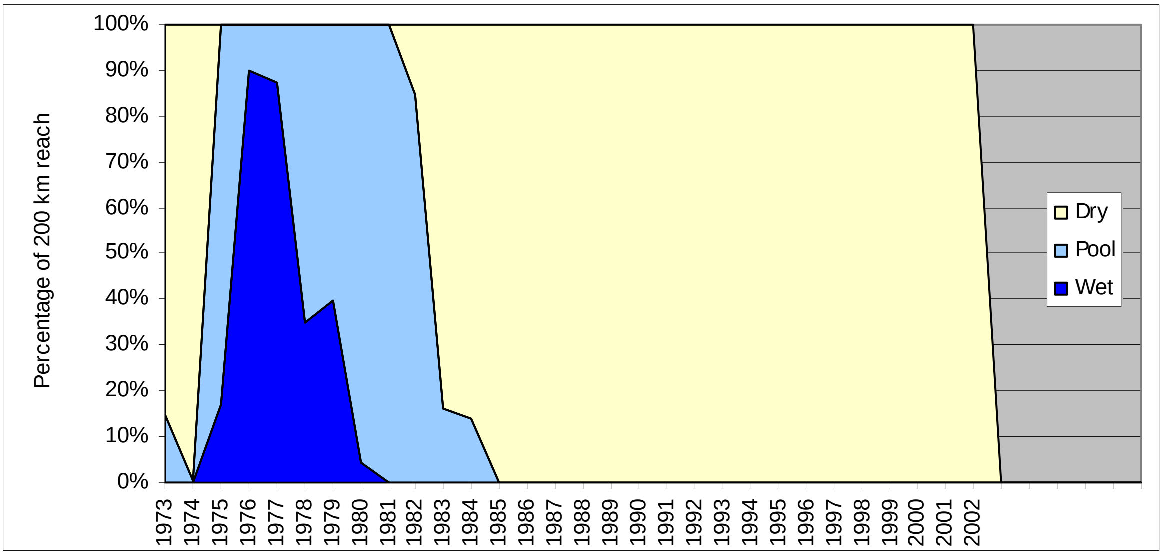

Figure 3.7 **Percentage of the 200-km study reach of the Boteti River that will be inundated (wet); isolated pools (pool) and dry under the high scenario given climatic conditions that prevailed from 1973-2002.**

3.6. Process follow after the generation of ecological summary data

Once the summary ecological data are generated they are entered into the DSS. In the DSS, the response curves are used to predict the biophysical and social outcomes for the flow regime of interest. The DSS is described in more detail in Report 02/2009: Process Report.

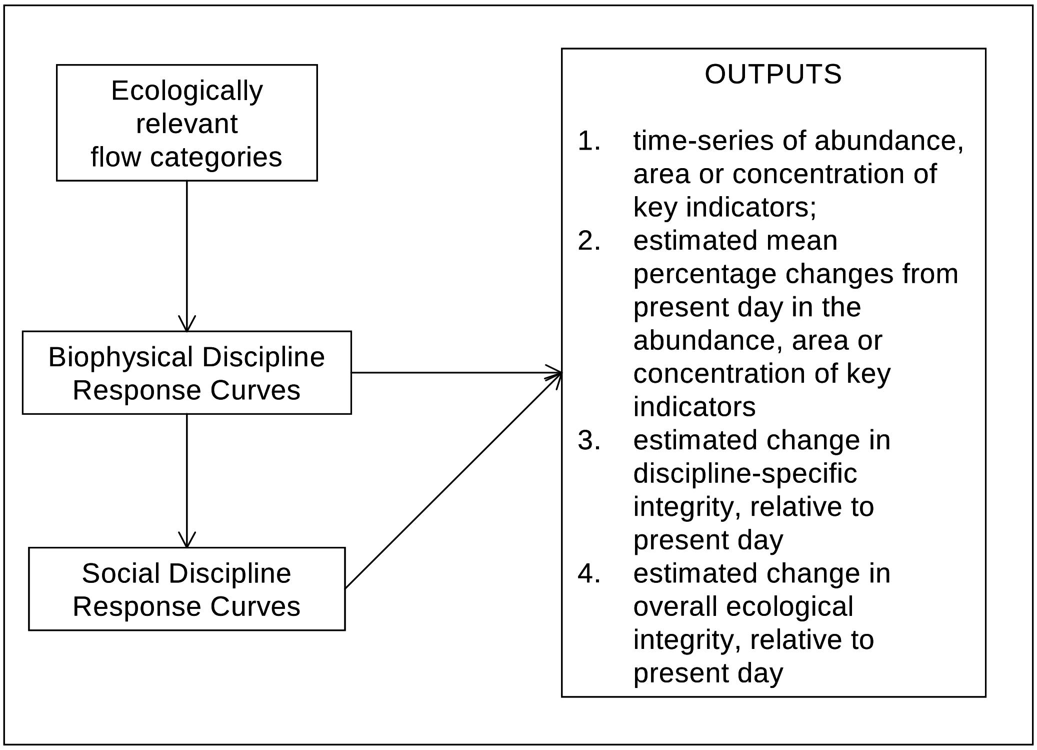

Figure 3.8 **Summary of process within the DSS**

4. Biophysical results: Disciplines

Note:

1. The results presented here are unique to the configuration of development options, and their operating rules, included in the water-use scenarios. Different configurations, and/or different operating rules would yield different outcomes for the biophysical environment.
2. The results presented here exclude consideration of:impacts of developments other than flow, e.g., changes in sediment supply;
   - landuse changes;
   - climate change.
3. The only water use included in the scenarios for the Cuito River upstream of Site 3: Cuito River at Cuito Cuanavale was a run-of-river hydropower plants that had no effect on the flows at Site 3. Thus, none of the scenarios affected Site 3.
4. The locations of the sites prohibit the prediction of likely impacts of any of the scenarios on the lower Cuito River.

4.1. Introduction

The Chapter summarises the results for each of the biophysical indicators in terms of overall changes in their area, concentration or abundance relative to the simulated present day situation.

Additional details on the biophysical results for each scenario are provided in Report 07/2009: Scenario Report: Ecological and social predictions (VOLUME 2).

4.2. Geomorphology

4.2.1 Indicator 1: Extent - exposed rocky habitat

Summary of characteristics

This indicator considers the extent of exposed rocky habitat at a site during the low flow season. It does not consider the other potential impacts, such as of sediment deposition covering bedrock exposures, only the exposed bedrock above the water surface. Exposed rocky areas provide valuable habitat for birds and wildlife. There is a direct relationship between flow level and rocks exposed above water level. As water level rises, less rocky area is exposed.

This indicator is used for Sites 1, 2 and 5.

Impact of the Water-use Scenarios

It is predicted that there will be a drastic increase in seasonal exposure of rocky habitat at Capico (Site 1) because of loss of the dry-season flows (c. 200% increase) under the low, medium and high scenarios. There will be similar increase at Site 2 under the low and medium scenarios, but exposure will approximate present day levels under the high scenario, because of the lowflow season releases from the proposed dam included in the scenario. Site 5 will also be seriously affected by the medium and high flow scenario, with 50% and 200% increases in lowflow season exposure, respectively.

4.2.2 Indicator 2: Extent – coarse sediments

Not used in final analysis.

4.2.3 Indicator 3: Cross sectional area of channel

Summary of characteristics

The cross sectional area of the channel responds mainly to flood conditions. Floods larger than the historical maximum should rapidly enlarge the cross sectional area, and a reduction of floods should result in a narrowing of the flood channel (and a reduction in channel cross-sectional area). However, the channel also responds to low flow conditions or extended low flow conditions, which enables vegetation to encroach into the channel, trapping sediment, ultimately reducing the channel cross section. This process is much slower than channel enlargement, and intervening floods will offset this to a certain extent.

This indicator is used for Sites 1, 2, 3, 4, 5 and 6.

Impact of the Water-use Scenarios

It is predicted that there will be a drastic decrease(c. 70%) in cross-sectional area at Capico (Site 1) under the low, medium and high scenarios. This type of drastic decrease as a result of encroachment, coupled with a decline in flood magnitude and duration of floods is also predicted for Sites 2 (40% reduction) and 6 (60% reduction) under the high scenario. For the rest, there will be slight changes in cross-section areas, but these are unlikely to be significant.

4.2.4 Indicator 4: Extent: backwaters

Summary of characteristics

Backwater provide valuable habitat for plants, fish, birds and wildlife. Filling or emptying of backwaters is directly related to the water level in the river. Backwaters gradually fill with sediment and therefore may be shallower than the main channel - in that case they may empty before the river dries up. The backwaters tend to be steep sided, so the surface area changes little as water depth changes.

This indicator is used for Sites 1, 3 and 4.

Impact of the Water-use Scenarios

It is predicted that the high level of abstraction at Site 1 under the low, medium and high scenarios will considerably reduce flows in the rivers during the low flow season (hot season in October-November) when the river is at its lowest, and there will be a drastic decrease (c. 60%) in backwaters. This is somewhat offset at Sites 2 and 4 by lowflow season releases.

4.2.5 Indicator 5: Extent: vegetated islands

Summary of characteristics

Vegetated islands in the Mukwe-Andara-Popa Falls section of the Okavango River (and upstream) are normally comprised of sand on bedrock. Grass, reeds, bush and trees stabilise the sand by reducing wash away during above-average high flows and also promoting deposition of more sand during overtopping of the island.

Reduced flows have little impact on vegetated islands as long as the plants there still get enough water to survive and regenerate. Excessively high floods, however, are likely to cause erosion of the margins of islands. In many cases this erosion is limited to the margins because of the bedrock base to the island.

This indicator is used for Site 5.

Impact of the Water-use Scenarios

It is predicted that there will be no appreciable impact on vegetated islands under any of the scenarios.

4.2.6 Indicator 6: Sandbars at lowflow

Summary of characteristics

Extensive exposed sand bars exist mainly below Popa Falls. Upriver, although much of the river bed is sand, the sand bars are mostly submerged just below the surface during the low flow season.

If only the effect of water flow on sandbanks is considered, then lower flow will expose a greater extent of sandbanks. However, the real issue the fact that dams and weirs trap sediment. Downstream of a weir or dam the river is deprived of sediment, so it erodes its bed, banks and floodplains until it is once again carrying its maximum load. Thus, for some distance downstream of a weir or dam the sandbanks will be removed. This is important at Sites 2 and 5 were dams/weirs form part of the high scenario, but is not included in the results for this indicator as sediment trapping by dams was not included in the DSS. If there were, the impacts would likely be considerably higher than predicted here.

This indicator is used for Site 5.

Impact of the Water-use Scenarios

There will be little noticeable difference in the extent of exposed sandbars under the low or medium scenarios. Under the high scenarios, however, lowflow season lowflows will be considerably reduced, and seasonal exposure of sandbars will be considerably more (*c.* 250%) than under the present-day scenario.

4.2.7 Indicator 7: Percentage clays and silts on floodplain

Summary of characteristics

This refers to the silts and clays in the top 300 mm of the floodplain surface sediments. Floodplains are made predominantly of fine sand, but there is a small amount of silt and clay-sized particles, which is also deposited by the river. The silt and clay is significant for agriculture because it helps to retain moisture and nutrients. Silt and clay tend to get lost due to downward mixing by soil organisms, trampling by livestock, and removal by wind, and are replenished by flooding. Both loss and replenishment occur over fairly long time scales, c. 20 years or so, although sudden depositions do occur under large floods.

This indicator is used for Sites 3 and 4.

Impact of the Water-use Scenarios

None of the scenarios affect Site 3. At Site 4, there will be little or no effect on silts and clays under the low and medium scenarios. Under the high scenario, however, it is predicted that there will be a gradual reduction in the amount of slits and clays on the floodplain corresponding to a reduction in the frequency and duration of over-bank flooding.

4.2.8 Indicator 8: Extent: inundated floodplain

Summary of characteristics

This indicator considers the extent of inundation of the floodplains at Sites 3, 4 and 6. Inundation of the floodplain is strongly linked to the peak and duration of the flood season flows, i.e., their volume (Figure 4.1). Reduced volume of flow in the flood season will result in less over-bank flooding. This results in smaller areas of the floodplain being inundated.

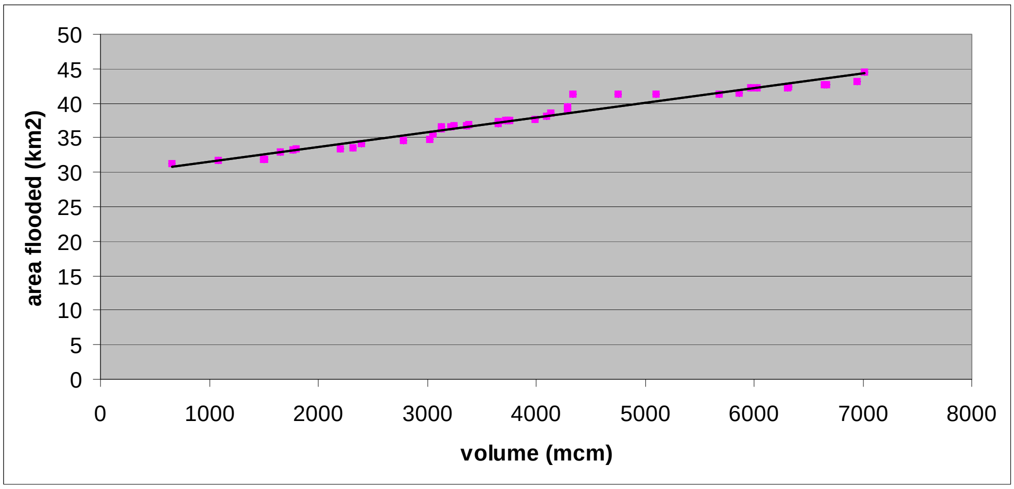

Figure 4.1 Relationship between flood season volume and area of floodplain inundated for Site 4: Kapako.

This indicator is used for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

None of the scenarios affect Site 3. Under the low scenario, no significant effects are predicted for either Site 4 or 6. Under the medium scenario, there will be a slight reduction in the extent of inundation of the floodplain at Site 6 and a clear reduction in *c.* 20% of the years at Site 4. This represents a considerable increase in the periods between inundation events for some components of the floodplain. Under the high scenario there is reduced flooding in *c*. 30% of the years, and a doubling of the years where the floods 'fail' completely. This will, of course, have knock-on effects for the biota and people using the floodplain resources.

4.2.9 Indicator 9: Extent: pools and pans

Summary of characteristics

This indicator considers the extent of perennial pools and pans on the floodplains at Sites 3, 4 and 6. These are partly dependent on refilling from overbank flooding and rain, but are sustained through the lowflow season by the high water table on the floodplains. As the river level drops, so the water table in the floodplain will also drop. If the bed of a pool no longer intersects the water table, the pool will dry out, although seepage from the non-saturated zone may also contribute to pool water.

This indicator is used for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

None of the scenarios affect Site 3. At Site 4 all the scenarios will result in a reduction (20-30%) in perennial pools and pans on the floodplain, but this will be highest for the medium scenario (*c*. 30% reduction). This is because the abstraction during lowflow season will be offset slightly by releases in the high scenario. The pattern is a little different at Site 6, where there is more of a ponding effect of low season flows. At Site 6, the low and medium scenarios are not predicted to have an appreciable effect, but the high scenario will result in a c. 10% reduction.

4.2.10 Indicator 9: Extent: cut banks

Summary of characteristics

Cut banks are a natural phenomenon in the Okavango, particularly in the middle reaches through Namibia. Higher flow velocities during flooding erode banks, building meanders and creating cutoffs. This process is enhanced if water levels drop rapidly, as hydrostatic pressure of water in the sandy bank material tends to result in bank collapse. A decline in bank cutting will result in a gradual stabilization of the channel and a loss of habitat.

This indicator is used for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

None of the scenarios affect Site 3. There will be no appreciable effect at the other sites for the low and medium scenarios. Although some decrease in bank cutting is expected under the high scenario, this is unlikely to be significant. The inference is that overall channel pattern, e.g., straight, meandering or braided, should not be affected. This is mainly because, although there will be a reduction in the magnitude and duration of flooding events, many of these will still occur under all of the scenarios analyses. However, if sediment supply were to be curtailed for any reason, there would probably be a marked increase in bank erosion, and a concomitant change in channel pattern.

4.2.11 Indicator 10: Carbon storage

Summary of characteristics

Wetlands affect the levels of atmospheric carbon in two ways: First, many wetlands, particularly boreal and tropical peatlands, are carbon reservoirs. Carbon is contained in the standing crops of trees and other vegetation and in litter, peats, organic soils and sediments that have been built up, in some instances, over thousands of years. These carbon reservoirs may supply large amounts of carbon to the atmosphere if water levels are lowered or land management practices result in oxidation of soils. Second, many wetlands also continue to sequester carbon from the atmosphere through photosynthesis by wetland plants; many also act as sediment traps for carbon-rich sediments from watershed sources. However, wetlands also simultaneously release carbon as carbon dioxide, dissolved carbon, and methane. The net carbon sequestering versus carbon release roles of wetlands are complex and change over time although net, gradual sequestration occurs over time for peatland wetlands such as the Okavango Swamp[1].

This indicator considers the net peat/carbon storage in the swamps.

This indicator is used for Site 7.

Impact of the Water-use Scenarios

It is predicted that there will be a c. 70% reduction in carbon storage in the area represented by Site 7 under the high scenario. Carbon storage is also predicted to decline under the low and medium scenarios but this is unlikely to be significant.

4.2.12 Summary of geomorphological response to scenarios

Increasing off-stream water use in the Okavanago catchment is likely to result in a trend towards stabilisation and narrowing of the main channels, possibly accompanied by a deepening of the channel and a terrestrialisation of the vast floodplains.

In general, however, exclusion of consideration of changes in sediment supply liked with water-resources developments and/or landuse changes means that the predictions for the geomorphology are incomplete, and quite possibly the changes are seriously underestimated.

4.3. Water Quality

4.3.1 Indicator 1: pH

Summary of characteristics

Values are those for the main channel. Generally, pH increases with decreasing flow.

This indicator is used for all eight sites.

Impact of the Water-use Scenarios

Under Present Day conditions, values mostly range within 70% and 115% of the median. Values are predicted to increase very slightly, without the range necessarily extending, under the Low and Medium Scenarios, but show a significant increase under the High Scenario at Sites 4, 6, 7 and 8 to up to 46% higher than Present Day median and with very few values below the median. This is probably because as dry-season flows fall progressively lower there will be higher concentrations of carbonates and bicarbonates.

[1] www.usgcrp.gov/usgcrp/Library/nationalassessment/newsletter/1999.08

4.3.2 Indicator 2: Conductivity

Summary of characteristics

Values are those for the main channel. Generally, conductivity increases with decreasing flow.

This indicator is used for all eight sites.

Impact of the Water-use Scenarios

Modelled Present Day values range between 34% and 268% of the Present Day median, increasing in drier years of lower flow. Most scenario predictions remain within that range, but it is worth noting that there is tendency for the range to progressively shift upwards through the scenario, with Site 4 (Kapako) showing values higher than the PD range up to 307% under the High Scenario.

4.3.3 Indicator 3: Temperature

Summary of characteristics

Diel temperature ranges are addressed. These are expected to increase with development that reduces river flow.

This indicator is used for all eight sites.

Impact of the Water-use Scenarios

Diel temperature ranges in the river under Present Day are 48-58% of median in the wet season, and a slightly greater range of 80-98% in the delta and Boteti. The ranges in the dry season, when flows are lower and ambient temperatures have more influence, are 153-230% along the river, and up to 343% in the Boteti due to its tendency to dry out.

Diel ranges mostly stay within these ranges in the scenarios, but the High Scenario pushes the diel range permanently into the higher end of the range – that is - higher than the present median - at Sites 5, 6 and 7, and maintains a greater range for longer in the Boteti.

4.3.4 Indicator 4: Turbidity

Summary of characteristics

Turbidity decreases with decreasing flow at Sites 1 and 2. Values increase with high flows in the flood season, as sediments are lifted into suspension.

This indicator is used for all eight sites.

Impact of the Water-use Scenarios

No significant changes are expected for the Low and Medium Scenario at all sites. Median turbidity levels are predicted to increase for Sites 6-8 under the High Scenario.

4.3.5 Indicator 5: Dissolved oxygen

Summary of characteristics

Decrease in flow results in an increase in Dissolved Oxygen at sites 1 - 6. At sites 7 and 8 the concentrations decrease with a decrease in flow.

Impact of the Water-use Scenarios

Sites 1 to 6 show progressively increased median DO concentrations through the scenarios, whilst median concentrations decrease at Sites 7 and 8.

4.3.6 Indicators 6, 7 and 8: Total nitrogen, total phosphorus and chlorophyll a

Summary of characteristics

Concentrations increase with decreasing flow at all the sites, but the relationship is slightly weaker for phosphorus.

This indicator is used for all eight sites.

Impact of the Water-use Scenarios

Concentrations are predicted to increase progressively through the scenarios as flow volumes decrease, with Sites 1, 5, 6 and 7 showing more than doubling of the Present Day medians.

4.3.7 Summary of water-quality responses to scenarios

The water quality of the Okavango system is good, and values of all indicators are predicted to remain mostly within the natural variability through the Low and Medium Scenario. Most indicators are predicted to noticeably move away from Present Day values with the High Scenario, particularly in the lower basin, from Site 4 downstream.

It should be noted that not all chemical variables are addressed in this exercise, and that for those included only the direct changes as a result of flow changes are described. Water-use developments, as represented by the three scenarios, will likely cause additional water-quality changes, brought about by increased effluents from urban areas, agricultural return flows carrying pesticides and fertilisers, and changed DO and temperature levels caused by storage dams.

4.4. Vegetation

4.4.1 Indicator 1: Channel macrophytes (submerged)

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

Summary of characteristics

These are species that grow along the edges of main channel or in side channels. All or part of vegetation is permanently submerged, and the plants are either rooted or floating. They need permanent, flowing, clear water. Their cover increases or decreases depending on water volume in lowflow season and could decline to zero if the channel dries out. Sudden or very large floods could also reduce cover. Poor water quality or low light penetration will also negatively affected them.

These plants are used as indicators for Sites 1, 2, 3, 4, 5 and 6.

Impact of the Water-use Scenarios

It is predicted that there will be a drastic decrease (*c*. 90%) in the cover of submerged macrophytes in the channel at Capico (Site 1) under the low, medium and high scenarios. This is in direct response to the abstraction of 95% of the water in the lowflow season that will, at times, dry the river out completely. At Site 2 and 4, there will be a sharp decline in channel macrophytes under the medium scenario (c. 80% at Site 2), but only a slight decline under the low and high scenarios. This is mainly because the lowflow releases offset some of the other impacts under the high scenario. At Sites 5 and 6, the situation is somewhat different, with slight declines under the low and medium scenarios but a nearly total decline (c. 80-90%) under the high scenario. This is mainly in response to the reductions in flows during the lowflow season.

4.4.2 Indicator 2: Lower wet bank

Representative species: *Vossia cuspidata*, *Cyperus papyrus.*

Summary of characteristics

These are species that grow along the permanently wet inner margin in main channel. They are either floating plants with stems forming dense mat, with leaves and flowers above water or rooted in the sand/peat. They prefer flowing water to standing water.

Vossia cuspidata is a robust, perennial grass with spongy, floating, creeping stems, associated with deep, permanent water. It is rooted in the channel bed, but the extremely long, floating stems can trail out into the current. *Cyperus papyrus* is a large, perennial sedge with stout creeping stems and erect stems in permanent swamps and on the margins of large rivers.

Papyrus and hippo grass respond slightly differently to flow but as a general rule they do not occur at the same site (or at least they dominate at different sites). Hippo grass will survive as long at there is water to cover its roots, and its leaves will float higher or lower as water level rises or falls. It can tolerate more desiccation than can papyrus.

These plants are used as indicators for Sites 4, 5 and 6.

Impact of the Water-use Scenarios

There is no impact expected for any of the scenarios at Site 4. At Sites 5 and 6, however, the predicted impacts are expected to be gradually more severe under the low, medium and high scenarios, respectively. Under the high scenario, the lower wetbank will be severely reduced (c. 20% of present), mainly as a result of the severe reductions in flows during the lowflow season, when the wetter channel will shrink significantly leaving the wetbank vegetation stranded, and dry. While it is expected that the vegetation may be able to withstand occasional drying out it is unlikely to be able to cope with the long periods without water that will characterise the lowflow season under the high scenario.

4.4.3 Indicator 3: Upper wetbank 1 (reeds)

Representative species: *Phragmites australis.*

Summary of characteristics

Phragmites grows on the outer edges of the main channel. It is typically emergent vegetation with its roots wet, but can withstand being out of water provided the soils are water logged. It reproduces vegetatively by means of stolons (underground horizontal stems) and rapidly colonises new areas, extending into areas that are further away from water and often becoming the dominant plants. It does not need flowing water but it does best where there is at least some soil moisture. With a lowering of the volume and duration of flooding it is likely to expand into areas occupied by the indicators on either side of it.

These plants are used as indicators for Sites 1, 2, 3, 4, 5 and 6.

Impact of the Water-use Scenarios

A *c*. 50% decrease is predicted for the cover of reeds at Capico (Site 1) under the low, medium and high scenarios. This is a result of two main impacts. Firstly the loss of lowflow season flows, which will strand the reeds on the outer margins of the channel, and secondly, the continued presence of the large floods, which will prevent the reeds from migrating closer to the new lowflow water's edge. Further to that, no major impacts are expected under either the low or medium scenarios for any of the sites. Under the high scenario, however, there are slight decreases (20%) expected at Site 5 and 6.

4.4.4 Indicator 4: Upper wetbank 2 (trees/shrubs)

Representative species: *Searsia (Rhus) quartiniana, Ziziphus mucronata.*

Summary of characteristics

Searsia (Rhus) quartiniana is a dense shrub or tree with a wide range of ecological tolerances within the context of perennial rivers. It is found along the banks and floodplains of perennial rivers, on islands in permanent swamps, as well as occasionally in ephemeral watercourses. *Ziziphus mucronata* is found in a variety of different habitats; very often close to water, but can also be found far from water.

These plants are used as indicators for Sites 1, 2, 4 and 5.

Impact of the Water-use Scenarios

A gradual decrease is predicted for the cover of trees and shrubs at Capico (Site 1) under the low, medium and high scenarios (*c*. 40% loss over 43 years). Under the medium scenario Sites 2 and 4 will be most impacted, with 30-50% reductions expected (higher if sediment supply is curtailed). No major changes are expected in trees and shrubs at Site 5 under the medium scenario, but there a c. 80% decline is predicted for the high scenario. Declines will be gradual over time, with partial recovery in good flood years.

4.4.5 Indicator 5: River dry bank

Representative species: *Combretum imberbe*, *Acacia tortilis*, *Albizia versicolor*, *Ficus sycomorus*, *Garcinia livingstonei* and *Diospyros mespiliformis*[2].

[2] Different species occur at different sites.

Summary of characteristics

This group of species comprises large trees and dense shrubs that grow on the outer margins of river banks. They are important for stabilising the river bank, and filter runoff from the adjacent catchment. They grow near water but generally not in the water, although some can withstand short periods of inundation. These trees and shrubs get their water via groundwater seepage from the river.

These plants are used as indicators for Sites 1, 2, 3, 5 and 6.

Impact of the Water-use Scenarios

A gradual decrease is predicted for the cover of trees and shrubs at Capico (Site 1) under the low, medium and high scenarios (*c*. 40% loss over 43 years). At the other sites, the low or medium scenarios are not expected to significantly affect dry bank vegetation. The high scenario may, however, result in a slight decline in dry bank vegetation at Sites 5 and 6.

4.4.6 Indicator 6: Floodplain dry bank

Representative species: *Combretum imberbe*, *Acacia tortilis*, *Albizia versicolor*, *Ficus sycomorus*, *Garcinia livingstonei* and *Diospyros mespiliformis.*

Summary of characteristics

This group comprises the same species are Indicator 5: River dry bank. The difference between them lies in the fact that this groups grows on the outer margin of the floodplain, which means that they are more dependent on periodic inundation of the floodplain than are their riverbank counterparts.

These plants are used as indicators for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

There will be no significant impacts on the floodplain dry bank vegetation for the low and medium scenarios, and only a slight negative impact (c. 10% over 43 years) for the high scenario.

4.4.7 Indicator 7: River floodplain residual pools

Representative species: *Nymphaea nouchali* var. *caerulea*

Summary of characteristics

The plants of this community are all dependent on standing or slow-flowing, permanent water, which is linked to and recharged by the main river. This is a seasonal effect as rain will fill the pools during the rainy season and flood-waters will fill them during the flood season.

These plants are used as indicators for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

The persistence of perennial pools on the floodplain is closely linked to water levels in the channel during the lowflow season as these support the water table on the floodplain, and thus the water level in the pools. Since all of the scenarios involve some abstraction during the lowflow period, they all have some impact on the persistence of pools on the floodplain during the dry season. The predicted impact increases gradually from low (>90% of present), to medium (> 80% or present) to high (20-60% of present).

4.4.8 Indicator 8: River lower floodplain

Representative species: *Miscanthus junceus, Persicaria* spp., *Ludwigia* spp.

Summary of characteristics

These plants are found in the deeper depressions on the floodplains, which receive water from the river at high flow and presumably retain water for long periods, based on the water-loving species that are found in them. The group comprises a mixture of species that prefer permanent water or grow on dry land but close to water (*Persicaria, Ludwigia*). They are all tolerant of total inundation for long periods and desiccation for varying periods. Their leaves float on the surface of the water, while the flowers are held above the water.

Miscanthus junceus (swamp savanna grass/pampas grass) is an important floodplain thatching grass in Namibia (Barnes, in litt. 2009).

These plants are used as indicators for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

The lower floodplain vegetation is highly dependent on seasonal inundation. Consequently there is a steady decline in this indicator at Sites 4 and 6 in response to a progressive reduction in the magnitude and duration of flood flows from present day to the low, medium and high scenarios. While the predicted loss is moderate for the low and medium scenarios (<10%), it is high for the high scenario (80% at Site 6). Of more concern, however is that it drier climatic conditions prevail for an extended period of time, e.g., during a drought, these species will be almost completely lost from the system.

4.4.9 Indicator 9: River middle floodplain

Representative species: *Setaria*, *Panicum*, *Vetiveria nigritana*[3], thatching grasses.

Summary of characteristics

Plants in this group are able to grow in areas away from water, but thrive in seasonally wet areas. They are found predominately on the middle floodplain, on either clay or sand. There tend to be large areas dominated by thatching and grazing grasses. An increase in the length of inundation may be detrimental, but they would probably survive longer dry periods.

These plants are used as indicators for Sites 3, 4 and 6.

Impact of the Water-use Scenarios

At Site 4, the middle floodplain vegetation is expected to increase in area gradually from low (*c*. 124% of present), to medium (*c*. 126% of present) to high (*c*. 130% of present). This is because the slightly reduced flooding will enable these species to encroach on parts of the floodplain that were previously too wet for them to survive. At Site 6, although there is a very

[3] Angolan sites and the Panhandle.

slight trend towards increasing middle floodplain vegetation, this is negligible for all the scenarios.

4.4.10 Indicator 10: River upper floodplain (islands)

Representative species: *Searsia* (Rhus) with *Acacia hebeclada*, *Acacia sieberiana*, *Diospyros lycioides*, grasses.

Summary of characteristics

These are the highest points on the floodplain itself and are seldom inundated. Long inundation is detrimental to these plants. They are, however, dependent on some inundation to recharge ground water, and for nutrients. The plant community is comprised of grasses, shrubs, a few trees, and is equivalent to the wildlife discipline's secondary floodplain.

These plants are used as indicators for Sites 2 and 4.

Impact of the Water-use Scenarios

There will be no significant impacts on the upper floodplain island vegetation for the low and medium scenarios, and only a slight negative impact for the high scenario.

4.4.11 Delta (Site 7) Indicators

The indicators used for Site 7: Okavango Delta at Xaxanaka are:

5. Open water
6. Permanent swamps
7. Lower floodplain
8. Upper floodplain
9. Occasionally-flooded grassland
1. *Sporobolus* islands (These are small islands that form on termitaria in the seasonal grasslands).
2. Riparian woodland, trees
3. Savanna, scrub.

These represent a gradient of wetness from open water through to savanna. Under natural conditions proportion of these vegetation types fluctuates with climatic variation. Essentially, under wet conditions there will be a predominance of open water, permanent swamp and lower floodplains. If conditions dry out, the relative extent of upper floodplain and occasionally-flooded grasses will increase. If conditions were to dry out even further, there would be a gradual terrestrialisation of the delta and large portions thereof would revert to savanna, with small *Sporobolus* islands on termitaria.

Impact of the Water-use Scenarios

The relative proportions of the vegetation indicators in the study area under present day, low, medium and high scenarios are shown in Figure 4.2 to Figure 4.5, respectively.

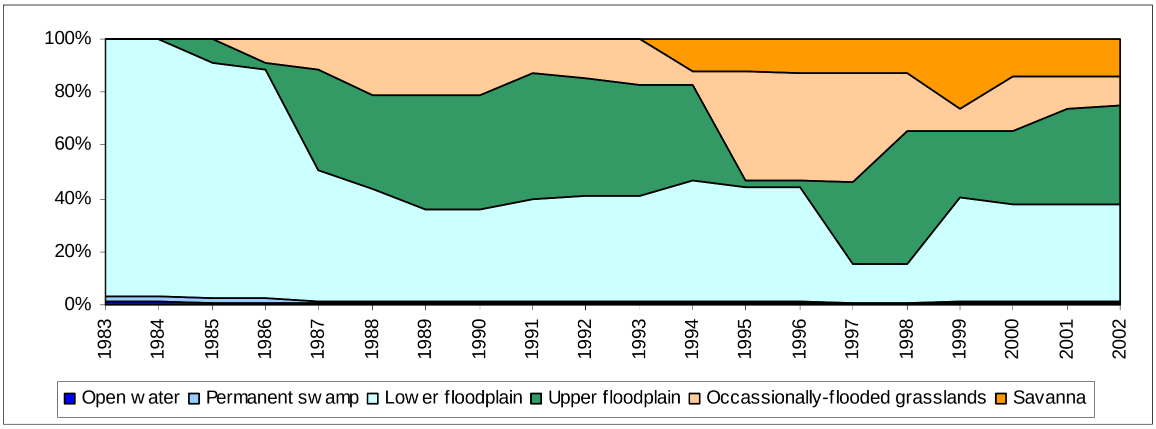

Figure 4.2 **Proportions of the vegetation indicators in the study area over a 20-year period under present-day conditions.**

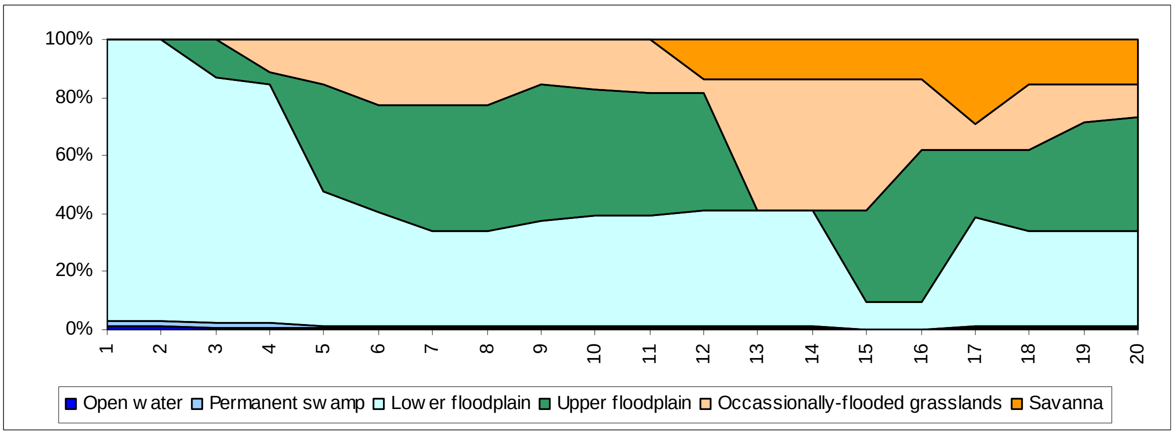

Figure 4.3 **Proportions of the vegetation indicators in the study area over a 20-year period under the low scenario.**

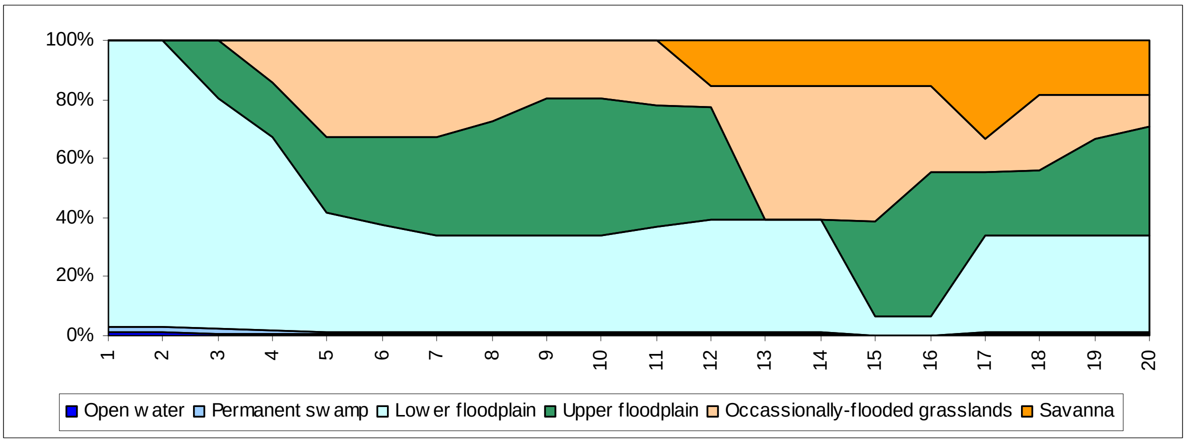

Figure 4.4 **Proportions of the vegetation indicators in the study area over a 20-year period under the medium scenario.**

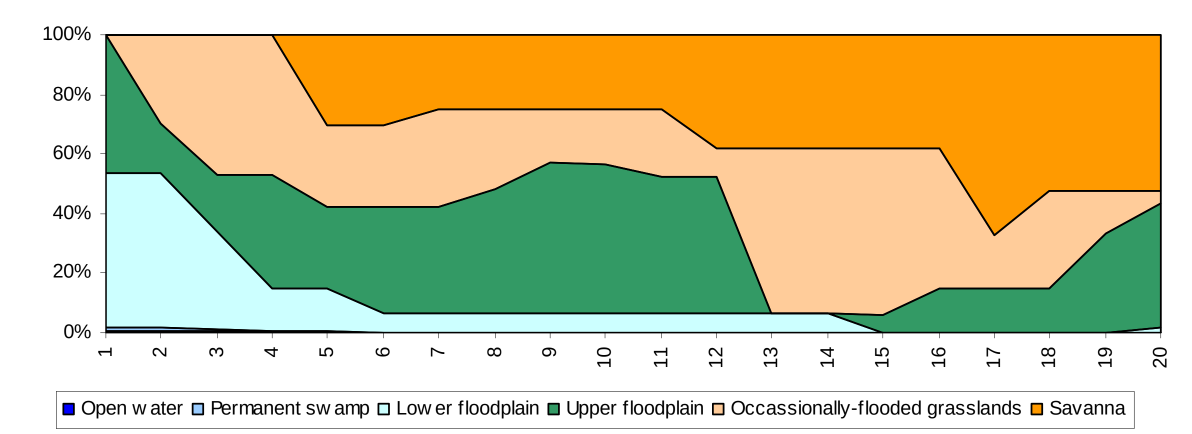

Figure 4.5 Proportions of the vegetation indicators in the study area over a 20-year period under the medium scenario.

Although some slight effects will be evident in the delta under the low and medium scenarios, these are predicted to be negligible. Under the high scenario, however, it is predicted that there will be a general drying out of the delta at Xaxanaka, a loss of open water and permanent swamp and terrestrialisation of large portions of the area, relative to present day. It is predicted that the area covered by savanna and scrub will be 3.5 times greater under the high scenario than under present day.

4.4.12 Boteti (Site 8) Indicators

The indicators used for Site 8: Boteti River are:

1. Open water
2. Riparian woodland, trees.

Open water species occur in the Boteti River when the river course is inundated, when there are isolated pools. The riparian woodland species on the other hand tend to persist for some time (possibly as long as 50 years) even when the river is dry, as they are able to access groundwater. Prolonged periods of no flow would, however, result in a gradual decline in these species.

The relative extent of inundation, isolated pools and dry river bed in the Boteti River varies with climatic variations. Under present day conditions, in wet periods as much as 100% of the channel can become inundated and remain that way for several years. In dry periods however, surface water in the Boteti River can dry up for extended periods, although people are still able to access water by sinking wells into the river bed.

Impact of the Water-use Scenarios

The open water species are predicted to decline by c. 20% under the low scenario and c. 30% under the medium scenario. Under the high scenario, however, they will decline by as much a 70% in direct response to a reduction in the number of years when there is water in the system. During drier periods they will be absent from the system.

Riparian woodlands are predicted to show little change under the low and medium scenarios. Under the high scenario, however, there will be a c. 20% decline in the cover of woodlands species as a result of extended periods on no-flow.

4.4.13 Summary of vegetation responses to scenarios

The riparian vegetation can loosely be divided into in-channel vegetation, floodplain-pool vegetation, marginal vegetation, floodplain grasses and riparian trees and shrubs. In general, the in-channel vegetation, floodplain-pool vegetation and marginal vegetation are more dependent on lowflows and the floodplain grasses, and riparian trees and shrubs on flood flows. Consequently, in-channel vegetation, floodplain-pool vegetation and marginal vegetation are most 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 are slightly negatively affected, particularly under the high scenario, possibly because there is a long lag time to their response. Of course, this also means that once impacted, they will take even longer to recover, if they recover at all. In some cases, floodplain grasses are expected to increase in line with a general terrestrialisation of the systems.

4.5. Aquatic macroinvertebrates

4.5.1 Indicator 1: Invertebrates in channel submerged vegetation

Representative species: Crustacea (Freshwater shrimps).

Summary of characteristics

Water must always be present. At minimum flow habitat will be greatly reduced leading to population decline as predation increases.

These invertebrates are used as indicators for Site 6.

Impact of the Water-use Scenarios

Abundances are predicted to decline slightly over the scenarios, with the only significant impact being a permanent drop to about half Present Day levels under the high scenario.

4.5.2 Indicator 2: Invertebrates in channel marginal vegetation

Representative species: Crustacea (Freshwater shrimps).

Summary of characteristics

Water must always be present. High, long-duration flooding may lead to destruction of habitat and reduction in abundance. Long duration of minimum flows restricted to the river bed may also lead to loss of habitat.

These invertebrates are used as indicators for Sites 1, 2, 3, 4, 5, 6 and 8.

Impact of the Water-use Scenarios

Severe decline at Site 1 under all scenarios due to river flow almost failing in the dry season. Very little noticeable impact elsewhere, although populations will shrink slightly as habitat declines, most noticeably at Sites 5 and 8 under the high scenario.

4.5.3 Indicator 3: Invertebrates in channel fine sediments

Representative species: Unionidae, Sphaeridae.

Summary of characteristics

This group of invertebrates lives under the sediments of the river bed. They will normally survive as long as there is some water covering the sediment. Long dry spells will reduce abundance or even eliminate these indicators.

These invertebrates are used as indicators for Sites 1, 4, 5 and 6.

Impact of the Water-use Scenarios

Little if any change predicted for the Low and Medium Scenarios, except at Site 1 where the group is predicted to decline to about half Present Day abundances under all scenarios. A similar level of decline is predicted for Sites 5 and 6 under the high scenario.

4.5.4 Indicator 4: Invertebrates of channel cobbles and boulders

Representative species: Hydropsychidae, Ecnomidae.

Summary of characteristics

This group of indicators lives among the cobbles and boulders of rocky river beds. They will decline in abundance and may disappear if exposed to long duration of low flows that expose the rocks.

These invertebrates are used as indicators for Sites 2, 5 and 8.

Impact of the Water-use Scenarios

Little if any impact until the high scenario, when abundances are predicted to drop to about 80% at Site 5 and 25% at Site 8.

4.5.5 Indicator 5: Invertebrates of fast-flowing channels

Representative species: Simuliidae, Hydropsychidae.

Summary of characteristics

These species inhabit fast-flowing sections of channels, where they depend on the flow of water to provide food in suspension, which they collect from the current. They must live in water throughout their lives. They will reduce in abundance and may disappear if flow slows and water levels drop to expose the river bed.

These invertebrates are used as indicators for Sites 2,5 and 7

Impact of the Water-use Scenarios

Very little impact is anticipated under the Low and Medium Scenarios, although small drops in abundance would follow any drying out and loss of wetted habitat. The High Scenario is anticipated to cause a sever decline in abundances at Sites 5 and 7, to below 25% and 4% respectively.

4.5.6 Indicator 6: Invertebrates in channel bedrock pools

Representative species: Dytiscidae.

Summary of characteristics

The representative species is dytiscid diving beetles that inhabit pools in bedrock. High, long-duration flooding will destroy this habitat through constant scouring flows while long durations of low flows may result in the pools drying out and all habitat being lost.

These invertebrates are used as indicators for Site 2.

Impact of the Water-use Scenarios

No impact of any scenarios is anticipated.

4.5.7 Indicator 7: Invertebrates of floodplain marginal vegetation

Representative species: Coenagrionidae, Physidae, Planorbidae.

Summary of characteristics

The species inhabit vegetation growing at the sides of wet channels. They need water at all times. Drying out of floodplains consequent to prolonged low flows will reduce or eradicate their habitat and their abundances will decline accordingly.

These invertebrates are used as indicators for Sites 3 and 4.

Impact of the Water-use Scenarios

The Low and Medium Scenarios are anticipated to show no impact. An approximate 50% decline in abundance is predicted for Site 4 under the High Scenario.

4.5.8 Indicator 8: Invertebrates of seasonal floodplain pools and backwaters

Representative species: Dytiscidae

Summary of characteristics

These species inhabit backwaters and temporary pools in seasonal floodplains. Drying out of these areas will eradicate their habitat.

These invertebrates are used as indicators for Sites 4, 6 and 7.

Impact of the Water-use Scenarios

The Low and Medium Scenarios are anticipated to show little, if any, impact. The High Scenario would cause drastic declines in abundance at Sites 6 and 7 to lower than 20% of Present Day medians as these areas would receive less floodwaters less often.

4.5.9 Indicator 9: Invertebrates of mopane woodland pools

Representative species: Lyncedae, Daphnidae, *Gammarus* sp.

Summary of characteristics

Pools in mopane woodlands are rain-fed and so not dependent on flow regimes. Areas of mopane woodland will expand where seasonal floodplains receive less flooding.

These invertebrates are used as indicators for Site 7.

Impact of the Water-use Scenarios

The Low and Medium Scenarios are anticipated to show a mild increase in abundance as floods decline and mopane woodland expands. The High Scenario is expected to cause a noticeable increase in mopane woodlands, their pools and thus their aquatic invertebrates, perhaps to 4 or 5-fold their Present day median abundances.

4.5.10 Summary of aquatic invertebrate responses to scenarios

With the exception of Site 1, the Low and Medium Scenarios are expected to have a low to negligible impact on all indicators. The High Scenario is predicted to cause significant declines in some indicators, mostly at Sites 5, 6, 7 and 8, whilst indicator 9 will increase several fold at Site 7 as mopane woodlands expand.

4.6. Fish

4.6.1 Indicator 1: Fish resident in river

Representative species: Tigerfish [*Hydrocynus vittatus*]

Summary of characteristics

This fish guild spends most of its time in the main channel, undertaking longitudinal migrations along the river system. They require deep, clear, running water and pools throughout the year. They respond readily to seasonal and annual flow variability, increasing in abundance up to double their median numbers in wet years/cycles and decreasing in abundance to possibly half their median numbers in dry years/cycles. Natural variability in abundance is greater in the upper basin and less from Site 5 (Popa) downstream probably due to a less flashy hydrograph. Numbers can decline to zero in the Site 8 (Boteti) as this ephemeral river periodically dries out. Changes in the natural flow pattern, increased turbidity and deteriorating water quality will affect this guild of fish negatively.

These fish are used as indicators for Sites 1, 2, 3, 4, 5, 6, 7 and 8.

Impact of the Water-use Scenarios

It is predicted that there will be a drastic decline to very low numbers at Capico (Site 1) because of loss of the dry-season flows. In the rest of the system, the low and medium scenarios would result in a mild shift toward fewer years with high abundances and more with low abundances. This trend would be accentuated in the high scenario where in the lower part of the river system, at Site 2 and from Site 5 downstream, there would be no good years and abundances would be permanently suppressed to half or less of their present levels with little or no recovery in wetter years. This guild of fish would probably disappear from the Boteti (Site 8).

4.6.2 Indicator 2: Migratory floodplain dependent fish: small species

Representative species: Bulldog [*Marcusenius macrolepidotus*]

Summary of characteristics

These are small-bodied fish species that are dependent on lateral migration to floodplains for breeding and feeding. They are resident in the river through the lowflow season and migrate into floodplains during the flood season for feeding, breeding and protection against predation. As a result they depend on regular flooding of shallow vegetated floodplains in the flood season. They are also reliant on deeper [>50 cm] refuges during low flow conditions. Major disruptions of the flooding patterns or sedimentation regimes will have a detrimental effect on this species. However, minor changes that fall within the natural variability will not have a major effect on these species.

These small, relatively short-lived fish can respond quickly, and increase to large numbers, under good flooding conditions. As such their numbers are highly variable even under present day (350-50%, and possibly even higher) as they track climatic variations in the system.

These fish are used as indicators for Sites 1, 2, 3, 4, 5, 6 and 7.

Impact of the Water-use Scenarios

It is predicted that these fishes will be severely reduced or absent from the Capico River under low, medium and high scenarios. For the rest of the catchment, they will only be affected slightly by the low and medium scenario in the lowflow season, e.g., 180-20% at Mucundi (Site 2). There will still be a fair amount of variability in their numbers but with more of an emphasis on lower numbers than in the present day, i.e., slight loss of really good breeding years. Under the low and medium scenarios the sites most affected will be Sites 2 and 8. Under the high scenario there will be very few good breeding years at any of the sites. Sites 5, 6, 7 and 8 will be worst affected with few or no years where numbers will exceed 100% of present day medians, and some years down to 0%. Median numbers for Sites 7 and 8 will be lower than 25% of present day, and for Sites 5 and 6 they will be *c*. 50% of present.

4.6.3 Indicator 3: Migratory floodplain dependent fish: large species

Representative species: Redbreast tilapia [*Tilapia rendalli*]

Summary of characteristics

These are large-bodied fish species that are dependent on lateral migration to floodplains for breeding and feeding. They are resident in the river through the lowflow season and migrate into floodplains during the flood season for feeding, breeding and protection against predation. As a result they depend on regular flooding of shallow vegetated floodplains in the flood season. They are also reliant on deeper [>200 cm] refuges during low flow conditions. Major disruptions of the flooding patterns or sedimentation regimes will have a detrimental effect on this species. However, minor changes that fall within the natural variability will not have any major effect on these species.

These large, relatively long-lived fish can respond quickly, and increase numbers, under good flooding conditions, but their numbers tend to be less variable year-on-year than those of the small-bodies counterparts (Indicator 2).

These fish are used as indicators for Sites 1, 2, 3, 4, 5, 6 and 7.

Impact of the Water-use Scenarios

It is predicted that these fishes will severely reduced or absent from the Capico River (Site 1) under low, medium and high scenarios. At Sites 2 and 4, the nett effect of high scenario will be similar to that of the medium scenario because the loss in flooding will be offset by releases in the lowflow season. Under the medium scenario at the rest of the sites, however, there will be a noticeable impact on good years and increase in poor years, e.g., 37-40 our of 43 years less than 100% PD. For the high scenario this trend will be enhanced and all of the years could have abundances considerably less than present, with median abundances ranging between 37-53% of present day.

4.6.4 Indicator 4: Sandbank dwelling fish

Representative species: Sand catlet [*Leptoglanis cf dorae*]

Summary of characteristics

This group of species lives on actively moving sandbanks and habitats with sandy bottoms. As such they are dependent on flows that maintain sandbanks. However, the real issue here is not water but the fact that dams and weirs trap sediment. Downstream of a weir or dam the river is deprived of sediment, so it erodes its bed, banks and floodplains until it is once again carrying its maximum load. Thus, for some distance downstream of a weir or dam the sandbanks will be removed.

These fish are used as indicators for Sites 1, 2, 3, 4, 6 and 7.

Impact of the Water-use Scenarios

It is predicted that these fishes will severely reduced or absent from the Capico River under the low, medium and high scenarios. The impacts for the low scenario will be minor for the other sites. Under the median and high scenarios, however, there will be a noticeable impact on good years and increase in poor years. This is particularly so for the high scenario when there will be no good years and median numbers will range between 29 and 29% of present. It is also important to re-emphasise that at Site 2, and to a lesser extent the downstream sites, the sediment trapped by the dam included in this scenario has not been considered, and would probably have a major negative impact on the habitat of these species.

4.6.5 Indicator 5: Rock dwelling fish

Representative species: Sand catlet [*Leptoglanis cf dorae*]

Summary of characteristics

These are rheophillic (flow-loving) species of riffles and rapids, which are usually found living amongst the rocks and in crevices in strongly flowing water. Unlike some of the other groups these fish tend to be resident in a particular part of the river and their numbers show much less marked fluctuations under present day.

These fish are used as indicators for Sites 2, 4 and 5.

Impact of the Water-use Scenarios

It is predicted that flow changes under the low scenario will not seriously affect these fishes. Under the median and high scenarios, however, there will be a marked increase in the season and year-on-year fluctuations in numbers of these species, mainly as a result of reduced flows in the lowflow season and median numbers fall considerably under the high scenario. This of course assumes that they will have some refuges to which they can retreat during poor years, which will dominate under the high scenario. It is possible that this will not be the case, and that over time the numbers of these species will become severely reduced throughout the system.

4.6.6 Indicator 6: Marginal vegetation fish

Representative species: Banded tilapia [*Tilapia sparrmanii*].

Summary of characteristics

This group of species lives mainly amongst vegetation on margins of river and may move into floodplains during flood conditions. As such they are depend on the presence of marginal vegetation, stable soils and naturally varying water levels for establishment of emergent and submerged vegetation.

These fish are used as indicators for Sites 1, 2, 3, 4, 5, 6, 7 and 8.

Impact of the Water-use Scenarios

It is predicted that these fishes will severely reduced or absent from the Capico River (Site 1) under the low, medium and high scenarios. Under the medium scenario there will be a slight emphasis on poor years at Site 2 (39 out of 43 years where present there are 14 out of 43). The situation will be similar at Sites 5, 6, 7 and 8. There no noticeable effect predicted for Site 4. Under the high scenario the effects on Sites 2 and 4 are likely to be similar as for the medium scenario, but all the years will be strongly negative at Sites 5 and 6 and there will be a marked reduction in the abundance of these fishes at Sites 7 and 8 (down to 26-29% of present).

4.6.7 Indicator 7: Backwater dwelling fish

Representative species: Okavango tilapia [*Tilapia ruweti*]

Summary of characteristics

This group of species shares a similar habitat with the marginal vegetation group but tends to be more restricted to vegetated backwater areas and pools. They may also move into floodplains during flood conditions. Their continued presence is dependent on the maintenance of oxbows and pools on the margin of the floodplain of the river by the hydrological regime, including standing-water conditions during low flow.

These fish are used as indicators for Sites 4, 6 and 7.

Impact of the Water-use Scenarios

It is predicted that moving from present day to the low, medium and high scenarios will result in an increasing loss of the benefits of good years for these species, mainly as a result of the suppression of flood flows. Under the high scenario there will be a marked reduction in good years and a corresponding marked reduction in overall numbers at Sites 6 and 7.

4.6.8 Summary of fish responses to scenarios

With the exception of Site 1, where fish losses are expected to be high for all three scenarios, mainly as a result of run-of-river abstraction during the lowflow season, 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, the fish communities in the lower part of the catchment, e.g., Sites 4, 5, 6, 7 and 8 are expected to be severely and negatively impacted, and local extinctions are highly likely, particularly from Popa Falls (Site 5) downstream to the Boteti (Site 8).

4.7. Wildlife

4.7.1 Indicator 1: Semi aquatic animals.

Representative species: Hippopotamus, crocodile, otters, monitors and terrapins.

Summary of characteristics

These animals dwell in the main channel, and also range over banks, floodplains and islands. They are particularly sensitive to dry-season water depths, as they need sufficient water to maintain their aquatic habitat but not too much so that islands are present. The DSS predicts that they will increase in abundances in wet cycles and decrease during dry cycles.

These animals are used as indicators for all eight sites.

Impact of the Water-use Scenarios

Under Present Day conditions, the DSS shows that abundances can occasionally climb to almost double median abundances and fall as low 20% in long dry periods. Under the scenarios, they are predicted to decline at all sites under all scenarios. The most noticeable declines will be a permanent drop to very low levels (about 20%) at Capico (Site 1) under Low Scenario, at Mucundi, Kapako and Panhandle under all scenarios, and at Popa, Delta and Boteti under the High Scenario.

4.7.2 Indicator 2: Frogs, snakes and small mammals.

Representative species: snakes, ridged frogs, musk shrews.

Summary of characteristics

These animals inhabit pools, permanent swamps and the lowest floodplain areas. They are particularly sensitive to dry-season water levels and duration, and reduced floods, as they depend on backwaters and marginal vegetation.

These animals are used as indicators for Sites 2-7.

Impact of the Water-use Scenarios

There is Present Day natural variability in abundances, with modelled drops to as low as 20-30% of median during dry cycles and some modest increases during wet cycles. The scenarios are predicted to induce more severe declines during dry periods with populations probably becoming permanently depressed to levels as low as 10% of median in the High Scenario. Boteti is predicted to be the site most severely affected.

4.7.3 Indicator 3: Lower floodplain grazers

Representative species: Lechwe, sitatunga, reedbuck, waterbuck.

Summary of characteristics

The species in this indicator rely on grazing in areas of permanent swamp, and primary and secondary floodplain. These areas need floods for 4-6 months per year.

The animals are used as indicators for Sites 1-3 and 5-8.They would also have occurred at Site 4: Kapako, but this is no longer the case and cattle have no replaced them.

4.7.4 Indicator 4: Middle floodplain grazers

Representative species: elephant, buffalo, tsesebe, warthog.

Summary of characteristics

This guild of animals depends for grazing on primary and secondary floodplains, which flood for 2-6 months per year.

These animals are used as indicators for Sites 2, 3, 5, 7 and 8.

Impact of the Water-use Scenarios

This indicator group fares best in years with good flooding, and Present Day abundances are thought to decline in dry cycles. They range in abundance between about 50% and 180% of median values from year to year, and are most abundant in the Delta in years where permanent swamps shrink and seasonal wetlands expand. They disappear from the Boteti in dry cycles. They are predicted to progressively decline in abundance through the scenarios, to eventually disappear or remain at very low numbers by the High Scenario except in the Delta where they should progressively increase in numbers.

4.7.5 Indicator 5: Outer floodplain grazers

Representative species: Wildebeest, zebra, impala, duiker, aarvark, mice.

Summary of characteristics

This group of animals relies for grazing on secondary and tertiary floodplains that must flood periodically.

They are used as indicators for Sites 1-3 and 5-8.

Impact of the Water-use Scenarios

This indicator group is thought to increase in abundance in wet years and decrease in dry cycles. Present Day abundances could drop to 50% or less of median and possibly double in wet cycles. In the Delta the species thrive when permanent swamps shrink and seasonal wetlands expand, and they disappear from the Boteti as it dries out. In the scenarios they would progressively decline in numbers at all sites except the Delta, possibly becoming locally extinct in parts of the basin under the High Scenario. In the Delta, they are predicted to benefit from the scenarios, showing up to three-fold increases under the High Scenario.

Impact of the Water-use Scenarios

The species in this group are thought to increase along the river in wetter years to up to 50% more than Present Day median values, and decline in dry cycles to perhaps as low as a fifth of the PD median. They increase in numbers in the Delta in drier years as permanent swamp shrinks and seasonal wetlands expand, and disappear from the Boteti in dry periods. The scenarios are predicted to permanently depress abundances to very low levels along the river – perhaps for some sites and species to as low as 5% of PD median, with the most severe declines being associated with the High Scenario. Abundances along the Boteti will have significantly more years of low or no abundances. Populations in the Delta are expected to increase slightly or remain stable through the Low and Medium Scenarios, but decline under the High Scenario as seasonal wetlands shrink and savanna expands.

4.7.6 Summary of wildlife responses to scenarios

Abundances of wildlife are predicted to decline progressively through the scenarios, with the High Scenario having the most severe impact. Some species at some sites could permanently decline to as low as 5% of Present Day medians. The notable exception to this is the Delta, where the three indicator groups of grazers would benefit from the scenarios as permanent swamp gave way to seasonal floodplains, but even they may show an eventual decline as wetlands give way to savanna. Many of the wildlife species no longer occur at the other floodplain sites, but in areas where they do occur, similar patterns would be expected in response to the scenarios.

4.8. Birds

4.8.1 Indicator 1: Piscivores of open water.

Representative species: kingfisher, cormorant, darter, fish eagle.

Summary of characteristics

This group of birds predominantly feeds on fish from the river and adjacent pools. They generally thrive in times of low flow because their fish prey is more concentrated and vulnerable in the main river and/or isolated pools. The DSS indicates that present-day conditions produce more variability in abundances in the higher parts of the basin than in the lower parts, and abundances are generally lower in wet years and higher in drier years. If low flows are prolonged, however, the prey base will be negatively affected if the floodplains where fish breed are not inundated.

These birds are used as indicators for all eight sites.

Impact of the Water-use Scenarios

Higher abundances are generally favoured under the Low, Medium and high scenarios, but the high scenario is detrimental in the Boteti (Site 8). Here, abundances under this scenario are predicted to fall drastically, possibly to local extinction, as the river tends toward drying out.

4.8.2 Indicator 2: Piscivores of shallow waters

Representative species: larger herons and egrets.

Summary of characteristics

These birds hunt fish from overhanging trees on shallow backwaters using ambush techniques. Under Present Day conditions, the DSS indicates that their numbers tend to be lower in drier years, with good variability from year to year and many years with above median abundances. In the lower part of the basin they are less abundant in the lagoon and savanna parts of the Delta/Boteti and rather favour the seasonally flooded areas. Shallow waters in the main channels and on the floodplains concentrate the prey species into smaller areas and hunting opportunities are thus better than in lagoon areas.

These birds are used as indicators for all eight sites.

Impact of the Water-use Scenarios

Under the low scenario, this guild of birds is predicted to disappear from Site 1 (Capico) after a few years. The guild would also disappear from Site 2 (Mucundi) in all three scenarios within a decade or two. Further downstream, they would not be noticeably impacted by any of the scenarios, with the following two exceptions: 1) there would be an estimated and permanent 20% drop in numbers at Site 5 (Popa) under the high scenario; and 2) there would be a sequential decline in abundance to an eventual loss of more than half the present median abundances at Site 8 (Boteti) under the high scenario due to increased extent and time of drying out of the river.

4.8.3 Indicator 3: Piscivores and invertebrate feeders

Representative species: Little Egret, Black Heron, Glossy Ibis, Saddle-billed Stork, Lapwings.

Summary of characteristics

This group of birds feeds on fish-fry and invertebrates when water levels are receding after spawning in flood-plains; they also feed on fish trapped in drying pools. They respond to the flooding and draining of floodplains, when feeding conditions are optimal, and tend to be more abundant in wetter years.

These birds are used as indicators for all eight sites.

Impact of the Water-use Scenarios

As with the previous indicators, this group is predicted to disappear from Site 1 (Capico) under the low scenario and will decline to low levels at Site 2 (Mucundi) with the medium scenario causing the greatest decline to very low abundances. They will continue to respond normally to wet and dry cycles, with abundances increasing up to four-fold of their median value in very wet periods and decreasing down to half or less in drier times. The range of abundances between wet and dry climatic periods will noticeably shrink with the high scenario and the lower level of abundances decline to about one-fifth of median, particularly at Site 6 (Panhandle). They should increase in abundance in the Delta (Site 7) due to the loss of permanent swamp and increase in seasonal flooded areas, but disappear from the Boteti (Site 8) under the high scenario.

4.8.4 Indicator 4: Specialists of floodplains

Representative species: African Openbill, ducks, geese, Wattled Crane.

Summary of characteristics

This group of birds feeds on molluscs, frogs, fish or selective vegetation and organisms occurring in shallow floodplains. They utilise newly-flooded floodplains because food availability is optimal due to new breeding and germination activities. They also take advantage of times when waters are receding from floodplains and food items are confined and concentrated into smaller areas. Thus, times of both new inundation and receding of waters are vitally important to them. Abundances increase in wet years and decrease in dry years.

These birds are used as indicators for Sites 2, and 4-8. They were not used as indicators for Site 3 due to lack of information.

Impact of the Water-use Scenarios

The group is not listed for Site 1 (Capico) or for Site 3 (Cuito Cuanavale). At the other river sites, under Present Day conditions, they have a wide range of abundances: up to 230% of median in wet cycles and down to 3% in very dry cycles. These fluctuations become more violent with advancing development at Sites 2 (Mucundi) and 4 (Kapako), leading to no years of good abundances and possible local complete loss under the Medium and high scenarios. Populations are predicted to be more stable at Sites 5 (Popa) and 6 (Panhandle) and 7 (Delta), but declining to local loss in the Boteti (Site 8) under all scenarios.

4.8.5 Indicator 5: Specialists of water-lily habitats

Representative species: African and Lesser Jacanas.

Summary of characteristics

This group frequents floodplain pools, in both rising and receding water levels, and also lily-pad covered inlets, both of which are essential feeding habitats. Whatever the flood regime, pockets of water lilies generally survive, either in backwaters, lagoons or isolated pools, providing suitable habitat for these birds, and so they appear less vulnerable to flow changes than some other indicators.

These birds are used as indicators for Sites 2-7.

Impact of the Water-use Scenarios

The group is not reported to occur at Site 1. At Sites 3 and 4, the species are predicted to increase to quite high abundances in Present Day wet cycles (up to 353% of median abundances) and decrease slightly in dry years. The range of variability in Present Day abundance is less at Site 2 (87-105%) and Sites 5-8 (59-150%). This pattern is repeated through the scenarios, with years of higher abundance gradually becoming rarer and less pronounced. Under the high scenario, abundance levels are permanently depressed, mostly never reaching present-day median abundance levels. However, they do not decline to close to disappearance, except in the Boteti (Site 8) where they drop to perhaps 5% for all scenarios due to drying out of the river.

4.8.6 Indicator 6: Specialists inhabitants of riparian fruit trees

Representative species: Turacos, bulbuls.

Summary of characteristics

This group of birds are specialist frugivores in riparian fruit trees; when the trees are in fruit they are an important food source for many bird species. The birds are indirectly influenced by changes in water flows because they depend on the fruit-bearing riparian trees, which in turn respond to changes in water flows. Because most of the trees are long-lived, there will be a time lag of several years after the onset of unfavourable flows before fruit production fails and the trees start dying from lack of water. Abundance of the birds should mirror to some extent that of the trees since if the trees die due to low flows, there will not be a source of food for the birds.

These birds are used as indicators for Sites 2-7.

Impact of the Water-use Scenarios

Abundances are predicted to increase in wet cycles and decrease in dry years. The Present Day abundances can drop to half of median in dry years and increase to more than double the median in wet years, except at Site 4 (Kapako) where they can drop to very low (<10%) in long dry spells. With basin development, Capico (Site 2), Kapako and the Panhandle (Site 6) appear to be the most vulnerable sites, with population abundances dropping steadily to reach close to zero in the high scenario. This guild is predicted to benefit from basin development in the Delta, as open water shrinks and is replaced by sedge lands and grasslands, but would show a progressive decline at Site 8 (Boteti) to about half of Present Day median abundances.

4.8.7 Indicator 7: Breeders in reedbeds and floodplains

Representative species: Fan-tailed widowbird, weavers, bishops, herons and egrets.

Summary of characteristics

This guild of birds relies on reedbeds lining river banks and islands, and other vegetation that stands in water, for nest-building. This is a protective mechanism against predator access to their nests. The birds generally wait for high water levels before constructing nests, so that their nests do not become flooded and so that the water level stays high throughout the breeding cycle. The DSS predicts that they increase in abundance in wet years and decline in dry years.

These birds are used as indicators for Sites 1-7.

Impact of the Water-use Scenarios

At Sites 1 (Capico) and 4 (Kapako) the species show good response to dry and wet periods under Present Day conditions, with high variability from year to year leading to a wide range of abundances. The range is more muted at Sites 2 (Mucundi) 5 (Popa) and 7 (Delta) and the guild does not occur at Site 8 (Boteti). The range and variability of abundances reduces progressively through the scenarios: the species are expected to disappear from Site 1 under all scenarios because of the almost non-existent dry-season flows, and to reduce to low levels at Site 2 (1-15% of Present Day medians) and Site 6 (about 50%). This is probably because upstream developments would affect suitable nesting habitat through erratically changing water levels. The guild appears to be less affected at Sites 4 and 5 and even to benefit under the high scenario in the Delta (Site 7), presumably because of the loss of lagoons and spread of seasonal grass and sedge lands.

4.8.8 Indicator 8: Breeders in overhanging trees

Representative species: Herons, cormorants, darters.

Summary of characteristics

These species are colonial breeders or solitary nesters in trees hanging over the water. The trees are critical to their breeding success, providing protection against predators, safety for the nest and a refuge for chicks as they begin to vacate the nest. They should not be affected by changing flows in this aspect of their lives as long as the trees are not affected.

These birds are used as indicators for Sites 1-7.

Impact of the Water-use Scenarios

Their abundances are predicted to increase in wet cycles and decrease in dry cycles. The response is through a larger range at Sites 1, 3 and 4 (up to 336% increase and down to 6% over the years), and is more muted with more years at median values at Sites 5 and 6. Abundances will decline progressively through the scenarios, with no or virtually no above-median years at Sites 2, 5 and 6 under Medium and High Development. The exception to this trend is the Delta (Site 7), where the guild may experience beneficial conditions and some increase due to the increase in sedge and grasslands.

4.8.9 Indicator 9: Breeders in banks

Representative species: Bee-eaters, Collared Pratincoles, lapwings.

Summary of characteristics

This guild of birds requires vertical banks for nest holes or grassy banks for nest sites and fledgling development (note that kingfishers have been excluded). The birds need reliably lowering water levels that expose vertical or grassy banks for breeding. They are not necessarily dependent on flow for their food supply, but will be affected if changing flows influence the moisture level and texture of the bank materials or if unexpected high flows flood their nests. The guild has not been included for Sites 1, 2 and 8.

These birds are used as indicators for Sites 3-7.

Impact of the Water-use Scenarios

The direct impacts of flow changes are predicted to be very mild, with the high scenario showing mostly above-median abundances at Sites 4, 5, 6 and 7. It must be noted, however, that the indirect affects of flow changes, such as changing bank conditions and possible surges of unseasonal higher flow from dam releases that swamp nests have not been assessed.

4.8.10 Indicator 10: Breeders on rocks and sandbars

Representative species: Rock Pratincole, African Skimmer, sandpipers, thick-knees.

Summary of characteristics

These species are totally dependent for nesting on rocks, sandbars and islands in the main river that emerge above the water. Low flow levels generally benefit them, as this is the time when sandbanks and rocks are exposed for breeding. Very low flows will result in sandbanks becoming accessible to predators, however, and negatively affect the food supply of those that eat floodplain-breeding fish. Unseasonal high flows could swamp nests.

These birds are used as indicators for Sites 1, and 5-7.

Impact of the Water-use Scenarios

The guild has not been listed for Sites 2, 3, 4 and 8. The different species could occur wherever rocks or sandbars emerge from the water. They will generally benefit from lower flows as more rocks and sandbars will be exposed, but it is predicted that their numbers will decline at Site 5 (Popa) under the high scenario, perhaps because dry-season flows fall extremely low to 18% of Present Day thereby exposing nesting sites to predators.

4.8.11 Summary of bird responses to scenarios

Sites 1 (Capico), 2 (Mucundi), 4 (Kapako), 6 (Panhandle) and 8 (Boteti) are identified as river reaches where local extinctions of one or more indicator groups could occur, especially under the high scenario. The same sites also most often list moderate declines in several indicators if local extinction is not anticipated. Site 7, conversely, is predicted to have mild to moderate increases in several indicators as open water and permanent swamp give way to seasonal grass and sedge lands.

It is worth noting that birds are highly mobile and will 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 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.

5. Biophysical results: Integrity

5.1. Integrity ratings and classification of overall impact

The predictions presented in the previous Chapter were generated from the information provided by the biophysical specialists in the form of Response Curves. This is essentially a set of consequences for a particular indicator to changes in a range of flow categories expressed as Severity Ratings of that describe increase/decreases for an indictor on a scale of 0 (no measurable change) to 5 (very large change; see Section 1.3). These rating were then taken further to indicate whether that change would be a shift toward or away from the natural condition. The Severity Ratings hold their original numerical value of between 0 and 5, but are given an additional negative or positive sign, to transform them from *Severity Ratings* (of changes in abundance or extent) to *Integrity Ratings* (of shift to/away from naturalness), where (Brown and Joubert 2003):

- *toward natural* is represented by a positive Integrity Rating; and
- *away from natural* is represented by a negative Integrity Rating.

The Integrity Ratings were then used to place the three flow scenarios within a classification of overall discipline integrity and overall river condition, using the South African ecoclassification categories A to F (Table 5.1; DWAF 1999; Kleynhans 1996; Brown and Joubert 2003). The ecological integrity of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of ecosystems of the region.

Table 5.1. The South African River Categories (DWAF 1999)

CATEGORY	DESCRIPTION
A	Unmodified, natural.
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

Note : A D-category is widely considered to represent the lower limit of degradation allowable under sustainable development (e.g., Dollar et al. 2006; Dollar *et al*. In press).

In this study, the predictions provided by the specialists for each of the three were summarized in terms of their effects on the integrity of each discipline at each study site and the overall riverine ecosystem represented by each study site. If the present status of a river is say a B-category, a scenario with a negative Integrity Score would represent movement in the direction of a Category C-F river, whilst one with a positive score would indicate movement toward a Category A river.

5.2. Present-day ecological integrity for the study sites

The present day ecological integrity of the aquatic ecosystems at each of the eight study sites was determined using a Habitat Integrity Assessment (Kleynhans 1996). The Habitat Integrity Method uses easily assessed physico-chemical and habitat characteristics as surrogates for physical and biotic condition. The method is based on the qualitative assessment of a number of pre-weighted criteria that indicate the integrity of the instream and riparian habitats available for use by riverine biota (Table 5.2). The criteria used are the basis that anthropogenic modification of their characteristics can generally be regarded as the primary causes of degradation of the integrity of a river.

The assessment of the severity of impact of modifications is based on six descriptive categories with ratings ranging from 0 (no impact), 1 to 5 (small impact), 6 to 10 (moderate impact), 11 to 15 (large impact), 16 to 20 (serious impact) and 21 to 25 (critical impact).

The assessment was done using the professional judgement and experience of the study team, and was conducted on-site at each of the study sites. Assessments were made separately for instream and riparian components, and then combined and expressed as a percentage and subtracted from 100 to produce a score for overall Habitat Integrity.

Table 5.2 Criteria and weights used for the assessment (from Kleynhans 1996).

INSTREAM CRITERIA	WEIGHT	RIPARIAN ZONE CRITERIA	WEIGHT
Water abstraction	14	Indigenous vegetation removal	13
Flow modification	13	Exotic vegetation encroachment	12
Bed modification	13	Bank erosion	14
Channel modification	13	Channel modification	12
Water quality	14	Water abstraction	13
Inundation	10	Inundation	11
Exotic macrophytes	9	Flow modification	12
Exotic fauna	8	Water quality	13
Solid waste disposal	6		
TOTAL	100	TOTAL	100

The results of the assessments are presented in Table 5.3. The total scores for the instream and riparian zone components are then used to place the habitat integrity of both in a specific intermediate habitat integrity category. These categories are also indicated in Table 5.3.

Table 5.3 **Results of the Habitat Integrity (after Kleynhans 1996) assessments done on-site by the biophysical specialists at each of the study sites (October 2008)**

Site No	River	Place	PD Category	Habitat Integrity	Instream	Riparian	Abstraction	Quality	Floods	Lowflows	Bed	Channel	Inundation	Macrophytes	Fish	Waste	Removal	Encroachment	Erosion
1	**Cuebe**	**Capico**	**B**	84.1	91.7	76.48	8	0	0	5	0	5	0	0	0	0	18	0	5
2	**Cubango**	**Mucundi**	**B**	87.3	92.8	81.76	6	0	0	5	0	5	0	0	0	0	16	0	0
3	**Cuito**	**Cuito Cuanavale**	**B**	91.0	93.5	88.52	0	1	0	5	1	5	1	0	0	5	12	0	0
4	**Okavango**	**Kapako**	**B**	86.2	86.6	85.72	5	7	0	0	8	0	0	1	0	9	16	1	0
5	**Okavango**	**Popa Falls**	**B**	91.2	92.6	89.72	2	3	0	0	0	1	0	0	0	17	11	0	2
6	**Okavango**	**Panhandle**	**B**	93.5	96.7	90.28	2	2	0	0	0	2	0	0	0	0	11	0	0
7	**Okavango**	**Xaxanaka**	**B**	98.6	98.3	98.88	2	1	0	0	0	0	0	0	0	0	0	0	0
8	**Boteti**	**Maun**	**B**	88.2	88.5	87.88	6	6	0	4	3	3	0	2	0	0	9	0	0

Where:
A Category = 100
B Category = 80-99
C Category = 60-79
D Category = 40-59
E Category = 20-39
F Category = 0-19.

Additional details for the method used are provided in Report 03/2009: Guidelines for data collection, analysis and scenario creation.

5.3. Interpretation of integrity plots

The integrity plots presented in this Chapter list each of the study sites (1-8) along the x-axis, and the Overall Integrity Rating on the y-axis. Zero on the y-axis equals the present day integrity of the system. Since all of the study sites have a present-day integrity of a B category, zero on the y-axis equals a B-category.

There is a series of lines marked on the integrity plot representing the general position on the graph when the overall integrity ratings would be expected to result in a move from one category to the next.

5.4. Effects on the integrity of each discipline

The present-day (2008) integrity was a B-category for all disciplines.

5.4.1 Geomorphology

The integrity plot for geomorphology for the three scenarios at each of the study sites is shown in Figure 5.1.

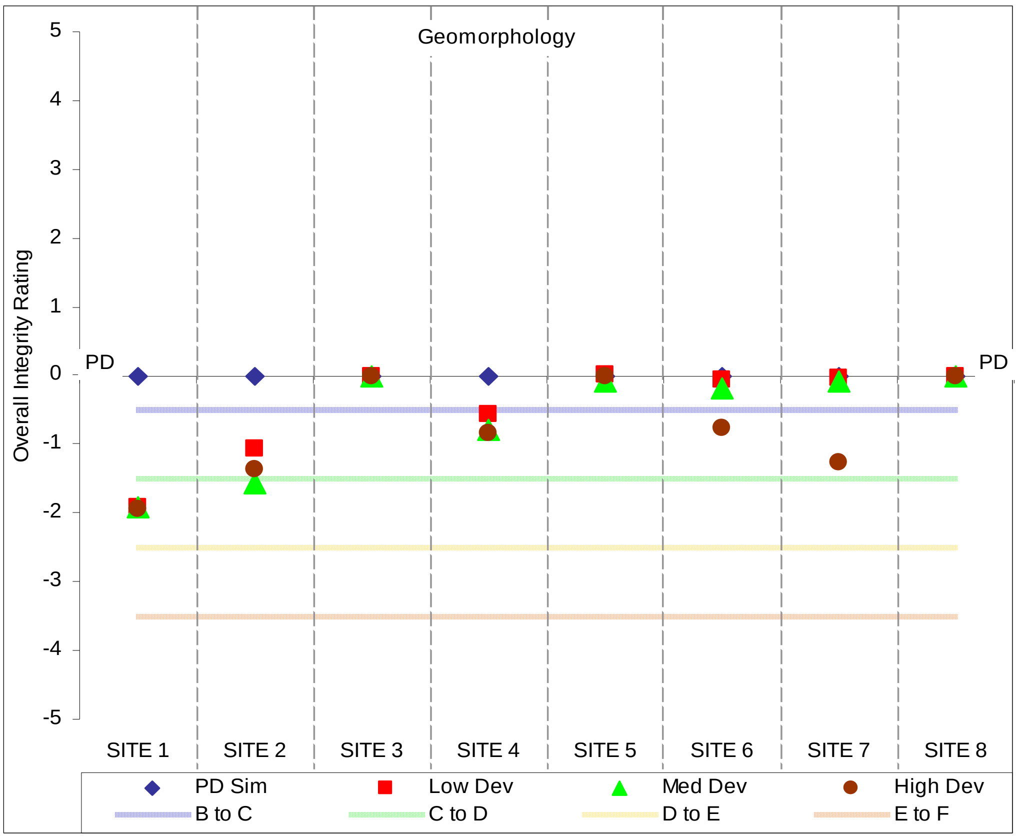

Figure 5.1 Integrity plot for geomorphology for the three scenarios at each of the study sites

The impacts on geomorphological integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of two categories from a B-category to a D-category for all scenarios.
Site 2 (Mucundi):	A drop of one category to a C-Category for the low and high scenarios, and a drop of two categories to a D-Category for the mdeium scenario.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	A drop of half a category to a B/C for the low scenario, and a drop of two categories to a C-category for the medium and high scenarios.
Site 5 (Popa Falls):	No change in category.
Site 6 (Panhandle):	No change in category for the low and medium scenario and a drop of one catgeory to a C-category for the high scenario.
Site 7 (Xaxanaka):	No change for the low and medium scenarios. Drop of one category from a B-category to a C-category for the high scenario.
Site 8 (Boteti):	Geomorphology not assessed for the Boteti.

5.4.2 Water Quality

The integrity plot for water quality for the three scenarios at each of the study sites is shown in Figure 5.2.

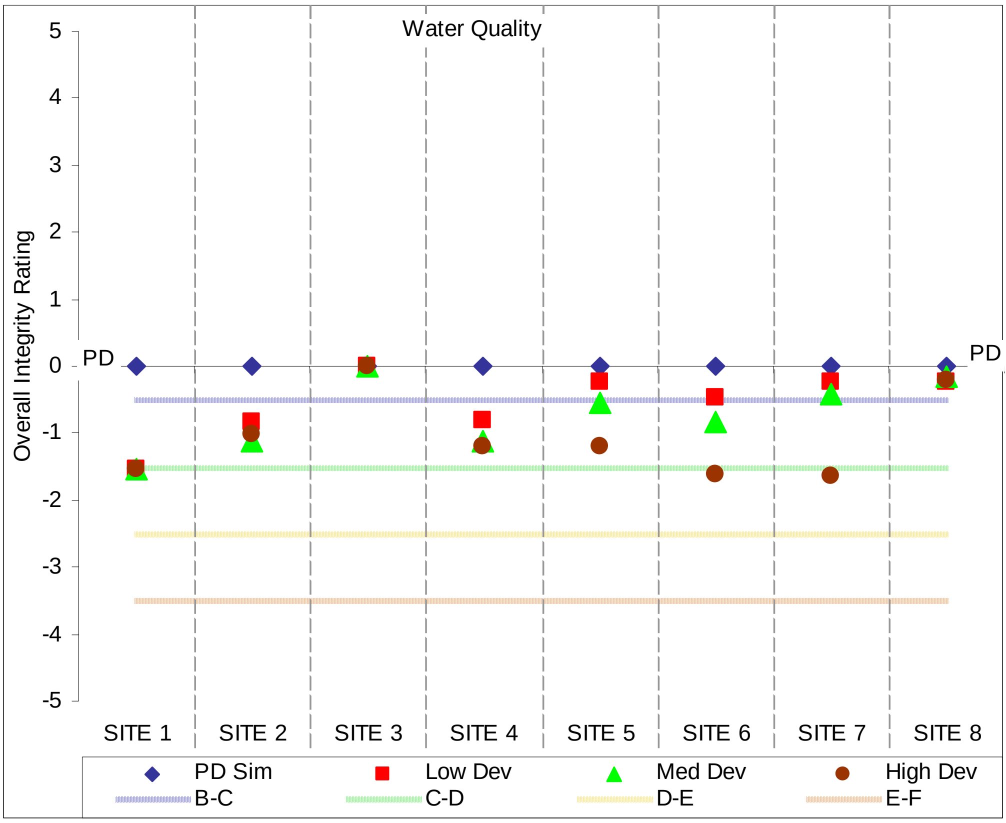

Figure 5.2 Integrity plot for water quality for the three scenarios at each of the study sites

The impacts on water quality integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of two categories from a B-category to a D-category for all scenarios.

Site 2 (Mucundi):	Drop of half a category from a B-category to a B/C-category for the low and medium scenarios, and a drop of one category to a C-category for the high scenario.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	Drop of a category from a B-category to a C-category for the low scenario, and slightly greater drop but still only one category to a C-category for the medium and high scenarios.
Site 5 (Popa Falls):	Drop of half a category from a B-category to a B/C-category for the low and medium scenarios. Drop of one category to a C-category for the high.
Site 6 (Panhandle):	Drop of half a category from a B-category to a B/C-category for the low scenario. Drop of nearly one category to a C-category for the medium scenario, and a drop of two categories to a D-category.
Site 7 (Xaxanaka):	No change for the low and medium scenarios, but a drop of two categories to a D-category for the high scenario.
Site 8 (Boteti):	No significant change in water quality, mainly because the river is predominately dry under the medium and high scenarios.

5.4.3 Vegetation

The integrity plot for vegetation for the three scenarios at each of the study sites is shown in Figure 5.3.

The impacts on vegetation integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of two categories from a B-category to a D-category for all scenarios.
Site 2 (Mucundi):	Drop of half a category from a B-category to a B/C-category for the low and high scenarios, and a drop of one category to a C-category for the medium scenario.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	No change for the low scenario, and a drop of half a category from a B-category to a B/C-category for the medium and high scenarios.
Site 5 (Popa Falls):	No change for the low and medium scenarios, but a drop of two and half categories from a B-category to a D/E-category for the medium and high scenarios.
Site 6 (Panhandle):	No change for the low and medium scenarios, but a drop of one category from a B-category to a C-category for the medium and high scenarios.

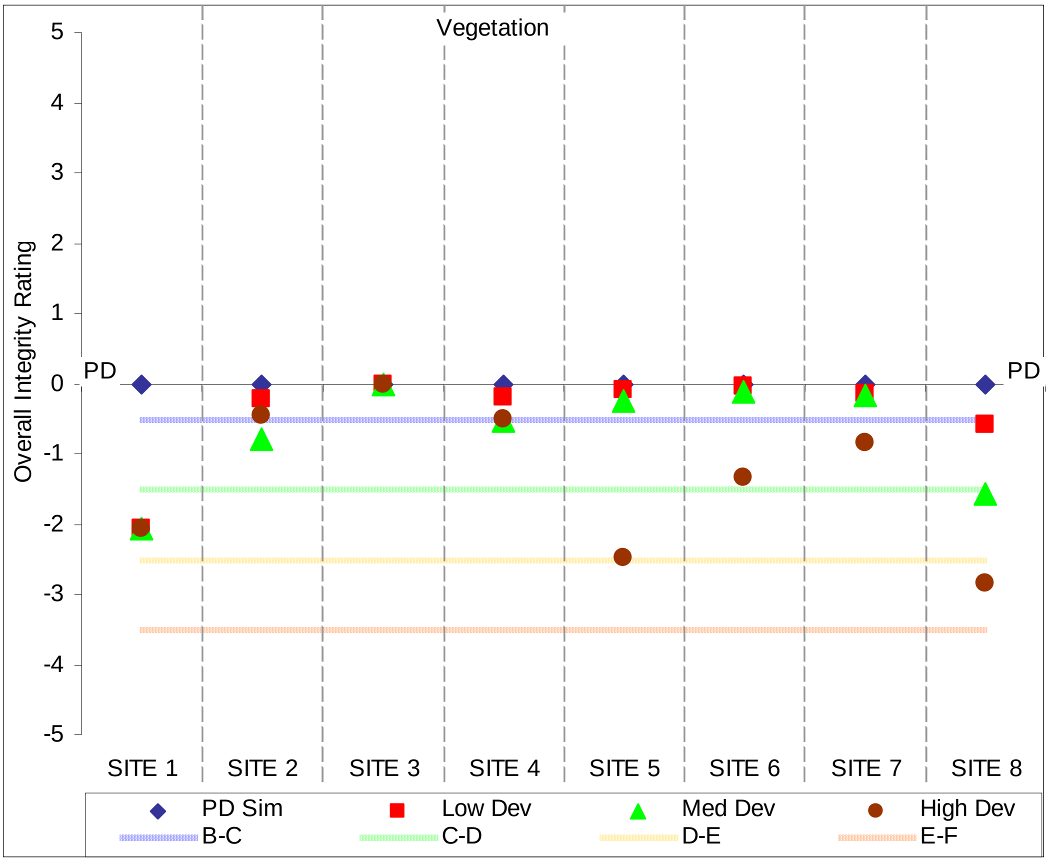

Figure 5.3 **Integrity plot for vegetation for the three scenarios at each of the study sites**

Site 7 (Xaxanaka):	No change for the low and medium scenarios, but a drop of one category from a B-category to a C-category for the high scenario.
Site 8 (Boteti):	Drop of half a category from a B-category to a B/C-category for the low scenario, a drop of two categories to a D-category for the medium scenario and a drop of three categories to an E-category for the high scenario.

5.4.4 Aquatic macroinvertebrates

The integrity plot for aquatic macroinvertebrates for the three scenarios at each of the study sites is shown in Figure 5.4.

The impacts on aquatic macroinvertebrate integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of three categories from a B-category to an E-category for all scenarios.
Site 2 (Mucundi):	No change in category.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	No change in category.

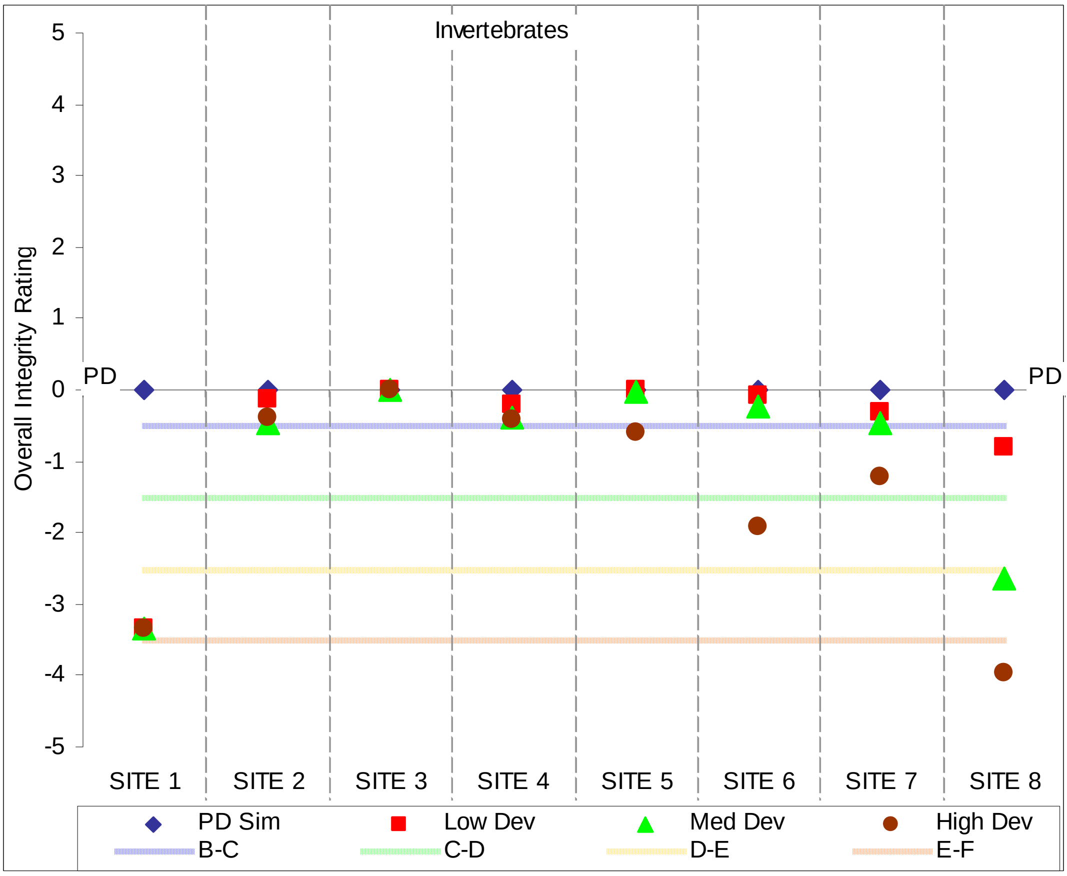

Figure 5.4 **Integrity plot for aquatic macroinvertebrates for the three scenarios at each of the study sites**

Site 5 (Popa Falls):	No change for the low and medium scenarios, and a drop of half a category from a B-category to a B/C-category for the high scenario.
Site 6 (Panhandle):	No change for the low and medium scenarios, and a drop of two categories from a B-category to a D-category for the high scenario.
Site 7 (Xaxanaka):	No change for the low and medium scenarios, and a drop of one category from a B-category to a C-category for the high scenario.
Site 8 (Boteti):	Drop of half a category from a B-category to a B/C-category for the low scenario, a drop of three categories to an E-category for the medium scenario and a drop of four categories to an F-category for the high scenario.

5.4.5 Fish

The integrity plot for fish for the three scenarios at each of the study sites is shown in Figure 5.5.

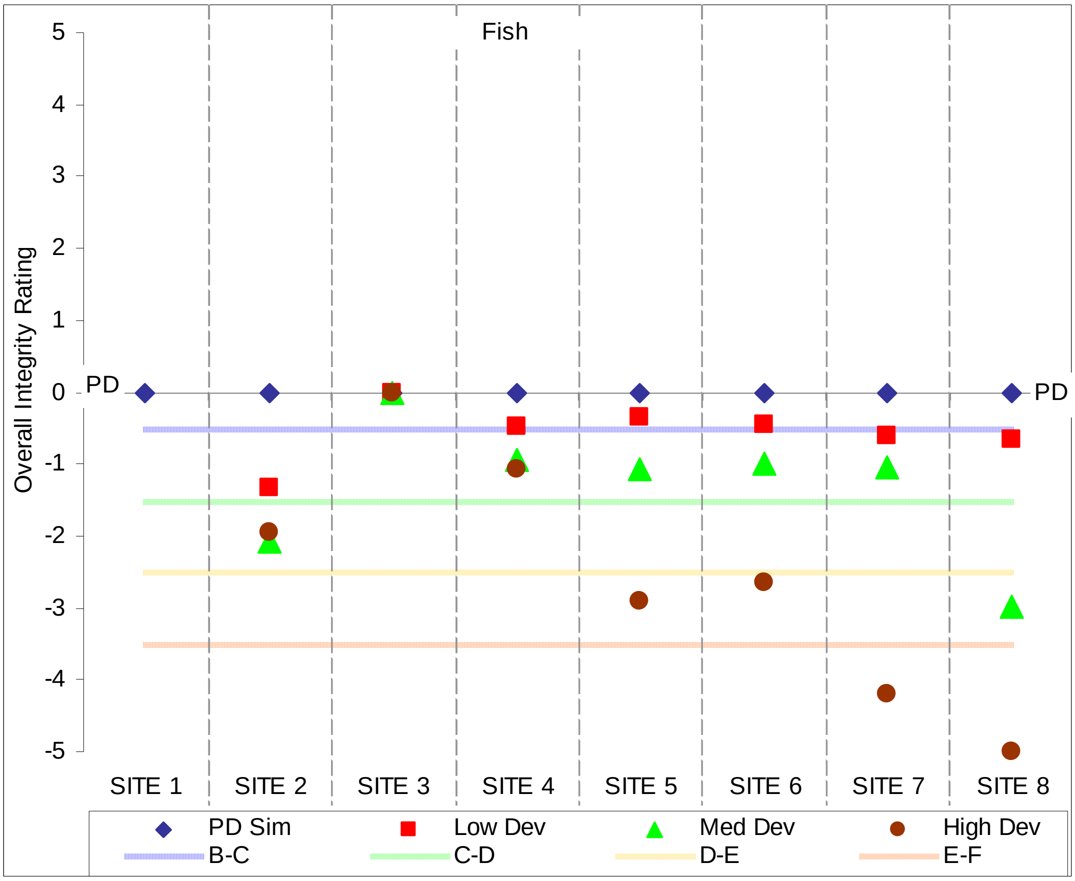

Figure 5.5 **Integrity plot for fish for the three scenarios at each of the study sites**

The impacts on fish integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of four categories from a B-category to an F-category for all scenarios.
Site 2 (Mucundi):	Drop of one category from a B-category to a C-category for the low scenarios, and a drop of two categories to a D-category for the medium and high scenarios.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	A drop of half a category to a B/C for the low scenario, and a drop of one category to a C for the medium and high scenarios.
Site 5 (Popa Falls):	No change for the low scenario. A drop of one category to a C-category for the medium scenario, and a drop of three categories to an E-category for the high scenario.
Site 6 (Panhandle):	No change for the low scenario. A drop of one category to a C-category for the medium scenario, and a drop of three categories to an E-category for the high scenario.
Site 7 (Xaxanaka):	Drop of half a category from a B-category to a B/C-category for the low scenario, a drop of one category to an C-category for the medium scenario and a drop of four categories to an F-category for the high scenario.
Site 8 (Boteti):	Drop of half a category from a B-category to a B/C-category for the low scenario, a drop of three categories to an E-category for the medium scenario and a drop of four categories to an F-category for the high scenario.

5.4.6 Wildlife

The integrity plot for wildlife for the three scenarios at each of the study sites is shown in Figure 5.6.

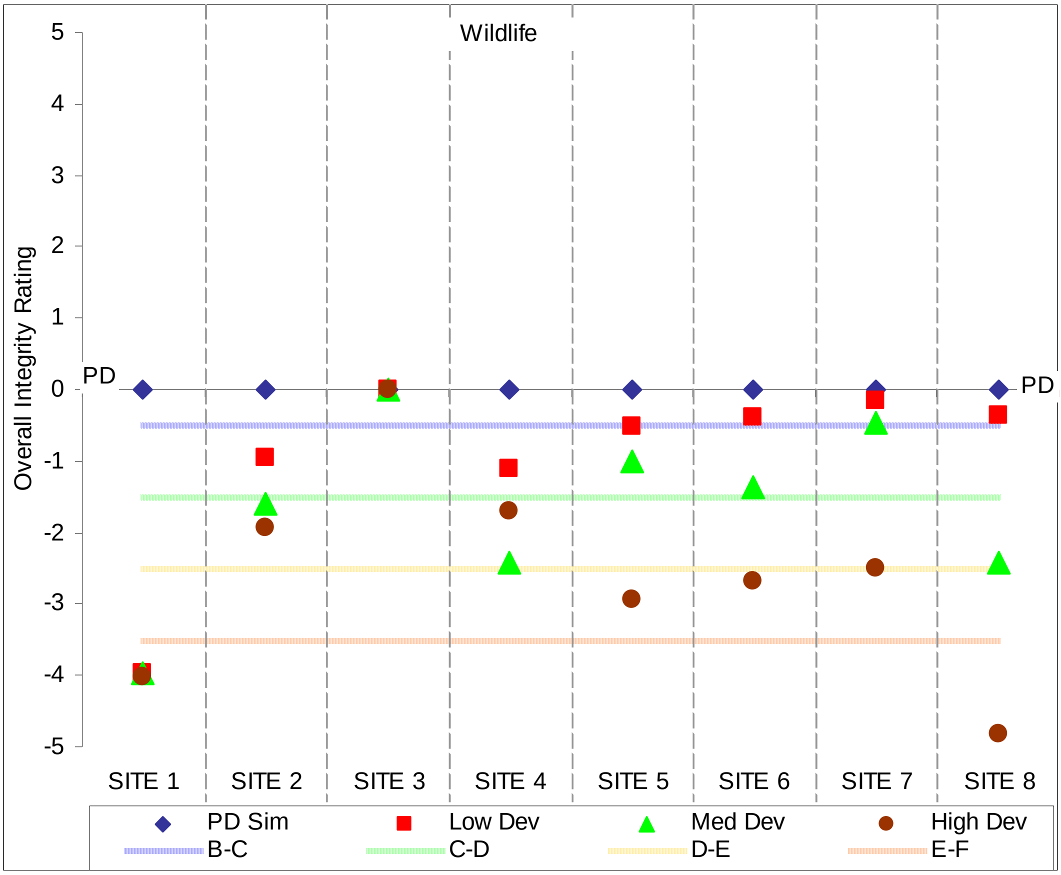

Figure 5.6 Integrity plot for wildlife for the three scenarios at each of the study sites

The impacts on wildlife integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of four categories from a B-category to an F-category for all scenarios.
Site 2 (Mucundi):	Drop of one category from a B-category to a C-category for the low scenario, and a drop of two categories to a D-category for the medium and high scenarios.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	A drop of one category to a C-category for the low scenario. A drop of two categories to a D-category for the medium scenario. The high scenario scored between the low and medium scenario.
Site 5 (Popa Falls):	A drop of half a category to a B/C-Category for the low scenario. A drop of one category from a B-category to a C-category for the medium scenario, and a drop of three categories to an E-category for the high scenario.
Site 6 (Panhandle):	A drop of half a category to a B/C-Category for the low scenario. A drop of one category from a B-category to a C-category for the medium scenario, and a drop of two categories to an D-category for the high scenario.
Site 7 (Xaxanaka):	No change for the low and medium scenarios. A drop of two and a hald categories to a D/E-Category for the high scenario.

Site 8 (Boteti):	No major change for the low scenario. A drop of two categories to a D-category for the medium scenario, and a drop of four categories to an F-category for the high scenario.

5.4.7 Birds

The integrity plot for birds for the three scenarios at each of the study sites is shown in Figure 5.7.

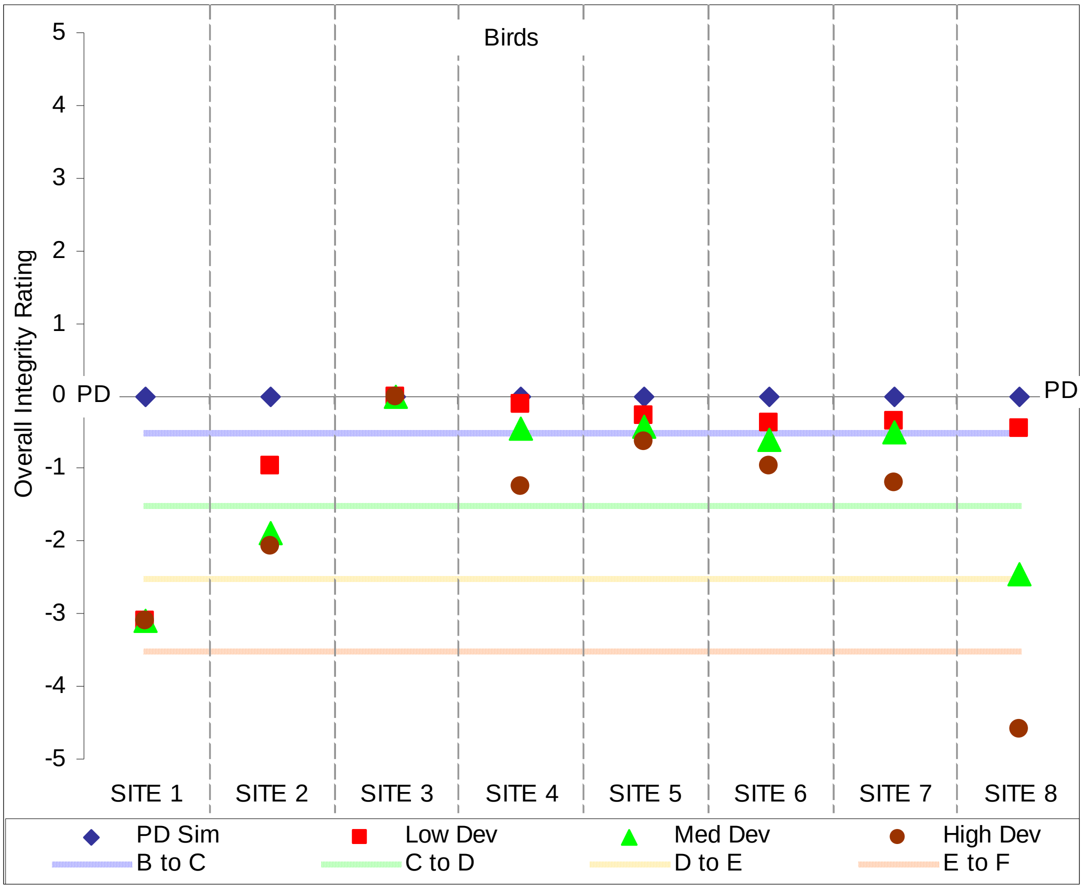

Figure 5.7 Integrity plot for birds for the three scenarios at each of the study sites

The impacts on bird integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico):	Drop of three categories from a B-category to a an E-category for all scenarios.
Site 2 (Mucundi):	Drop of one category from a B-category to a C-category for the low scenario, and a drop of two categories to a D-category for the medium and high scenarios.
Site 3 (Cuito Cuanavale):	No change.
Site 4 (Kapako):	No change for the low scenario. A drop of half a category to a B/C-category for the medium scenario and a drop of one category to a C –category for the high scenario.
Site 5 (Popa Falls):	No change for the low scenario. A drop of half a category to a B/C-category for the medium and high scenarios.
Site 6 (Panhandle):	A drop of half a category to a B/C-category for the low and medium scenarios and a drop of one category to a C –category for the high scenario.

Site 7 (Xaxanaka): A drop of half a category to a B/C-category for the low and medium scenarios and a drop of one category to a C –category for the high scenario.

Site 8 (Boteti): A dopr of half a category to a B/C for the low scenario. A drop of two and a half categories to a D/E-category for the medium scenario, and a drop of four categories to an F-category for the high scenario.

5.5. Effects on the integrity of the whole ecosystem

The plot for overall ecosystem integrity for the three scenarios at each of the study sites is shown in Figure 5.8.

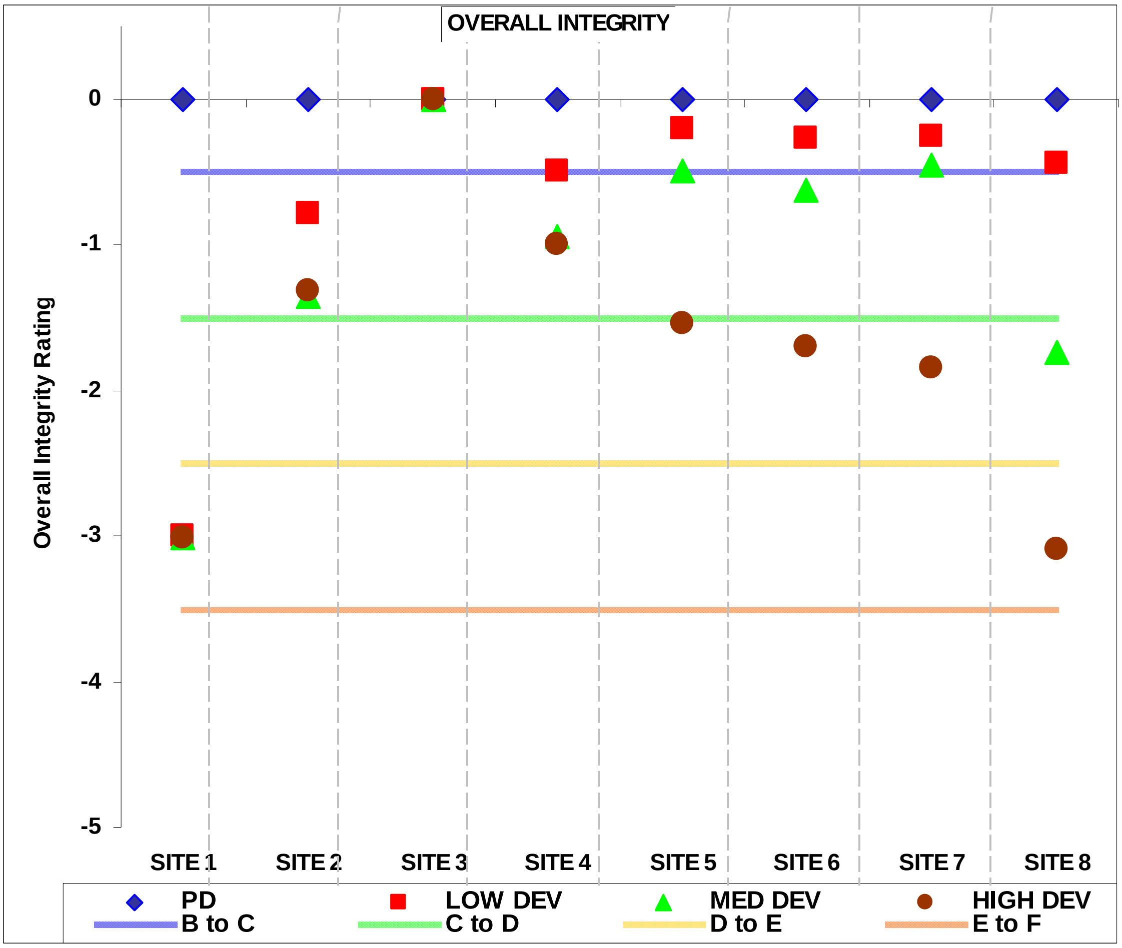

Figure 5.8 Overall ecosystem integrity for the three scenarios at each of the study sites

The impacts on overall ecosystem integrity for the low medium and high scenarios can be summarised as follows:

Site 1 (Capico): Drop of three categories to a E-category for all scenarios.

Site 2 (Mucundi): Drop of one category to a C-catgeory for all three scenarios, although the low scenario results in a mcuh higher C than the other two.

Site 3 (Cuito Cuanavale): No change.

Site 4 (Kapako): Drop of half and category to a B/C-category for the low scenario, and a drop of one category to a C-category for the medium and high scenarios.

Site 5 (Popa Falls):	No change for the low scenario. Drop of half a category to a B/C-category for the medium scenario, and a drop of one and a half categories to a C/D-category for the high scenario.
Site 6 (Panhandle):	No change for the low scenario. Drop of half a category to a B/C-category for the medium scenario, and a drop of two categories to a D-category for the high scenario.
Site 7 (Xaxanaka):	No change for the low scenario. Drop of half a category to a B/C-category for the medium scenario, and a drop of two categories to a D-category for the high scenario.
Site 8 (Boteti):	Drop of half a category to a B/C-category for the low scenario. A drop of two categories to a D-category for the medium scenario, and a drop of three categories to an E-category for the high scenario.

Thus, apart from Site 1: Capico, the greatest impacts on integrity are for the high scenario at Sites 5, 6, 7 and 8 (Figure 5.9). Importantly, the situation in Capico is one of local impacts and locally accrued benefits, whereas the water-use benefits associated with the medium and high scenarios at Sites 5, 6 and 7 are expected to accrue outside of the basin and, for Botswana, outside of the country. This is also true for the low and medium scenarios in the Boteti, while the high scenario at Boteti include a dam at Samedupi, which should deliver local water-use benefits.

In Figure 5.9, those sections of the river in a D-category and in an E-category have been marked with a red flag. This is because the expected decline in their condition is likely to result in difficulties in sustaining the benefits offered by theses ecosystems. This is particularly so given the fact that neither the localised impacts of the water-resource developments themselves (such as sediment changes) nor the longitudinal impacts of a fragmented river system have been considered in these predictions.

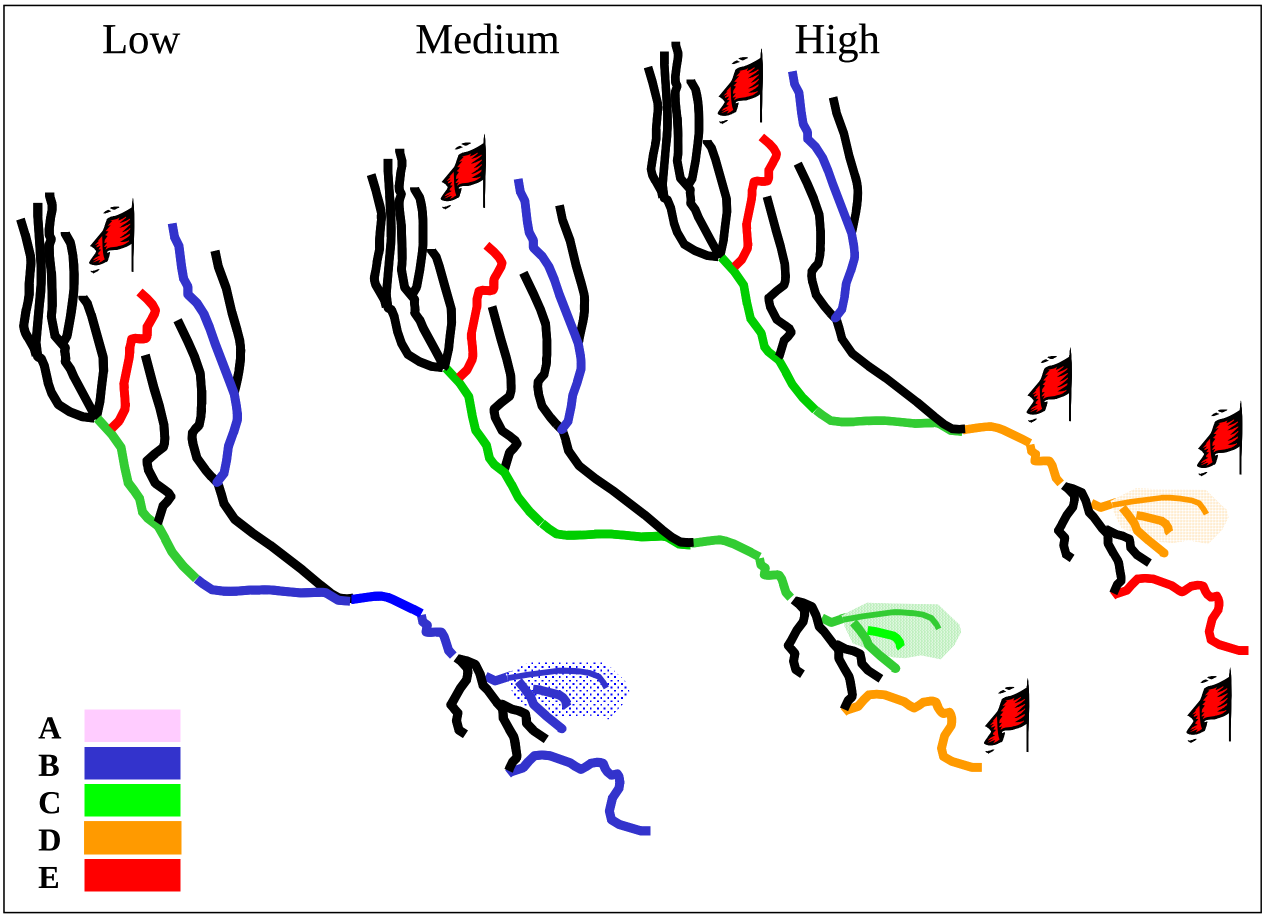

Figure 5.9 Summary of expected changes in ecosystem integrity for the low, medium and high scenarios. Present-day conditions are estimated as B-category.

6. Social results

6.1. Introduction

The chapter summarises the results for each of the socio-economic indicators in terms of their overall contribution to the livelihoods of the people in the basin, as well as their contribution to the economies of the basin countries. Livelihoods are measured in terms of net income earned by households in the basin. Economic contributions are measured in terms of the change in national income generated by the use of the indicators concerned.

6.1.1 Indicator 1: Household income - fish

Summary of characteristics

Fish are caught throughout the basin in river channels, floodplains during floods, and residual floodplain pools. Seasonal floods can bring a marked peak in catch. Only in Botswana and only in the Panhandle area is fishing done commercially in groups of semi-motorised small scale fishers. Elsewhere fishing is small scale at household level and traditional gear (locally made traps), gill nets hook, and line and dugout canoes are used. It is a small-scale household-based fishing activity, using traps, and/ or gill nets, hook and line and mokoros (canoes), for own use as fresh food product, and very limited marketing, with very limited processing (drying). Species caught a numerous dominated by vegetarian and predatory bream (Cichlidae), tiger, and barbel (Claridae). Fish catch is dependent on fish abundance - perennial flows in channels, regular seasonal floods on floodplains.

Used as indicator for Sites 1 to 12 (all sites).

Impact of the Water-use Scenarios

The catch tends to peak during floods in areas with floodplains. In areas without floodplains catches are more stable. At prolonged low flows or excessively low flows fish abundance will be negatively affected if the floodplains where fish breed are not inundated. Generally the scenarios will progressively reduce catch. In the lower basin the high scenario will severely reduce fish catch. The net incomes for fishers or livelihoods tend along with catches to peak during floods in areas with floodplains. In the areas without net incomes are more stable. The relatively simple small scale enterprise is not particularly sensitive to catch reduction and so the patter is similar to that for catch.

6.1.2 Indicator 2: Household reeds

Summary of characteristics

Reeds and sedges are harvested from the wetter parts of floodplains and riverbanks, and used for building, and craft making. The representative species is *Phragmites australis.* Reeds are subject to small-scale household-based harvesting of reeds using sickles, for own use in housing and compound wall construction, and very limited marketing. It is found in upper wetbank 1 and river lower floodplain situations, and relies on the perennial flows in channels, regular seasonal floods on upper wetbank 1, and river lower floodplain.

Used as indicator for Sites 1 to 7 (all sites except 8).

Impact of the Water-use Scenarios

Reeds occur in two indicator vegetation sites; upper wetbank, and lower floodplain, and are harvested at both. Harvest response is complex and tends to reflect change in the extent of these stands. Also making it complex is a limit in terms of capacity to harvest and market demand to the response to changes in extent of reeds. Thus the response is muted, and it depends on how well used the PD stocks are. There is no longer significant reed use at site 8. The net income or livelihood from household reed harvest is expected to remain relatively stable in all sites where reeds are harvested except in site 1, where an already well used resource will decline notably. Elsewhere there will be small increases in household reed livelihoods at sites 4 and 7. Small decreases may be experienced with the high water use scenario at sites 5 and 6.

6.1.3 Indicator 3: Household income – floodplain grass

Summary of characteristics

Throughout the basin, households harvest thatch grass for use in housing. This takes place in upland areas and also on river floodplains, where certain, specific, high quality thatch grass species are also harvested. These wetland floodplain grasses make up indicator 3. It involves small-scale household-based harvesting of grass using sickles for own use as specialised construction thatch and very limited marketing. Several species are involved, but *Miscanthus junceus*, is representative found on river lower floodplain, river middle floodplain situations. It depends on regular seasonal floods on floodplains

Used as indicator for Sites 1 to 7 (all sites except 8).

Impact of the Water-use Scenarios

Floodplain grass occurs in two indicator vegetation sites; middle and upper floodplain, and it is harvested at both. Harvest response is complex and tends to reflect change in the extent of these stands. Also making it complex is a limit in terms of capacity to harvest and market demand to the response to changes in extent of floodplain grass. Thus the response is muted, and it depends on how well used the PD stocks are. There is no longer significant floodplain grass use at site 8. The net income or livelihood from household floodplain grass harvest is expected to remain relatively stable in all sites where floodplain grasses are harvested except in site 1, where an already well used resource will decline notably. Elsewhere there will be small increases in household floodplain grass livelihoods at sites 4 and 7. Small decreases may be experienced with the high water use scenario at sites 5 and 6.

6.1.4 Indicator 4: Household income – floodplain gardens (e.g. molapo)

Summary of characteristics

Households throughout the basin grow crops. In Angola crop production is the most important source of household income and food earning some 80% of household income. Here, the sub-humid and humid climate makes it possible to grow most crops in uplands. In the lower semi-arid parts of the basin the growth of crops is carried out in both uplands and on floodplains, where additional wetness and fertility enhance yields by some 40%. Crop production is small-scale in gardens and tillage is limited largely to that by hand or by draft livestock. Very limited tractor power is available, and mainly in the Namibian and Botswana parts of the basin. In Namibia and Botswana crop production is of lesser importance for households because yields are low and losses to wildlife such as elephant can be significant. Floodplain gardens can be described as small-scale household-based flood-recession crop production using animal draft power and manual labour, on floodplains for own consumption as food and very limited marketing and with home milling, complementary to household upland rain-fed crop production. Representative crops are maize, sorghum, millet, vegetables. It takes place on river lower floodplain and river middle floodplain sites, and requires regular seasonal floods on floodplains and regular transitional season 2 to allow crop growth.

Used as indicator for Sites 3, 4, 7 and 8.

Impact of the Water-use Scenarios

Floodplain gardens are produced in two indicator vegetation types; lower and middle floodplain and only at sites 3, 4, 7 and 8. Harvest response is complex and tends to reflect change in the extent of these habitats. Also making it complex is a limit in terms of capacity to increase production in response to changes in extent of habitat. Thus the response tends to be muted. The net income or livelihood from household floodplain gardens is expected to remain relatively stable in all sites, but will follow the same patterns noted for garden production. Thus there will be small increases in household floodplain garden livelihoods at sites 4 and 7. Decreases will be experienced at site 8.

6.1.5 Indicator 5: Household income and wealth - livestock

Summary of characteristics

Livestock are very important for households in the lower basin, providing a range of household utilities, such as meat, milk, draft power, and store of value. Their value further up the basin is less, mainly because many households in Angola lack stock, and the money to buy stock. The indicator involves small-scale household-based open access grazing of livestock on floodplain, as part of broader upland small-scale livestock keeping for meat milk, transport and as a store of wealth, with limited marketing. Some 22% of small scale livestock-keeping value is attributable to use of floodplain grasslands where wetness enhances production. Local breeds of cattle (*Bos indicus*) and goats are representative. It takes place on river middle floodplain and river upper floodplain sites, and depends on regular seasonal floods on floodplains.

Used as indicator for Sites 3, 4, 6, 7 and 8.

Impact of the Water-use Scenarios

Floodplain grazing takes place in three indicator vegetation types; lower middle and upper floodplain and only at sites 3, 4, 6, 7 and 8. The grazing production response to scenarios is complex and tends to reflect change in the extent of these habitats. At sites 4 and 6 production will tend to be stable. At site 7 it is likely to expand significantly with increase in drier floodplains. At site 8 it would decrease as drier floodplains change to savanna. The net income or livelihood from household floodplain grazing is expected to remain relatively stable in sites 4 and 6, but at sites 7 and 8 will follow the same patterns noted for grazing production. Thus there will be increases in household floodplain grazing livelihoods at site 7 and decreases will be experienced at site 8.

6.1.6 Indicator 6: Household income - tourism

Summary of characteristics

Tourism in the Namibia and Botswana basin areas is overwhelmingly non-consumptive, nature-based, and focused on wildlife viewing, although some guided recreational fishing and hunting operations are involved. Medium to large scale lodges and camps with between 10 and 30 beds, serving middle and upper market tourists are most common. Self-drive camping and guided mobile operations are also present in significant numbers. Nearly all the value of this tourism is attributable to the presence of the river/wetlands, although the activities offered can be either land- or water-orientated. Most tourism income for local households comes through wages and salaries, from full- and part-time employment in local tourism industry as labour, skilled labour, and occasionally management. To some extent local households directly provide small-scale services, such as guided canoe trips, to tourists, supplementing the commercial lodge operations. Representative resources are general wildlife, including semi aquatic animals, lower, middle, and outer floodplain grazers, associated predators and birds generally, general scenic habitats and attributes linked to a mosaic of all the vegetation indicators. It is sited commonly on upper dry banks but making use of all vegetation indicators as part of product – dependent on dry season low flow and flood volume, perennial flows in channels, and regular seasonal floods on floodplains

Used as indicator along with indicator 9.1 below for Sites 4, 5, 6, 7 and 8.

Impact of the Water-use Scenarios

Tourism makes use of a complex range of habitats including river banks channels, and floodplains at sites 4 to 8. It appears to be responsive to changes in dry season low flow, flood type, and wildlife abundance. The response to scenarios shows a generally sharply declining trend with increasing water use development upstream. The only exception is in the central Delta (site 7). In site 4 the high scenario gives higher numbers than is better than the medium scenario but both are lower than present day. Site 8 shows complete elimination of tourism with high scenario. The net income or household livelihoods from tourism shows the same trends as for tourism numbers, but the changes are not as extreme. This because the household income is made up of wages and salaries, which are less sensitive than other income such as profits.

6.1.7 Indicator 7: Potable water/water quality

Summary of characteristics

Potable water/water quality was identified as an indicator which might affect household wellbeing in the basin. It entails small-scale household-based use of river water for household needs. The valuation of water use has been carried out separately as part of the valuation of water supply in the analysis of water development scenarios. It also forms part of the indirect use values as a function of the ecosystem water purification function. The general water quality indicators are representative. Small scale water extraction mostly takes place from channels, floodplains during floods, and residual floodplain pools. It relies on perennial flows in channels, good water quality.

Used as indicator for all Sites but not valued.

Impact of the Water-use Scenarios

Potable water quality, as a measure of dissatisfaction (non-wellbeing), was not valued, and the impact on this from scenarios was only assessed subjectively in terms of percentage of PD (present day). At most sites a small increase was predicted, while at site 8, drying of channels would result in significant increase in negative effects increasing with scenario. A moderate impact would be seen at site 1 with all scenarios, and at sites 5 and 6 a moderate impact would be seen with high scenario.

6.1.8 Indicator 8: Wellbeing/welfare from intangibles

Summary of characteristics

It was recognised that while households in the basin derive welfare from income from indicators 1 to 7, above, they can also also benefit from general individual, household and community feeling on ecosystem integrity in the face of flow change. Thus, an indicator to capture the benefits of indicators 1 to 7 together as well as overall ecosystem integrity was recognised. It is related to channels, floodplains, and all habitats associated with ecosystem integrity, and among other things it requires perennial flows in channels, regular seasonal floods on floodplains.

Used as indicator for all Sites but not valued.

Impact of the Water-use Scenarios

Household and community wellbeing from intangibles was not valued but assessed in terms of percentage deviation for PD (present day). It is intended to reflect household perception of ecosystem integrity. The response to scenarios shows a generally declining trend with increasing water use development upstream. Declines are mostly small, but greater in site 8 and site 1, where effects on flow and flooding may be most noticeable.

6.1.9 Indicator 9.1: Macro-effects from tourism income, excluding household income (including multipliers)

Summary of characteristics

Tourism in the Namibia and Botswana basin areas is overwhelmingly non-consumptive, nature-based, and focused on wildlife viewing, although some guided recreational fishing and hunting operations are involved. Medium to large scale lodges and camps with between 10 and 30 beds, serving middle and upper market tourists are most common. Self-drive camping and guided mobile operations are also present in significant numbers. Nearly all the value of this tourism is attributable to the presence of the river/wetlands, although the activities offered can be either land- or water-orientated. Indicator 6, above, deals specifically with tourism income for local households comes through wages and salaries and occasionally services. This indicator deals with the income received by the other stakeholders in tourism investments - the owners of capital, government and entrepreneurs. Representative resources are general wildlife, including semi aquatic animals, lower, middle, and outer floodplain grazers, associated predators and birds generally, general scenic habitats and attributes linked to a mosaic of all the vegetation indicators. It is sited commonly on upper dry banks but making use of all vegetation indicators as part of product – dependent on dry season low flow and flood volume, perennial flows in channels, and regular seasonal floods on floodplains

Used as indicator along with indicator 6 above, for Sites 4, 5, 6, 7 and 8.

Impact of the Water-use Scenarios

The contribution to the national income from tourism shows the same trends as for tourism numbers and livelihoods, but the changes are less extreme at site 4 and much more extreme at the other sites. In particular at sites 5, 6, and 8 the short term impacts of the high scenario are major economic losses. This will in the longer term result in a much reduced tourism industry in the basin. The medium scenario will have a similar impact, but not as large. It is predicted that overall there will be a moderate decline for the low scenario and a drastic decline for the macro-economic contribution of tourism with the medium and high scenarios. This will not affect sites 1 to 7 since there is no tourism there.

6.1.10 Indicator 9.2: Macro-effects from household income 1-6, (including multipliers, etc)

Summary of characteristics

The small-scale use natural resources under indicators 1 to 6 provide net incomes contributing to livelihoods and they also contribute other income to the economies through linkages and multiplier effects. This indicator is to capture this additional income. It is thus based on all small-scale household-based activities described under indicators 1 to 6. All species, ecosystems, attributes listed under indicators 1 to 6 are representative, as well as all locations described under these. It requires perennial flows in channels and regular seasonal floods on floodplains

Used as indicator for all Sites (1 to 8) and measured along with each indicator, 1 to 6.

Impact of the Water-use Scenarios

The contribution to national income (economic contribution) of household fishing tends, along with catch and net income, to peak during floods in areas with floodplains. In areas without floodplains economic contribution is more stable. Generally the scenarios will progressively reduce economic contribution. In the lower basin the high scenario will severely reduce fish economic contribution.

The pattern for the contribution of household reed harvest to national income is very similar to that for livelihoods (indicator 2). The contribution is expected to remain relatively stable in all sites where reeds are harvested except in site 1, where an already well used resource will decline notably. Elsewhere there will be small increases in reed economic contribution at sites 4 and 7. Small decreases may be experienced with the high water use scenario at sites 5 and 6.

The pattern for the contribution of household floodplain grass harvest to national income is very similar to that for livelihoods (indicator 3). The contribution is expected to remain relatively stable in all sites where floodplain grasses are harvested except in site 1, where an already well used resource will decline notably. Elsewhere there will be small increases in floodplain grass economic contribution at sites 4 and 7. Small decreases may be experienced with the high water use scenario at sites 5 and 6.

The pattern for the contribution of household floodplain gardens to national income is very similar to that for livelihoods (indicator 4). It is expected to remain relatively stable in all sites, but will follow the same patterns noted for garden production. Thus there will be small increases in household floodplain garden livelihoods at sites 4 and 7. Decreases will be experienced at sites 8. The medium and high scenarios will actually result in economic losses in the short term.

The pattern for the contribution of household floodplain grazing to national income is very similar to that for livelihoods (indicator 5). It is expected to remain relatively stable in sites 4 and 6, but will increase significantly in site 7 and will decrease to result in a short term economic loss in site 8.

It is predicted that overall there will be moderate declines in the economic contribution of the rural household sectors in the basin with the low medium and high scenarios. The response will tend to be muted by increases in some resources.

6.1.11 Indicator 9.3: Indirect use

Summary of characteristics

This indicator embraces indirect use values, i.e., off-site local, national, regional, or global use values associated with river-based ecosystem services, including carbon sequestration, wildlife refuge, groundwater recharge, flood attenuation, scientific and educational value, among others etc. It is only studied for the Botswana basin, and is generally poorly studied. It is represented by general ecosystem integrity, providing the range of ecosystem services referred to above. It has no specific location – but is associated with a range of geo-morphological and ecological features, including vegetation and wildlife, which affect seasonal flooding patterns, as well as perennial nature of flow. Generally it requires perennial flows in channels, and regular seasonal floods on floodplains.

Used as indicator for all Sites (1 to 8) but not measured and not valued for response.

Impact of the Water-use Scenarios

Effects of scenarios on indirect use values were not valued for lack of data, but were subjectively assigned impacts in terms of percentage change from PD (present day). These showed quite significant progressive declines with increasing water use. These were most noticeable with site 1 and site 8.

6.1.12 Indicator 9.4: Non-use

Summary of characteristics

This indicator embraces existence, bequest, and option values for preservation, manifested as local, national, regional and global willingness to pay for preservation of resources in the river system. The values are poorly researched and only small amounts of data are available for Botswana. It is represented broadly including general wildlife, including semi aquatic animals, lower, middle, and outer floodplain grazers, associated predators and birds generally, general scenic habitats and attributes linked to a mosaic of all the vegetation indicators. It also embraces the broader ecosystem and its integrity, including all the vegetation and wildlife indicators, mostly in the better known lower parts of the basin (Okavango delta). It depends on perennial flows in channels, regular seasonal floods on floodplains.

Used as indicator for all Sites (1 to 8) but not measured and not valued for response.

Impact of the Water-use Scenarios

Effects of scenarios on non-use values were not valued for lack of data, but were subjectively assigned impacts in terms of percentage change from PD (present day). Here again the effects on ecosystem integrity were considered key. The assessment showed quite significant progressive declines with increasing water use. These were most noticeable with site 1 and site 8.

7. Conclusions

Scenarios describe the impacts of the specific developments that were chosen for consideration, and any other permutation making up a particular level of development (low, medium or high in this case) would not necessarily have the described impacts. A different arrangement of proposed water-resource schemes could produce different impacts. Altering the development placed in the hydrological model upstream of Capico, for instance, so that more water would continue to flow down the river in the dry season, could greatly reduce the predicted impact at that site. This highlights the value of the DSS, which has been set up to be queried, and to provide predictions of the impact of, any permutation of possible developments.

In this project, the EFlow Assessment was preliminary, based on available information, and the predictions are thus of low confidence. It sets the scene for a Phase 2 research-based EFlow Assessment, where major data gaps can be addressed, models improved, more scenarios and sites investigated, and higher-confidence predictions produced. Such a Phase 2 would also incorporate an improved DSS with indicators linked in series to better show the domino effect of changing flows – through hydraulic and water-quality changes, to impacts on the vegetation, then the fauna, then people.

The EF Scenarios focused on changes that were considered likely through potential changes in flow patterns. Impacts of constructing and operating water-resource infrastructure were not addressed, nor were knock-on effects such as increased agricultural return flows potentially laden with pesticide residues and fertilisers. Another aspect not addressed because of the lack of data and models, yet vitally important, is the sediment dynamics of the system and how flow changes and in-channel dams could change the movement of sediments through the system and thus the character of the channels, floodplains and delta.

Social aspects are also not addressed fully in the EFlow assessment. For example, changes in human population over time were not included, adaptations to flow pattern change and its effects over the medium and long terms were not included, and longer term changes in demand for products were also not included. The further interpretation and aggregation of the EFlow assessment social results for the TDA has to some extent addressed these issues.

The potential water-resource developments included revealed that the biophysical impacts would generally increase with distance downstream and therefore be greatest at the downstream end of the basin. The medium scenario would present some risk of severe degradation at some points in the basin, and the high scenario would greatly increase this risk and its potential area of impact. Overall, the low and medium scenarios would produce predominately in-country impacts whilst the high scenario impacts would tend to be more far-reaching and transboundary.

The majority, but by no means all, of the biophysical impacts, are predicted to stay within the natural range of variability of the system, but to increasingly compress this variability, decreasing the number of ‘good’ years when animal and plant abundances are high and increasing the number of ‘bad’ years when abundances are very low. The whole ecosystem would thus be gradually pushed into more prolonged stress, with habitats, species and perhaps even whole communities of plants and animals declining and some disappearing.

Impacts on people through changes in river basin livelihoods and changes in national income in the basin countries are predicted to be drastic and markedly more so with distance downstream. This is primarily because of the severely negative impact that the development scenarios will have on the tourism industry which makes up by far the majority of the income generated by the river ecosystem. The medium and high water use development scenarios will in particular have a devastating impact on this income. Impacts on household income from river/wetland based natural resource use are also predicted to decline. This is primarily because households rely on the tourism industry for a significant amount of their river-related income. Use of the river and wetland system for fish, reeds, grass, crops and grazing, will decline overall but some, relatively minor, uses are predicted to benefit and increase with the scenarios.

The response curves leading to the finding that water use impact would be drastic for tourism are based partly on the results of a small research project carried out in Botswana, as part of the EFlow Assessment. This was a small survey in the local tourism industry assessing likely impacts of flow change and its biophysical consequences on tourism. Given the significance of a massive impact on tourism, it is imperative that a Phase 2 research-based EFlow Assessment should include further more in-depth research into flow change and tourism in the basin.

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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)*
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		Jones, M.J.	*The Groundwater Hydrology of The Okavango Basin (FAO Internal Report, April 2010)*
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		Veríssimo, Luis	*GIS Database for the Environment Protection and Sustainable Management of the Okavango River Basin Project*
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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*

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