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SECTION A : ASSESSMENT OF THE STATUS QUO

1. INTRODUCTION

OKACOM is an initiative of the three Okavango River Basin states, Angola, Botswana and Namibia. The Commission has the functions of advising the respective governments on the sustainable development of the basin and of co-ordinating investigation and research activities.

A *Preparatory Assistance Project* funded by the Global Environmental Facility (GEF) is nearing completion and has had the aim of providing support for the implementation of a basin-wide Environmental Assessment, and the development of an Integrated Basin Management Plan. The aims of the preparatory project include the execution of a Diagnostic Study of the Okavango River Basin in all three countries, in order that an outline Strategic Action Programme and detailed GEF funding proposal can be drawn up.

In order to carry out the diagnostic study the inputs of a number of specialists were required in all three countries and their inputs have contributed in a major way to the compilation of this document, the ***"Transboundary Diagnostic Analysis (TDA)".***

This TDA has been divided in to two sections, Section A which describes the data available and an overview of the subject and Section B which attempts to highlight data deficiencies and to outline work that is required in the proposed Environmental Assessment.

2. AVAILABILITY OF INFORMATION AND DATA

In order to compile this Transboundary Diagnostic Analysis it has been necessary to commission a number of specialist reports in the three riparian states. A list of the reports compiled by national consultants is provided in Annex 6. In general the approach has been to commission reports to cover areas and topics not covered in other studies and to try by these means to acquire a good overall summary of existing knowledge within the basin. The general aim of the specialists was to carry out the following :

1. Provide a full description of what data have been gathered, in what form the data are (on paper?, in computerised format?, where they are stored? Whether they are available to the study.)

2. A description of previous work/studies. This should include an assessment of the completeness, relevance, level of detail and usefulness.

3. Using the above analysed works plus his/her own knowledge of the field as well as reference to new material (for example the satellite maps which will be made available), the specialist should provide his/her own summary of the situation. This is effectively the "diagnostic assessment".

4. Provide a description of the areas of his/her field of study in which there is lack of data or knowledge. Provide a clear description, in a step by step form, of the work which will need to be carried out to provide an improved and accurate diagnostic assessment.

For some of the topics covered this was easier than others, and the usefulness of the reports received varied considerably. The work of the consultants in Angola has been particularly difficult for a number of reasons. These include difficult communications, no possibility of visiting the catchment, it is difficult and sometimes expensive to obtain data from government offices, and a generally extreme lack of any up-to-date information on almost all the fields of study. If this TDA seems, therefore at times to have too many pages devoted to Namibia and Botswana, this should not be seen as a bias of any sort but rather as underlining the need for a concentration of efforts within the Angolan part of the catchment during the environmental assessment.

3. STAKEHOLDER CONSULTATION AND PARTICIPATION

3.1 Introduction/General

A key aspect of the Preparatory Assessment Study was to ***Establish Co-ordination and Consultation Mechanisms*** – that is to establish channels of communication for the further effective co-ordination, consultation and co-operation between stakeholders. This will facilitate stakeholder participation in the Environmental Assessment and the development of the Integrated Basin Management Plan.

One of the principle activities to be undertaken as part of the Preliminary Assessment Study was the establishment of co-ordination and consultation mechanisms. Mechanisms are to be established to enable more effective co-ordination, consultation and co-operation between OKACOM, the GEF implementing agencies, national and local governments, sectoral institutions, donors, the private sector, non-governmental organisations and local communities. Within this broad definition of activities the consultation advisor was tasked to work on the establishment and initiation of mechanisms of communication and consultation between interested and affected parties in Namibia and Botswana.

The main purpose of the consultation and communications process was to introduce to stakeholders as well as interested and affected parties the concept, purpose and goals of OKACOM, the Preparatory Assessment Study and the Environmental Assessment. Thus the aim was to inform and disseminate information rather than to seek the involvement and participation of stakeholders at this stage. This would follow as part of the formulation and implementation of the environmental assessment process.

A web-site for OKACOM has now been set up and is functioning, although not yet complete. The website address id www.namibianet.com/okacom. At this stage it is based on the introductory leaflet, but also includes :

- photo albums, divided into different subject matter
- a call for information and data
- maps
- articles and papers of interest
- Information on the Okavango River basin
- links
- reports on progress
- a guest book, which has already received several expressions of interest

3.2 Namibia and Botswana

3.2.1 The Stakeholders

One of the first tasks was the identification of stakeholders. Stakeholders were broadly defined as those parties which have a perceived interest in what happens in and to the Okavango River Basin as well as those who would be affected directly or indirectly by developments. Stakeholders were identified either through knowledge and experience of the region or through consultation with various parties.

A number of government agencies at national and local level in each country were identified. Some of these have a direct interest. In the majority of cases it was agreed that at this stage it would be more appropriate to inform rather than to consult and arrange meetings with them. The exceptions to this were the regional government structures such as councilors, the regional governor, the district commissioner and traditional authorities. These were to be directly informed and consulted with.

In addition to these, there were a number of non-governmental agencies which ranged from environmental groups, donors, aid and development agencies and local business groups. Again, only those with a direct involvement were targeted to be consulted with.

Apart from the members of the community living within the catchment itself, a number of other stakeholders were identified, and interviews/meetings took place with many of them. A full list, including addresses and telephone numbers, for Namibia under the headings :

i) NGOs; Okavango Region
ii) NGOs; Windhoek
iii) Government; Okavango Region
iv) Government; Central.

is provided in Annex 1. A similar list for Botswana, under the headings :

i) NGOs
ii) Government Ministries and Agencies

is also included under Annex 1. A full list of newspapers and other media groups to whom copies of the brochure and interviews were given is also provided.

3.2.2 Work Carried Out

In order to provide stakeholders with information and an introduction to OKACOM and more especially the proposed study, a colour pamphlet giving basic details was produced early in the PAS process. The pamphlet has been produced in English, Portuguese, RuKwangali and Setswana, these being the main languages spoken and understood in the three countries. It also includes contact addresses and telephone numbers. An example of the pamphlet in English is included overleaf. Other language versions are included as Annex 2.

The pamphlets were distributed during September 1997 to the identified stakeholders during visits to the Okavango Region in Namibia, the Delta area in Botswana and Windhoek and Maun. In several cases, a number of them were provided to NGO groups with a network of contacts within the target communities

English Okacom brochure

and thus further distributed. For example, a number of the environmental groups active in the Okavango Delta work together with women's groups or with local communities. Without exception, the NGOs consulted, which included almost l NGOs active in the basin within Namibia and Botswana, were very supportive of the project and keen to help. The pamphlets have also been made available to the newspaper media in both countries.

Contact has been made with the radio in Namibia and discussions held with both the national and RuKavango services with a view to their future involvement in publicising and disseminating information. Both services have expressed their willingness to participate on a regular and on-going basis. In the case of the national service, the weekly programme "Living World" which covers environmental issues and development has been proposed as being the most appropriate vehicle. With respect to the RuKavango service, a journalist has been identified who can act as the point of contact, and has made a number of updating press releases during the PAS In the case of Botswana, similar contacts have been made and, at the time of writing discussions are still to be held with Radio Botswana to see how this matter can be taken further.

A range of meetings have been held with identified stakeholders in order to inform them about the project and the Preparatory Assessment Study. The majority of these have been with traditional leaders and local communities supplemented by others with various interest groups. In Botswana meetings have been held with ;

Maun Kgotla - traditional leaders and community representatives,
North West District Councilors,
The Paramount Chief of the Batawana.

In Namibia meetings have been held with ;

Traditional leaders and local communities,
The Regional Governor.

A report on the meetings, including minutes of the discussions that took place is provided in the National consultant's report (NCR).

3.2.3 Feedback

Arising out of the meetings and discussions that have been held with stakeholders, interested and affected parties, are a few general points which can be highlighted. In general everyone who was spoken to was in favour of and supportive of OKACOM, the Preparatory Assessment Study and the proposed environmental assessment (the main study). Almost without exception it was felt that there was a great need for a study of this nature. It was the correct approach to first understand the environmental factors and parameters within which any future planning, development and utilization of resources would have to take place. Significant development should only be allowed once a framework for ensuring sustainability and co-ordination had

been developed. Having said this there was some concern as to the commitment and ability of the countries to achieve these objectives.
Traditional leaders and communities especially of all the groups consulted, wanted to be kept informed. They also wanted to be assured that their views and concerns would be reflected and addressed in any study. A frequently asked question was, how they would be informed. It would appear that based on past experience they feel that they have either not been properly consulted or have not had the findings or outcome of studies conveyed to them such that they felt that they were not in the picture about events. There was a feeling that they had lost control over events and developments that affect their lives. This was apparent from the comments about the impact of modern technology and the perceived practices of the "*younger generation*" which have led to degradation and loss of resources.

The issue of Namibia's emergency pipeline project surfaced at every meeting and discussion. In some cases the delegation were treated with caution and suspicion as it was thought that they had come to promote this project. A project which is not well thought of at all by the peoples of the region. It had to emphasized many times that this project had nothing to do with that one. There is, it is suggested, a need to get this message across as otherwise it may prove more difficult to win the trust and co-operation both of the people as well as other interest groups. It is felt that the meetings that have been held so far have been successful in getting that message across but this should and would need to be reinforced as part of future project actions.

There was a general perception that the environment and resources available to communities had become degraded and that communities no longer had the same access and availability of these as they used to. More importantly to them, there was a perception that the flow in the river had been significantly reduced in recent years. This was coupled with a feeling of vulnerability that this was going to continue and that eventually there would be no more water left in the river. The people in Botswana tended to blame Namibia and the people in Namibia tended to blame Angola for this. There did not seem to be a connection between flow in the river and climatic events such as rainfall. Indeed it was noted that there was some difficulty in relating local knowledge and observation to the wider basin context and the events in it. The people consulted realized this to an extent, and it was perhaps because of this that they stressed the importance of educating their children on these matters.

3.3 Angola

3.2.1 General

During the initial visit to Luanda from 8 to 12 July 1997, it seemed quite hopeful that some meetings could be held at Menongue and Cuito in the catchment, with the help of the World food Programme. These meetings were programmed for early in September. However, during a visit to Luanda early in August, it was became clear from discussions with OKACOM, Angola, that visits to either Menongue or Cuito would have to be postponed until the security situation improved.

Following this decision, the interim approach for Angola has now been modified. FIESA have been was given the task of liaising with a journalist, Ms dos Santos, who was given the job of disseminating information on OKACOM via the mass media. The main source of information was the introductory leaflet and interviews she held with the Study Manager and national consultants, and members of OKACOM and OBSC in Luanda. The leaflet in Portuguese and English, was provided in numbers to UNDP, Angola, for dissemination to interested parties.

The assignment effectively entailed :

1.. Interview members of OKACOM and OBSC, in particular, Mr. G. da Silva, Mr I Pinheiro, and Mr P. Mendes. The purpose of these interviews was to provide material for press releases.

2. Interview Mr R. Marques at FIESA, in order to get information on the progress of his specialists working on the Preparatory project.

3. Ensure that the background information provided in the brochure gets into the Angolan press and onto radio and to keep a record of all articles appearing in the newspapers and on radio or television.

4.. Discuss the project with UNDP representative Mr Minoru Tekada, and discuss with him which UN agencies and NGOs may be able to assist in distributing background information on the project.

4. DESCRIPTION AND HISTORY OF THE AREA

4.1 History

4.2 Geology, Soils, Topography, Geomorphology and Vegetation

4.2.1 Introduction

National consultants were appointed to look at geohydrology and soils in the catchments of all three riparian states, and a good deal of very useful information was gathered.

4.2.2 Data Available

4.2.2.1 General

The data available, often in the form of mapping or imagery is discussed under sections 4.2.2.2 to 4.2.2.4. Where information is useful for more than one theme it has not been repeated under each heading. For example, satellite imagery is discussed in broad terms under section 4.2.2.2, but more specific uses that it may be put to are also discussed in sections 4.2.2.3 – 4.2.2.4

4.2.2.2 Catchment Topography

Topographic Maps and aerial photography

Mapping at various scales is theoretically available for the entire catchment. The scales used vary from country to country, although all three countries have mapping available at both 1:250 000 and 1:500 000. In Angola mapping is also available at a scale Figures 4.1 and 4.2 provide an illustration of the maps that are required for full coverage of the catchment in each country. Table 4.1 summarizes the availability of these maps as well as providing an indication of how up-to-date they are.

Annex 3 provides a list of all the mapping and satellite imagery (hard copy and digital) that has been obtained during the PDF phase.

Table 4.1 : Scales, Dates and Availability of Topographical Mapping

Okavango River Basin in:	Scales	Date of source Photography	Number of maps Required for full coverage	Copy obtained (yes/no)	Availability
Angola	1:100 000	?	75	No	?```
	1:250 000	?	14	No	
	1:500 000	?	6	Yes (4 of 6)	90%
Namibia	1:50 000	1978*	+/-150		
	1:250 000	1978	5	Yes	Yes
	1: 500 000	1978	3	No	Yes
Botswana	1:50 000		80	No	75%
	1:250 000	1988/89	7	Yes (5 of 7)	Yes
	1:500 000	1988/89	3	No	Yes

*A project to update 1:50 000 mapping of the “Okavango” Region in Namibia is nearly complete.

Aerial Photography has been flown over the Namibian portion but only photography over the Okavango Region itself is recent.

Typically, contour intervals are 10 metres on the 1:50 000 maps. A detailed topographical survey (1:50 000) of the River and margins in Namibia from ??? to the border with Botswana was carried out in 19??. This mapping is archived at the offices of the Department of Water affairs in Windhoek. The contour interval is 1 metre.

In Botswana

Satellite Imagery

The most commonly used platforms for satellite imagery acquisition in the region are Landsat, Spot as well as lower resolution imagery such as NOAH. Both Landsat and Spot are dependant on cloud-free conditions while other options such as RADARSat provide the opportunity of acquiring imagery irrespective of the weather conditions. As part of the PDF, the UN Cartographic Division provided some hard copies of Radarsat images and these were scrutinized. As already stated they provide an opportunity of looking at the catchment despite the presence of clouds, but it was found that the cloud-free LandSat images provide much greater resolution and could be used for many aspects of detailed investigations.

Although detailed analysis of satellite imagery was beyond the scope of the PDF, satellite imagery was looked at in three ways:

1. To acquire some sort of imagery covering the whole catchment, especially Angola where very little research has been done for over twenty years and,

2. To assess what imagery has already been acquired, especially by government institutions, and which may be accessible to OKACOM

3. A national consultant had the specific task of looking at how satellite imagery could be used in the future work, and how it could be used interactively with GIS. This assignment is discussed in depth in Section 4.2.3.1.

It was calculated that 18 LandSat images (each of 180km x 180km) would provide coverage of the basin in Angola (excluding the largely hydrologically inactive parts of the catchment in Namibia and Botswana), but that it was clearly beyond the budget to purchase TM images (either digital or hard copy) at a cost of over US$4000 per scene.

Initially, therefore, an order was placed to purchase the most recent available MSS images at a cost of only US$300 per digital scene. However, processing problems at the Satellite receiving centre in South Africa resulted in OKACOM being offered TM scenes (3 reflectance bands only instead of 7) for the same price. The digital data were purchased and processed in-house. A schematic at the beginning of Annex 4 provides an image layout together with details of acquisition, scene ID etc

It should be stressed that the obtenance of good-quality and cloud free imagery for all scenes of the catchment for approximately the same date was very fortunate, and this will not always be repeatable on an annual basis.

Even with only three data bands, the TM imagery requires quite major processing time, especially since the images were supplied without georeferencing. For the PDF, the images were individually georeferenced by reference to the mapping that had been obtained from the three basin states. In addition, river and town names have been added to the image and the colours enhanced.

In this way it was possible to produce a mosaic of the basin, although this mosaic has not been saved as one data file. The mosaic has been printed out in full colour and is provided in Annex 4. Larger scale versions can be produced. the individual scenes have also been printed out at a scale of 1:1 000 000 on high quality paper and are included in Annex 4.

4.2.2.3 Catchment Geomorphology

According to the 1992 IUCN Directory of African Wetlands, the Cubango River rises from a sponge (12º34'S/16º12'E) over 1600m above sea level on the main highland massif 49km east of Huambo. This point can clearly be seen on Scene 1 in Annex 4.

Soils (Data available)

Key documents which have been referred to for information on climate include :

NCRs prepared for TDA:

-E. B Simmonds: Soils of the Okavango River Basin; Namibian, Botswanan (and Angolan) Sectors.
-E Bereslawski : Geohydrology, Geology and Soils of the Cubango River Basin; Angolan Sector.

A large number of other documents and maps have been referred to by the national consultants and copies of many of them have been collected and put in the PDF collection.

A significant amount of work has been carried out in Namibia and especially Botswana in recent years with a number of different goals in mind. However, due to the relatively scattered nature and paucity of published reports and data on the Namibian soils it was necessary to merge data collected in a variety of formats. Available reports lacked detailed soil survey results and were in some cases incomplete (maps without legends, reports without supporting data). Only one study provided comprehensive information on a regional scale (Loxton *et al*, 1971).

In contrast, comprehensive, recently produced and readily available Botswanan material (De Wit & Nachtergaele, 1990; Joshua, 1991; Radcliffe *et al*, 1991; 1992) provided this overview with considerably more information. For the Okavango Delta region, mapped soils and landform data were supported by detailed survey reports and soil profiles.

An important point to note is that available soils data were based on three systems of classification. Namibian soils data were based on the South African Binomial Soil Classification System (MacVicar et al, 1977) and on the earlier South African National Soil Series Classification System. The latter acted as an early approximation of the Binomial System. Botswanan soils data were correlated to the FAO/UNESCO/ISRIC Soil Classification Legend (1988). Due to the lack of correlation between the systems, and because soils information was derived from surveys undertaken at different intensities and mapping scales, this overview of soil resources of the river basin inevitably lacks comparative depth. It would make sense, therefore, to develop a methodology for correlation of the RSA systems with the FAO Revised Legend (1991) to provide a systematic description of the river basin. This however, would not be a straightforward exercise on the following grounds (*pers.comm,* Nachtergaele, 1998):

- The systems were developed with different guidelines for soil profile description,
- Certain soil features receive a different emphasis on parallel definitions,
- Some of the laboratory procedures supporting the RSA systems used in the 1970s were different to current FAO procedures.

Due to the difficulties in obtaining literature Bereslawski (NCR) has provided a description of the main contents of the documents that were sourced for soils in Angola. Sections of a number of these were copied and included in the specialist's report. The titles of these are included in Table 4.2.

Table 4.2: Documentation relating to Soils in Angola obtained for OKACOM

Ref No.	Details	Full/ excerpt?
1	Report on the Geological Reconnaissance of the Districts of Benguela, Huambo, Cubango and Cassinga	Excerpt
2	Study Plan of the Cubango River in Angola on Irrigation, Energy Generation and Navigation	Excerpt
3	Development of the South of Angola	Excerpt
4	Notes on the Geomorphology of Angola	Excerpt
5	Suitability of the Soils of the Cubango River Basin for Irrigation Purposes	Excerpt

Simmonds (NCR) includes a full bibliography listing reference documents relating to soils in Namibia and Botswana (and Angola). Copies of a number of these documents have been obtained for OKACOM and these are summarized in Table 4.3.

A number of studies included mapping exercises have been carried out, many of them recently and an attempt to summarize the services, information and end-products which are available as a point of departure for a detailed environmental assessment has been made. These are summarized here, but full details are available in Simmonds (NCR)

- **Caprivi Environmental Profile Project (Namibia) 1996/97**

  To produce a database of environmental parameters of the Caprivi Region, which included part of the Okavango River and an environmental profile and atlas of the Region

  Useful data and mapping includes one mid dry season LANDSAT TM scene 176-072 (28/06/94; processed to enhance bands 4-5-3 using IHS-decorrelations) spans a segment of the Okavango River Basin covering the border territories of Southern Angola, Northeast Okavango, West Caprivi and Northwest Ngamiland.. Copies of processed image data available from project; raw data stored at NRSC (viewing only on premises). Six environmental database files including soils.xls, erosion.xls and terrain.xls, and nine thematic map coverages including soil texture and pH (ArcView 3.0) are available.

- **A Geographical Information System for Okavango Region 1995/98**

  To digitize and update the topographic maps of the Okavango Region

  Useful data and mapping will include paper copy topographic maps will become available at 1: 50,000 and 1: 250,000 scales. Digital data, including databases and map coverages, will be available on CD

- **Reconnaissance Surveys of the North and Central SWA for Irrigation Potential 1966/71**

  Useful data and mapping includes reconnaissance level survey, assessment and classification of soils. Soils classified according to South African 'National Soil Series Classification' system. Maps of soil associations compiled at 1: 250,000 and 1: 500,000; paper copy. Major topographic and pedagogical features included on legend. Six soil association maps cover the Okavango River Basin within Namibia:- Sheet 5-11687/20; Sheet 6-11687/21; Sheet 10-11687/11; Sheet 11-11687/26; Sheet 14-11687/29; Sheet 15-11687/30. A limited number of copies are in circulation and all show evidence of photocopy stretch (see samples).

- **Feasibility Study on the Okavango to Grootfontein Link of the Eastern national Water Carrier – Initial Environmental Evaluation 1996/97**

  Useful data and mapping included in the four-volume Initial Environmental Evaluation report included a soils and geomorphology report which includes 16 digitized landform and soils overlays compiled from published data. Namibian basemaps (used in several specialist reports) digitized from 1: 250,000 topographic sheets (refs: 1718 Rundu, 1820 Mukwe, 1818 Karakuwisa, 1918 Grootfontein). Botswanan maps digitized from 1: 350,000 Okavango Delta reproduced basemap (Dept. of Surveys and Lands, Jan.1987). All report contents available in digital and hardcopy format. The digitized base, soils and landform maps on Namibian territory extend beyond the project areas to the boundaries of the 1: 250,000 topographic sheets, covering a significant portion of the 'functional' segment of the river basin.

- **Vegetation Mapping project (1993/94**

  Useful Data and mapping includes forty (40) LANDSAT TM and 160 SPOT XS satellite image scenes supplied as photographic paper copies and transparencies, and as geo-referenced digital data on CD. Dates of data capture range from 29/4/92 to 27/6/92. Data processed to enhance bands 3-2-1 for vegetation boundary definition and false colour composites produced on hard copy at 1:100,000 from LANDSAT and 1:50,000 from SPOT data. Information was subjected to unsupervised vegetation classification, amended after low-intensity ground-truthing, and digitized. Vegetation association maps produced in B/W at 1:100,000 and 1:50,000 (available from NRSC).

The Okavango Region is covered by 23 SPOT scenes which can be viewed at the NRSC. Scene references are given in appendix. It is noted that the utility of these satellite images for vegetation mapping has been questioned for two reasons:- (1) data were captured during an early to mid dry-season within a particularly dry period documented from 1991; (2) the compiled vegetation polygons failed to match with field-checks and vegetation mapping results of other projects.

- **Initiation of National Agroecological Zoning Procedures (Namibia)**

To produce an exploratory agroecological zones (AEZ) map at scale 1:1,000,000 of the whole country, a reconnaissance soil survey and land evaluation for the Grootfontein area at scale 1:250,000, and to start data management, processing and software product creation through GIS technology

The reconnaissance soil survey/land evaluation map of the Grootfontein area falls within the Okavango River Basin and the mapping scale would be adequate for environmental assessment watershed management and purposes.

- **Soil and Terrain map of Southern Africa (Planned only)**

FAO plan to produce Soil and Terrain Database of Southern Africa. Scale 1:1,000,000; FAO guidelines and classification. Angolan soils data were recently (1997) correlated to the FAO Revised Legend. This will be included in the Regional database. A hardcopy of the correlated Angolan soils map (unknown scale) with legend and report has been completed and has been made available to Okacom from FAO, Rome.

- **Okavango Environmental Profile Project**

Objective is as for Caprivi Environmental Atlas.
Data already obtained include six early dry season LANDSAT TM scenes:- 176-072, 176-073, 177-072, 177-073, 178-072, 178-073 captured April -May 1997. Digital data will be processed by NRSC when project funds are secured.

- **Botswana Rangeland Inventory and Monitoring**

To strengthen the land use planning process and the development of land management policy - by establishing a national range monitoring programme that will provide reliable technical and sociological information on the use and condition of the rangelands.

Data and mapping includes information in the form of user-friendly gender-sensitive reports and maps in paper form and on CD-rom using GIS and remote sensing. Production of a Rangeland Information System to include data on long-term vegetation change, seasonal vegetation change, a vegetation inventory, and socio-economic concerns. Quantitative drought status reports and maps produced monthly. Extent of rangeland fires identified by classification of NOAA/AVHRR imagery and mapped regularly as overlays on NDVI basemaps. Project has capacity and mandate to produce new thematic end-products on needs-driven basis.

Many of these reports have been obtained as originals or photocopied for OKACOM. A number of large format maps have also been obtained and details of these are summarized in Table 4.4

Table 4.4 : Reference List of Soil-related Maps obtained for OKACOM

Country	Title	Date and Map Reference No.	Author	Scale	Copy Status	Description
Namibia	'N Raamwerk vir Ontwikkeling van Kavango	December 1979	Page, D.	1: 1,000,000 (regional) 1: 100,000 (river terraces)	Photocopied from copies	One regional physiographic map. Okavango River terraces: 10 soil maps (RSA classification, 1977); 10 land potential maps (dryland farming and irrigation)
Namibia	Soil Survey of Northern South West Africa – Irrigation Potential	July 1970 Sheet 5-11687/20 Sheet 6-11687/21 Sheet 10-11687/11 Sheet 11-11687/26 Sheet 14-11687/29 Sheet 15-11687/30	Loxton, Hunting & Associates	Original scale 1: 250,000; presentation copies appear to have been re-scaled to 1: 500,000	Photocopied from presentation copies. Legend magnified x 200%	Six maps covering functional & non-functional areas of Okavango River basin, describing dominant soil series (early approximation of final RSA classification, 1977) and irrigation potential. Two-page legend includes associated soil series and landforms
Namibia	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Soils: maps 1-4.	January 1997 Soils: Map 1 Soils: Map 2 Soils: Map 3 Soils: Map 4	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four soil series maps (RSA soil classifcation) covering part of Okavango River Basin - Grootfontein district to Okavango River and Rundu to Mahango border post. Maps merge information from Page, D., Loxton, Hunting & Associates., and Schneider, M.B. Current borehole locations included (1997).
Namibia	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Landforms: maps 1-4.	January 1997 Landforms: Map 1 Landforms: Map 2 Landforms: Map 3 Landforms: Map 4	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four landforms maps covering part of Okavango River Basin - Grootfontein district to Okavango River and Rundu to Mahango border post. Maps derived from Land Types: Namibia map, Sheet 1 (FAO/UNDP, 1984)
Namibia	An Environmental Profile and Atlas of Caprivi	1997 Kavango.zip Releve.zip	Mendelsohn, J., & Roberts, C.	Tailored	Originals in digital format (ArcView 3.0); copied to diskette. Sample theme (soils) photocopied from presentation document.	Nine thematic map and six database files in two zip directories, covering the Okavango River basin within Caprivi Region. Kavango.zip contains thematic map files: kavango.shp; soil-ph; soil-text; veg-struc; arable; livestock; com-res; diversity; cons-val; area; legend. Releve.zip contains database files: plantdata.xls; erosion.xls; coverdat.xls; sample.xls; soildat.xls; terrain2.xls.

Country	Title	Date and Map Reference No.	Author	Scale	Copy Status	Description
Botswana	Soil Map of the Republic of Botswana	1990 FAO/BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:1,000,000	Original	National soils map on 2 pages. FAO soil unit classification; phases indicated.
Botswana	General Soil Legend	1985 BOT/80/003	FAO/UNDP/Govt. of Botswana	N/A	Original	Provides correlation between Botswanan soil mapping symbols and FAO soil classification system to unit level; phases indicated.
Botswana	Soil Map of Boro-Shorobe Area. Location Map of Boro-Shorobe Area.	1986 BOT/80/003	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:50,000	Original	Map 1: Soils of Boro-Shorobe area, covering the middle and southern reaches of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Map 2: Location of soil pits. Description given in document (2)
Botswana	Gumare – Soils	1989 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (3).	Soils of Gumare area south of the panhandle, covering the western boundary of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (3)
Botswana	Tsau – Soils	July 1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (3).	Soils of Tsau area south of Gumare, southwest of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (3)
Botswana	Shakawe - Land Suitability for Improved Traditional Dryland Farming - main crop: Sorghum	1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (3).	FAO land suitability classification of panhandle area. Description given in document (3)
Botswana	Maun – Soils	1986 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (4).	Soils north of Maun covering the eastern and southern reaches of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (4)
Botswana	Toteng – Soils	1988 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (4).	Soils of Toteng area south of Maun, covering Okavango Swamps outflow to the Thamalakane River. Botswanan map symbols, no legend. Refer to General Soil Legend. Description given in document (4).
Botswana	Nxai Pan – Soils	March 1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (4).	Soils of Nxai Pan area west of Maun, covering southeastern boundary of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification.
Botswana	Linyanti – Soils	September 1990 BOT/85/011	Soil Mapping and Advisory Services Project	1:250,000	Photocopied from original. B/W. Folded in	Soils of Linyanti area, covering northeastern boundary of Okavango Swamps.

			FAO/UNDP/Govt. of Botswana		back sleeve of document (5).	Botswanan map symbols, correlation to FAO classification. Description given in document (5).
Botswana	Land Systems Map of Botswana (partial coverage)	1991 BOT/85/011	Soil Survey Section, Land Utilization Division, Ministry of Agriculture FAO/UNDP/Govt. of Botswana	1: 2,000,000	Portion of original map colour photocopied x 200%. Scale approx. 1:1,000,000. Legend colour photocopied.	Land systems of Okavango Swamps area. FAO classification (1990). Explanatory notes given in document (6).
Botswana	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Soils: maps 5-8.	January 1997 Soils: Map 5 Soils: Map 6 Soils: Map 7,8	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four soil maps describing soil units (FAO classifcation) covering lower Okavango River Basin on Botswanan territory. Information derived from Soil Map of Botswana + explanatory notes (documents 1 & 7)
Botswana	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Landforms: maps 5-8.	January 1997 Landforms: Map 5 Landforms: Map 6 Landforms: Map 7 Landforms: Map 8	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four landforms maps covering lower Okavango River Basin on Botswanan territory. Maps derived from Land Systems of Botswana, Sheet 1 (FAO, 1991) + explanatory notes (document 6).
Botswana	Soils Distribution in the Okavango Delta Region	January 1997	Water Transfer Consultants	1: 1,000,000	Photocopy of hand-drawn map.	Sketch map describing soil groups (FAO, 1990) of the Okavango Delta area.
Angola	Ocorrências Minerais	1966	Direccâo Provincial dos Serviços de Geologia e Minas	1: 2,000,000	Photocopied from original.	National map describing mineral resources, overlaying feint surface drainage features.
Angola	Atlas Geográphico Volume 1	1982	Ministério da Educaçâo	1: 6,000,000	Available in digital format from Dr Carlos Amaral (tel: +264-61-232432). Paper samples photocopied from Atlas. B/W & hand coloured.	National atlas featuring 21 themes including soils (Portuguese system).
Namibia	Soil Map of Namibia	1997	FAO/Land Evaluation Unit, Ministry of Agriculture, Water and Rural Development.	1: 8,000,000	Copy of printout. Original digitized from FAO Soil Map of the World. Contact: M. Coetzee, Land Evaluation Unit Tel: +264 61 202 2080	FAO classification to soil unit level; climatic regions, vegetation associations, pedogenetic environment provided in legend.

Country	Title/Format	Date & Map Reference No.	Author	Scale	Source	Description
Botswana	Tsodilo – Soils *Hard copy*	1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1: 250,000	Josephine Magmbolwa (soils database) Tel: +267-350522 Fax: +267-307057 (Request form supplied, appendix *xx*)	Soils of Tsodilo area covering the panhandle & northwestern boundary of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (3)
Angola	Unknown *Possibly in digital format*	1997 FAO	Beernaert, F.	Unknown	Frank Beernaert Tel: +0032-9-282-2703 Fax: +0032-5-027-7683 Dr F Nachtergaele, FAO, Rome e-mail: freddy.nachtergaele@fao.org	Soils of Angola classified under Portuguese system, correlated to FAO (1990). Level of FAO classification unknown.
Angola	Atlas Geográphico Volume 1 *Digital format*	1982	Ministério da Educaçâo	1: 6,000,000	All maps digitized (ArcInfo). Dr Carlos Amaral (tel: +264-61-232432).	National atlas featuring 21 themes including soils (Portuguese system).
Namibia Botswana	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. *Digital format*	January 1997 Base maps: sheets 1-8 Soils maps: sheets 1-8 Landforms maps: sheets 1-8	Water Transfer Consultants	1: 250,000	Digitized maps (ArcInfo) held by CSIR, Division of Water, Environment and Forestry Technology, P.O. Box 395, Pretoria, 0001. Contact: Peter Ashton/Paul Donald. Tel:+0027-12-841-2022 Fax: +0027-12-841-2506 E-mail: pashton@csir.co.za	Eight base maps, soil maps and landform maps (total 24) covering Okavango River Basin on Namibian and Botswanan territory.
Namibia	Soil Map of Namibia *Digital format*	1997	Land Evaluation Unit, Ministry of Agriculture, Water and Rural Development	1: 8,000,000	Digitized from the FAO Soil Map of the World. Original scale 1: 5,000,000. Contact: Ms M. Coetzee Tel: +264-202-2080	FAO soil units; generalised.
Namibia	Okavango Region (Titles unknown) *Database, hard copy and digital format*	1998	Lux Development/ Ministry of Lands, Resettlement & Rehabilitaion	1: 50,000	Lux Development, contact: Walter De Frieze (mapping trainer) Tel:+00264-61-285-2111 Surveyer General's Office, contact: Tel: +264-61-245056/7	Database contains 35 main features subdivided into 80+ display definitions (see appendix). Soils are not included. Maps due to be completed in 1998.

<u>Vegetation</u>

4.2.3 Overview/Analysis

4.2.3.1 Catchment Topography

4.2.3.2 Catchment Geopmorphology

<u>Soils and Geology</u>

a) Soils Overview

As indicated in the previous section a number of soils related maps have been drawn up over the years for the catchment in the three countries. These include a number of relatively detailed studies, particularly for the catchment within Namibia and Botswana. The purpose for this mapping work was often agriculture-related as part of a search for irrigable land. Unfortunately these maps tend to be at differing scales, and levels of accuracy and often cover only parts of the catchment. It would, however, with some significant effort, be possible to consolidate all the information onto one map.

A soil map at a scale of 1 : 2 500 000 has recently been published (June 1997) by FAO using their 1990 classification system of Angola. A similar map exists for Botswana at a scale of 1 : 1 000 000 published in 1990. Excerpts from these two maps covering the catchment are included in Figure 4.3 and 4.4. Soil maps at a scale of 1 : 250 000 for the majority of the catchment within Botswana are also available from the Department of Survey and Mapping.

Although a number of studies have been examined by Bereslawski (NCR), there is little supplementary information on soils within the Angolan part of the catchment.

Within Namibia and Botswana, the catchment can be divided into four sections :

1. Functional and non-functional sub-catchments in the south-west
2. Okavango River hinterland, Namibia
3. Okavango River flood plain and terraces
4. The panhandle and Okavango Delta

Functional and non-functional sub-catchment in the south-west

The southwestern portion of the Okavango River basin can be divided into sub-catchments in terms of surface water inflow to the Okavango river and Delta system. Sub-catchments can therefore be characterized on the basis of 'functionality', whether they actively channel surface water to the major thoroughfares of the system. Such a first-order division of the river basin is practical for environmental assessment and river basin management purposes, although the capacity of non-functioning sub-catchments to channel meteoric water directly into aquifers may also contribute to the functioning of the system. This contribution is not likely to be significant in areas characterized by deep surface sand deposits. However, at the western boundaries of the southwestern reaches the Kalahari sand deposits overlying calcrete thin out considerably, providing favourable conditions for aquifer recharge.

Simmonds (NCR) provides detail on how the southwestern reaches of the river basin are classified into functional and non-functional sub-catchments as defined above.

To summarize the southwestern reaches, land surfaces gradually descend from 1200 masl in the south (Grootfontein District) to 1150 masl west of Rundu, and to 1000 m at Andara on the Caprivi West boundary. The south-north regional gradient is thus of the order of 0.8 m/km (0.08%).

Gentle slope factors combined with high permeability of the sandy soils combine to allow very little surface drainage. With the exception of rare high intensity rainfall events following favourable antecedent soil moisture conditions, the absorption capacity of these soils is never exceeded. However, where long slopes, shallow sands, and inadequate grazing management systems are combined, extensive aeolian and sheet-wash erosion surfaces are evident.

Deep horizontal drainage does occur after heavy rains in the catchment areas of well-defined omuramba, although surface flow is ephemeral and generally truncated by sand drift and alluvial deposits. Surface waters present at the confluences of deep omuramba and the eastward draining perennial Okavango River are largely the result of lateral flooding by the Okavango River itself. The deepest Omatako Omuramba has not drained into the Okavango River in recorded time.

In the extreme south and southwest of the basin no omuramba are developed. Drainage mainly occurs via shallow depressions into numerous pans where impeded drainage conditions are found in shallow to moderately deep vertisols (up to 50 cm) overlying and adjacent to calcrete outcrops.

Okavango River hinterland, Namibia

The Okavango river 'hinterland', situated immediately to the south of the river in Namibia, lies entirely inside the Kalahari landform (FAO, 1984), for which five land units are recognized. These are summarized below (Table 1) and illustrated on Landform Maps 3 and 4 .

Table 4.6 : Land Units Downstream of Rundu to Mahango Border Post

Land Unit	Land Unit Description
IVA 2	North-eastern stabilized E-W aligned Kalahari sand dunes
IVA 3	North-eastern (Caprivi) stabilized E-W aligned Kalahari sand dunes
IVB 3	North-eastern stabilized Kalahari sand drift
IVD 5	Northern river banks in Kalahari sand
IVD 6	North-eastern (Caprivi) river banks in Kalahari sand

Physiographically, two land units are dominant; the riverine borders of the perennial Okavango River, and the sand plateau of its 'hinterland'. The riverine unit (IVD5 and IVD6) comprises a floodplain 2-6 km wide showing evidence of a braided river system, and a terrace system differentially covered by alluvial deposits and situated 6-7 m above the river bed. The floodplain is partly inundated during the wet season, and as the water level drops, ponds and lakes remain.

On the sand covered plateau (IVA2, IVA3, IVB3), relief is flat to gently undulating in regions where low, linear dunes and intervening troughs (omuramba) occur. This area is crossed by the Omatako Omuramba. Although the Omatako is the largest tributary of the Okavango in Namibia, surface water flow from this omuramba has not been recorded to reach its Okavango confluence. As with all other omuramba, the valley of the Omatako is steeply incised and free of terrace deposits.

<u>Soil and Landform Associations</u>

Fundamental to the distribution of the soils of the Kalahari Region is an understanding of the interactive effects of two factors: depth of aeolian sand mantle and degree of relief (Loxton *et al*, 1971). Subsequent to their deposition on the Tertiary calcretes and other sedimentary rocks, the Kalahari sands were eroded and partially re-worked by wind and water, the end result being landforms varying from flat plains to massive seif dunes, and sand depths varying from 50 m or more to zero. Ignoring intermediate conditions, the main factorial combinations of sand depth and relief are listed below with map references:-

Table 4.7 : Relief / Sand Mantle Relationships

Relief/Sand Mantle Association	Map Reference
Deep sand mantle and no surface relief	Landform map 3 – IVB 3; Soils map 3 - D19
Deep sand mantle and marked relief	Landform maps 3 & 4 - IVA2, IVA3; Soils maps 3 & 4 - D16
Shallow or no sand mantle and no relief	Landform maps 3 & 4 -IVD5, IVD6; Soils maps 3 & 4 - D24, D33, A22

Okavango River flood plain and terraces

Soils of the Namibian and Botswanan segments of the Okavango River floodplain and terraces are composed predominantly of infertile aeolian sands of the Kalahari Formation with a low organic matter content (Bethune, 1991; OCC, 1995). These sandy soils are variously coloured (red, orange, grey and white), can contain deposits of fine-grained water-worn gravels, and are several tens to several hundreds of metres in depth (Bethune, 1991; OCC, 1995).

Along the Okavango River channel in Namibia, the sandy soils of the floodplain and river terraces are enriched with interspersed clay and silt layers deposited by seasonal flood waters (FAO, 1984). Vegetated slacks between scroll bars on the floodplain trap deposits of clay and fine silt, whilst layers of calcrete are exposed on many river terraces. Away from the main river channel the soils are predominantly grey to yellow-orange sands (Schneider, 1987). According to Bethune (1991) floods seldom deposit alluvial silt on the higher river terraces.

Both the floodplains (which regularly receive flood-borne deposits of silt), and the river terraces are intensively cultivated by subsistence farmers (Bethune, 1991). Formal (irrigation) agriculture is confined to the higher river terraces, and is restricted to a few locations with suitable soils, along the Okavango River between Rundu and Bagani (Cashman *et al.,* 1986).

Soil erosion is evident over much of the southern bank of the Okavango River between Rundu and Bagani. Extensive soil erosion is particularly evident for a distance of some 50 kilometres downstream of Rundu and between Andara and Popa Falls. Elsewhere along the Okavango River, soil erosion occurs in scattered areas which mark the sites of existing and former mahangu gardens, livestock kraals and villages. Most of this "scattered" erosion pattern is due to trampling by livestock, indiscriminate clearing of riparian vegetation for agriculture and collection of construction materials and fuel-wood.

Along the south and west banks of the Okavango River the terrace system constitutes a distinct but discontinous physiographic unit, lying some 7 m above the river and separated from it by a floodplain which varies in width between 2-6 km. The terrace itself is flat to even and gently sloping, and incised by numerous minor drainage lines.

Soil formation processes on the river terrace system have ultimately been controlled by the exogenic factors of topography and semi-arid climate. These factors, together with sandy parent materials and the accumulation of carbonates, soluble salts and silica, combine to yield soils unfavourable for agricultural purposes. However, the terraces of the Okavango river and its tributaries are intensively cultivated by traditional subsistence farming, and, during the past 15 years, by the establishment of centre-pivot irrigation schemes.

Subsistence farming on the river terraces downstream from Rundu is dominated by dryland cropping systems where maize and mahango are cultivated along the silt-enriched river banks, and stock (primarily cattle) are grazed on the flood plains. Terrace slopes are extensively cleared for vegetable production.

In the vicinity of Rundu, subsistence arable farming activities are intense although restricted to areas adjacent to the Okavango River, where maize and mahangu are produced. Both small and large stock are grazed on the terraces and floodplain.

A marked degree of environmental degradation is evident along the entire length of the riparian environment. Landslip features, slope failures and moderate gully formations can be observed on the discontinuous terrace slopes east of Rundu. In the area 0-4 km east of Rundu, these appear to be associated with excavations and earth diggings. Both incipient and extensively developed gully systems, observed from Rundu to Mukwe, radiate from numerous footpaths and animal tracks linking villages situated on terrace ridges to the floodplain and river banks. Accelerated and extensive riverbank erosion was observed on the northern (Angolan) river banks and floodplain where land has recently been cleared for village and garden development .

Parastatal irrigation schemes have been developed on the river terrace soils to increase and stabilize food production in the area. No comment can be made on the environmental status of these areas without further research, although detailed soil studies (Schneider, 1987; Engels, *pers.comm*) indicate that the quality of the terrace soils would be expected to deteriorate rapidly under irrigation, given their high potential to allow upward movement of carbonate-rich capillary water.

Production levels of the schemes do appear to be lower than the development opportunity suggests as volumes abstracted from the Okavango River for irrigation purposes have recently been measured at levels substantially lower than the maximum permissible abstraction limit of 13.223 Mm^3 /annum, set by the Agreed Commitment for irrigation permits in Namibian territory (Crerar,1997). It is possible that the reasons for under-utilization of available abstraction water for irrigation purposes are rooted in decreased production levels under conditions of declining soil fertility and the inability to fund increased production costs.

The panhandle and Okavango Delta

In Botswana, the sandy soils associated with the river channels of the upper Panhandle are overlain along the channel margins by deposits of alluvial clay and silt. Between Mohembo and Shakawe, areas of intensive small-scale agriculture along the river bank have denuded much of the vegetation and have led to extensive areas of soil erosion.

Lower down the Okavango Panhandle, the sandy soils along the river channel margins are overlain with deep organic peat deposits which have been produced in the peripheral swamp areas. The depth of peat layers decreases with increasing distance from the permanent swamps, eventually grading into grey and orange coloured Kalahari sands, overlying deeper white sands, in the zone of terrestrial vegetation (OCC, 1995)

Excluding the swamp and marsh zones, three major divisions of soils (with 40 different soil units or sub-units) have been identified for the Okavango Panhandle and Okavango Delta regions of north-western Botswana (OCC, 1995); these are:

- soils developed from lacustrine deposits, located in deflated pans or inter-dune depressions;
- soils developed from alluvial deposits or alluvially re-worked materials;
  soils developed from unconsolidated sand deposits or coarse-grained sedimentary rocks.

The Okavango Delta displays a succession of soil types and forms which are closely related to annual and long-term variations and arenaceous (sandy) sediment load of the inflowing rivers, and is modified by the precipitation of sodium, calcium and silica (McCarthy et al., 1991, 1993; OCC, 1995).

The topographic mosaic of perennial channels, seasonal channels, floodplains, riverine fringes and islands is dependent on minute changes in level and hydrology. Where finer-textured units accumulate in depressions, nutrient levels are appreciably higher (OCC, 1995).

Where sand cover is thin, as around pan margins and along drainage lines prominent calcified horizons are usually present (OCC, 1995).

Extensive areas of rich organic peat deposits have been formed in present and past regions of permanent swamp within the Okavango Delta (McCarthy et al., 1993). Several areas of permanent swamp along the lower Thaoge channel have dried out over many years and peat fires are a common occurrence in this region. In addition, numerous areas of small-scale agriculture have been opened up in this region, these are particularly evident in the area south-east and east of Gumare.

b) Geology and Geomorphology

The Okavango River terminates in the semi-arid Kalahari, forming one of the largest inland Deltas in the world. This setting can be explained by reference to the tectonic development of this drainage basin.

Du Toit (1933) states that the Okavango river once flowed across the Kalahari via what is now the Boteti River valley and the Makgadikgadi depression to link up with the Limpopo River. The link to the Limpopo was broken *circa* 2M years ago by upwarping of the Kalahari-Rhodesian axis, which resulted in the formation of a great lake covering the Makgadikgadi depression and possibly extending further north.

A subsequent major interruption of the drainage system occurred through the sinking of a tract of land north of a line joining the present Ngami Lake and Mabebe depression. This impounded the Okavango River, which then built a gigantic Delta across the depression. Consequently, the flow of water to the Makgadikgadi Lake was severely reduced. More recent climatic aridity caused the lake to dry out, forming the Makgadikgadi pans.

Today, the Okavango Delta lies within a seismically active zone. These events are relatively weak, and the majority of foci lie along the Kunyere and Thamalakane Faults. Seismic activity may affect the future hydraulic gradient and roughness indices of the Delta.

A general description of the landforms of the Okavango Delta is given to provide a geomorphological context to the pedological environment.

Lying at an elevation of 850 -1000 m the Okavango Delta comprises two major geomorphological features, or landforms. These are the Kalahari-sand plain, and the Okavango-Linyanti depression which is bounded by the Gomare fault to the northwest and the Kunyere and Thamalakane faults to the southwest.

The landforms are characterized by three land divisions within which five land regions can be recognized (De Wit & Bekker, 1990; Landform maps 5-8).

Table 4.8 : Landforms of the Okavango Delta

Land Division	Land Region
Sandveld	Aeolian sand deposits Partly submerged aeolian sand deposits
Alluvial System	Recent alluvial deposits Fossil alluvial deposits
Lacustrine System	Major lake and depression deposits

Five land regions are distributed throughout the Delta and the surrounding plains giving rise to fourteen land systems. These are described in detail by Simmonds (NCR).

The main hydrological feature of the Delta is the difference between water inflow and outflow (Manley, 1997). By far the greatest proportion of this difference (84%) can be accounted for by direct evaporation from open water surfaces, although a further 13% of the water losses can be attributed to the filling of voids in soils riparian to the Delta. The importance of each soil type to the water balance of the Delta is related to spatial coverage coupled with the degree to which each soil influences water flow through the system. In other words, the role of soils in the functioning of the Delta can be defined in terms of potential to transfer water from one point to another, together with position within the hydrological regime. It is therefore important to look at the characteristics of the major soil units and their spatial variability. These are discussed in relation to the hydrological regime as described by McCarthy (1997).

Soils are developed on five categories of land around the Delta: on the banks of the permanent channels, on seasonally flooded swamps, on seasonally flooded grassland, on intermittently flooded land, and on dryland. Together, these categories cover almost 70% of the total Delta region.

The water transfer potential of predominantly Arenosol soils in the panhandle and upper reaches of the fan is high. This encourages rapid water flux through poorly defined channels of the upper fan, and thereby discourages the concentration of salts. It also contributes to an estimated 40% loss of discharge.

This potential also causes soils to act as catalysts of change in Delta flow patterns. Water loss from the channel margins and consequent accumulation of bedload sediment in the channel can cause channel failure and the re-routing of distributaries. On the western margin of the Delta in abandoned channels such as the former Thaoge channel, peaty Fluvisols develop under seasonally inundated swamps.

Water transfer potential of the lower fan is considerably lower. The amount of water reaching the seasonal swamps to the east and southeast of the Delta is therefore a function of flow from the upper fan and direct rainfall, rather than flow from within the lower fan area. The low water transfer potential of Luvisols in the lower fan retard the further transfer of water reaching distal areas of the Delta system. On the eastern margins of the Delta floodplain the properties of heavy Luvisols produce environments favouring both the maintenance of seasonal swamps and high vegetation diversity.

Whereas most distributary channels are poorly defined, the Boro channel is incised in its upper reaches and carries water south even in years when the total area of inundation is relatively small. This channel becomes seasonal in the lower reaches of the Delta. Gleysols situated on Boro channel margins in the south of the Delta area exhibit the lowest water transfer potential of all Delta soils. These soils effectively block potential leakage and therefore prevent water losses by this mechanism. This would account for a significant proportion of the 2% outflow from the Delta to the Thamalakane River.

The catenery relationship of Calcisols and Luvisols situated at the southern end of the Delta and the high water holding capacities of these soil associations combine to supply a slow, small but steady outflow of groundwater during periods of minimum inundation and out of phase with periods of peak rainfall.

The potential use of these satellite composites and polygons to a soil classification and mapping exercise based on FAO guidelines should be investigated prior to the planning of any future soil survey, whether undertaken to compile a coherent, standardized regional soils database or for the management of soils within the Okavango River Basin.

A hardcopy of the correlated Angolan soils map (unknown scale) with legend and report has been completed and has been made available to Okacom from FAO, Rome.

4.2.3.3 Catchment Vegetation

4.3 Climate

4.3.1 Introduction

The broad term "climate" is used here to describe a number of weather features, an understanding of which are central to the understanding of the behaviour of the Okavango River Basin. The key climatic parameters are taken to be :

- Precipitation
- Evaporation
- Temperature

Precipitation and evaporation considered key parameters because they clearly relate directly to flow in the river system. This pattern of rainfall has a direct impact on the growth of vegetation and crops, the movements of people, domestic stock and wildlife, flooding of the river and groundwater recharge. Both spatial and temporal variations in rainfall affect the reliability of the resource base. High potential evaporation rates affect crop and grazing production.

The application of temperature data is wide-ranging, affecting both flora and fauna, the ecosystem in general and therefore also the quantity and quality of flow in the river.

Secondary, but also important are :

- Wind
- Relative Humidity
- Sunshine hours

Key documents which have been referred to for information on climate include :

NCRs prepared for TDA:

These documents include long reference lists and bibliography, which may have been consulted during the course of their compilation. A number of studies carried out in Botswana on climate, or with significant sections on climate are available and have been cited by Sefe (NCR) The most important reports, and most likely the only ones available, are the studies by Bhalotra (1987) and SMEC (1987). Bhalotra's study summarised the climatic data prior to 1987.

SMEC (1987) is a comprehensive study of evaporation in Botswana in which Penman's equation was modified to suit Botswana's conditions. Consideration was given to converting available pan evaporation data to evapotranspiration and coefficients were derived. The study also covered the Okavango Delta Region. Here vegetation factors are provided for computing evapotranspiration from the swamps.

Other documents which have been directly consulted are:

-Sub Saharan Africa hydrological Assessment SADCC countries; Country Report: Angola. Mott MacDonald; December 1990

-Climatological and Hydrological Characteristics Chapter of Volume 4 (Part3: Appendices) of Feasibility Study on the Okavango River to Grootfontein Link of the ENWC. Water Tranfer Consultants; August 1997

4.3.2 Data available

4.3.2.1 Rainfall

According to meetings held with the Director of the Meteorological Office in Luanda, up to 20 rain gauges have been operated within the catchment area at one time o another. For the past 20 years there is unlikely to be more than one gauge in operation. Nevertheless, pre-1975 data would be useful, and it should be possible to obtain this from the authorities. Climatic data for 4 useful stations were located in an FAO report of 19. Details, including approximate co-ordinates are provided in Table 4.9 below.

In the Namibian portion of the catchment relatively long rainfall records are available for 11 stations along the riverside. In addition there are numerous stations within the theoretical catchment boundary although these may be of limited interest. There would appear to be a clear lack of raingauges which are within the direct area of influence of the river, but yet not at the riverside. A useful map (1:1 000 000) indicating the position of all official raingauges in Namibia is available from the Hydrology Division in DWA , and the majority of rainfall data is available on electronic format. The vast majority of Namibian rainfall data is in the form of daily-read data, and it would appear that there are very few intensity data available. The stations are listed in Table 4.9.

There are 7 established raingauge stations located in the Delta area, generally around its peripheries.. This is bound to change in due course with the recent expansion of the gauge network into the Delta (Table 4.10). However, data are not yet available from these new stations

Table 4.9 : Location of Key Raingauges within or close to the Okavango River Catchment

ID Number	Station Name	Location
	Chitembo	
	Cuembe	
	Huambo	
	Menongue	
	Nyangana	
	Andara	
	Nkurenkuru	
	Tondoro	
	Kupara-Lupala	
	Bunja-Sambusu	
	Rundu	
16321	Moremi	Lat. 19^o 20'; Long. 23^o 25'
1626A	Qangwa	Lat. 19^o 33'; Long. 21^o 12'
1626B	Savuti	Lat. 18^o 39'; Long. 24^o 08'
1626C	Talana Farms	Lat. 22^o 12'; Long. 29^o 02'
626D	Two Rivers Game Park	Lat. 26^o 29'; Long. 20^o 40'
1626E	Nxai Pan	Lat. 19^o 39'; Long. 24^o 46'
1626F	Kumchuru / Xade	Lat. 22^o 20'; Long. 23^o 30'
16270	Lone Tree	Lat. 22^o 53'; Long. 22^o 08'
16271	Xanagas	Lat. 22^o 10'; Long. 20^o 19'

It is not known whether any rainfall intensity data exist for the catchment within Angola. In order to record useful intensity data it is necessary to record rainfall on a “continuous” basis, that is using an autographic or data logger type gauge. It may be that some such gauges were operated in Angola in the early seventies, but this will have to be checked. In Namibia, the authorities have recorded rainfall autographically from time to time, but no long records exist. Close to the catchment, rainfall intensity data have been collected for Katima Mulilo and other sites by the Hydrology Division of the DWA and may be useful.

There are some evaporation data for the study area, but these are very limited. In the Angolan portion of the basin it was possible to identify average evaporation rates based on observations as well as estimates of potential; evapo-transpiration, calculated both through Thornthwaite and Penman methods. Data are available for Menongue, Cuito cuanavale, Mavinga and Cuangar. The data used all dates back to the nineteen-seventies and earlier.

In Namibia, measurements have been made from time to time using class-A evaporations pans at Andara, Rundu and Bagani, and these data were used in conjunction with other information to compile a national Namibian map.

Evaporation is measured at Maun and Shakawe The data are considered unreliable (Sefe) and for hydrological studies in Botswana it is more common for evaporation or evapotranspiration to be computed using the Penman equation as modified for Botswana's conditions (SMEC, 1987) and are therefore based therefore on other determinant data.

4.3.2.2 Temperature

Temperature data for the Angolan portion of the catchment dates back to the nineteen-seventies and earlier, and details are not readily available. Monthly mean data (mean maximum, mean minimum, mean daytime, mean night time) have been found in an FAO document for stations at Huambo, Cuemba, Chitembo, Menongue and Mavinga to the east of the catchment

For the portion of the catchment within Namibia

Maximum and minimum temperature data are observed at Kasane, Shakawe and Maun. The start-dates of observations are shown in Table 4.10. There are gaps in the data for each station, but Kasane has more gaps and Maun fewer. In terms of data quality, Maun data would rank first.

Table 4.10 : Climatic Data Stations in the Okavango Delta region

Station	Start Date	Comments
Maun	01/10/21 -	Rainfall, temperature and humidity data available. Data quality very high. Humidity, temperature, sunshine and wind observations started on 01/10/63.
Gorokhu Agric. Station	01/02/80 -	Rainfall data available up to 1989. The gaps in the data are so numerous that it may not be possible to use it.
Shakawe Met. Station	01/02/32 -	Rainfall, temperature and humidity data available. Data quality is high. There are no gaps. Data obtained from Department of Meteorology started from 1954. Humidity, temperature, sunshine and wind observations started on 01/05/59.
Kasane	01/10/21 -	Rainfall, temperature and humidity data available. Poor data quality, numerous gaps. Humidity, temperature, sunshine and wind observations started on 01/12/84.
Qangwa	01/11/83 -	Rainfall data, very poor quality.
Sehitwa	01/09/58 -	Rainfall data, very poor quality.
Seronga Police Station	01/12/72	Rainfall data available from 1986; quality poor.
Gumare Agric. Station	01/05/59	Rainfall data available from 1986; quality very poor. There only two complete years of data between 1986 and 1991. No data entry since 1991.

4.3.2.3 Other Climatic parameters

As already stated these include Wind, humidity, and sunshine Some wind data exist for Menongue and Mavinga, and there are also sunshine and humidity data for these sites and Cuito cuanavale and Mavinga. The FAO report quotes sunshine data for Cuembo, Chitembo, Menongue, and Huambo. The origin and accuracy of this data is not known. The data are, however more than twenty years old.

In the Namibian portion of the catchment
Within the Botswanan portion of the catchment, data on wind - direction and speed - are available for Kasane, Maun, and Shakawe although these data have not been processed. With observations carried out at 3-hourly intervals and so without primary processing, the quantity of available data is just too massive to copy.

Relative humidity (RH) is measured twice a day at Kasane, Maun and Shakawe. The available data have undergone primary processing and been reduced to monthly means. There are gaps in the data at each station, with Kasane having the largest number of gaps and Maun the least. All data has been stored electronically.

Hours of sunshine are also measured at Kasane, Maun and Shakawe. Available data are limited and full of gaps. Due to the gaps in the data, mean values tend to be computed from very few observations. However, given the generally low temporal variability in sunshine hours in the region, the mean monthly values can be used for the computation of evaporation using the Penman formula.

4.3.3 Overview

4.3.3.1 General

Two factors have a strong effect on the climate over Angola and indeed over the Okavango River basin as a whole: the South Atlantic high pressure cell and the cold northward flowing Benguela current. The high pressure cell limits the southward migration of the intertropical convergence zone, while the cold Benguela current produces a strong temperature inversion along the coast that has a pronounced stabilizing effect on the lower atmosphere. The result is an increase in precipitation from south to north and from west to east.

Based on the referred classification, the Northern and Southern extremes can be located into two climatic zones which can be clearly identified as different:

i) The Septentrional extreme is comprised of higher altitude areas with annual rainfalls ranging between 1100 mm and 1300 mm, (Figure 1.7) of mesothermic and humid climate with diversified degrees determined by altitude variations;

ii) And the Meridional extreme, to the South of a line which, generally, can be identified through parallel 17° South, including lower altitude areas and subjected mostly to the Kalahari desert influence. This area has an average annual rainfall ranging between 550 mm and 700 mm of megathermic climate, or closer, and of semi-arid features;

iii) Marking the transition between these two extreme zones is the central area of the basin, with intermediate climatic characteristics, average annual rainfall ranging between 900 mm and 1100 mm, mesothermic climate, from sub-humid-humid to sub-humid-dry.

In the southern part of the catchment, the climatic year can be broadly divided into a long cool, dry season (7-8 months) and a shorter, hot, wet season (4-5 months) giving a highly seasonal pattern of rainfall. This is further compounded by rainfall being highly variable in time and space, both within and between years. This pattern of rainfall has a direct impact on the growth of vegetation and crops, the movements of people, domestic stock and wildlife, flooding of the river and groundwater recharge.

A high level of spatial and temporal variation in rainfall results in a resource base which is patchy and not constant. This variation is evident at a number of levels. Annual rainfall totals show considerable variation between years, and "droughts" (below average rainfall) are a feature of the region. Of more importance in crop and grazing resource production is the distribution of rainfall in any one wet season. Spatial variation results in patchy grazing and localised failure (or success) of crops. The number of days on which rain falls is also important in that a large number of rain-days of low falls result in better production than a few days of high falls. Peak rainfall months vary between years and affect ploughing, planting, weeding and harvesting schedules.

Potential evaporation rates are high, and exceed average annual rainfall by up to five times. This affects crop and grazing production.

The Okavango Delta Region is characterised by semi-arid to arid climatic conditions. Average annual rainfall ranges from 620 mm in the extreme northwest, around Shakawe, to 400 mm at Maun. About 90% of the total annual rainfall occurs in the five summer months from November to March. It is very rare for rainfall to occur outside of these months. It is also common for dry spells of variable duration to occur even within a rainy season. Rainfall is highly localised as it comes mainly from convective thunderstorm activity, and also exhibits considerable temporal variability causing recurring droughts. However, the Okavango Delta Region also experiences occasional heavy rainfalls. The maximum 24-hour rainfall recorded at Maun was 139.5 mm, and at Shakawe 118.1 mm.
Temperatures are generally high during the summer months, with average temperatures of 27^{o} C and 25^{o} C, being the norm at Maun and Shakawe, respectively. The winter months are cooler but dry, with temperatures averaging 17^{o} C at Maun and 15^{o} C at Shakawe.

Evaporation is constantly high, showing a slight reduction in the winter months. Annual potential evaporation at Maun usually exceeds 2000 mm.

Winds are generally mild, but can be quite strong especially if associated with a thunderstorm. Average wind speed ranges from 6 to 9 km/hr at Maun and 2 to 3 km/hr at Shakawe. There is very little seasonal variation. Atmospheric pressure is about 900 mb in the Okavango Delta Region.

4.3.3.2 Precipitation

Throughout the catchment there are distinct wet and dry seasons. Table 4.11 shows the mean monthly precipitation for a selection of rainfall stations through the basin.

Table 4.11 : Mean Monthly Precipitation (mm) for Selected Stations

Station Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Chitembo	67	149	191	203	164	236	90	9	0	0	0	11
Cuembe	115	195	233	248	200	215	105	12	0	0	2	23
Huambo	126	216	234	215	168	229	146	17	0	0	1	17
Menongue	27	83	149	190	165	181	58	7	0	0	0	8
Rundu	20.4	57.3	93.5	148.9	146.3	93.4	31.9	2.1	0.1	0.0	0.2	2.4
Andara	17.4	60.2	101.4	140.8	143.1	91.6	28.8	3.3	0.4	0.0	0.1	2.9
Shakawe	14	61	102	137	130	75	29	2	0	0	0	4
Maun	16	46	80	109	100	69	24	5	1	0	0	3

Table 4.12 provides mean and median annual precipitation for a wider selection of locations. The location of these stations is shown on Figure 4/3 together with isohyetes of mean annual precipitation.

Table 4.12 : Mean and Median Annual Precipitation for Selected Stations

Station Name	Record Length (years)	Mean Annual Precipitation (mm)	Median Annual Precipitation (mm)	Station Name	Record Length (years)	Mean Annual Precipitation (mm)	Median Annual Precipitation (mm)
Cuemba	-	1348	-	Tondoro	47	556.0	539.1
Chitembo	-	1120	-	Kupara-Lupala	32	546.5	524.4
Huambo	-	1369	-	Bunja-Sambusu	51	541.3	535.1
Menongue	-	868	-	Rundu	54	595.3	572.9
Nyangana	42	602.2	610.4	Shakawe	64	553	
Andara	70	591.2	556.9	Maun	74	453	
Nkurenkuru	73	583.4	576.6				

Figure 4.5 shows the rainfall isohyetes derived for the catchment.

It is accepted, especially in arid and semi-arid environments, that the use of mean monthly and annual rainfall data are limited. Often other measures of long term rainfall are also very useful (median, variability etc) and many of these can be ascertained from long enough daily records. In addition, to these, however, rainfall intensity data are also useful for certain specialist applications.

4.3.3.3 Temperature

In the extreme north of the catchment, September and October are normally the hottest months with mean maximum monthly temperatures of 30ºC, and June and July are the coolest with mean minimum monthly temperatures of around 9ºC (1941-1970 data for Luena). Figure 4/2 and 4/3 show the mean monthly temperature (minimum and maximum for selected sites in or close to the basin.

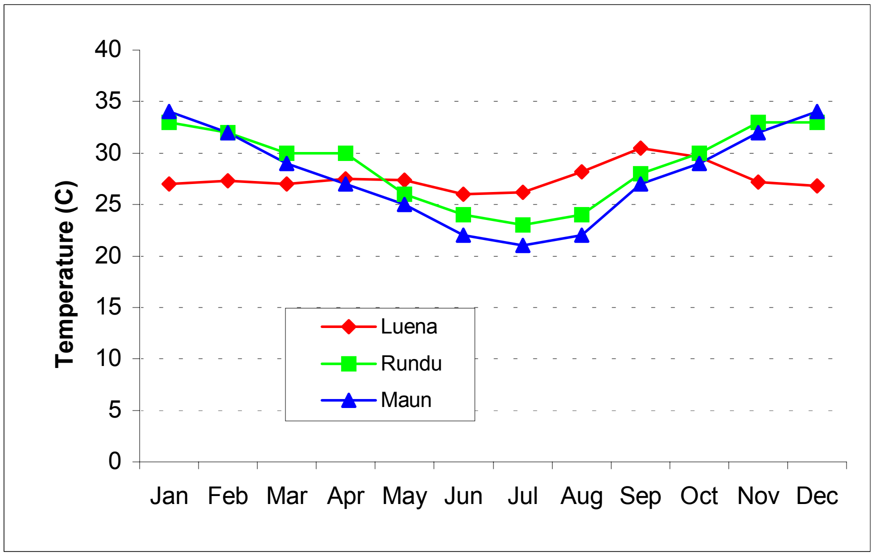


Figure 4.6 : Mean Monthly Maximum Temperature

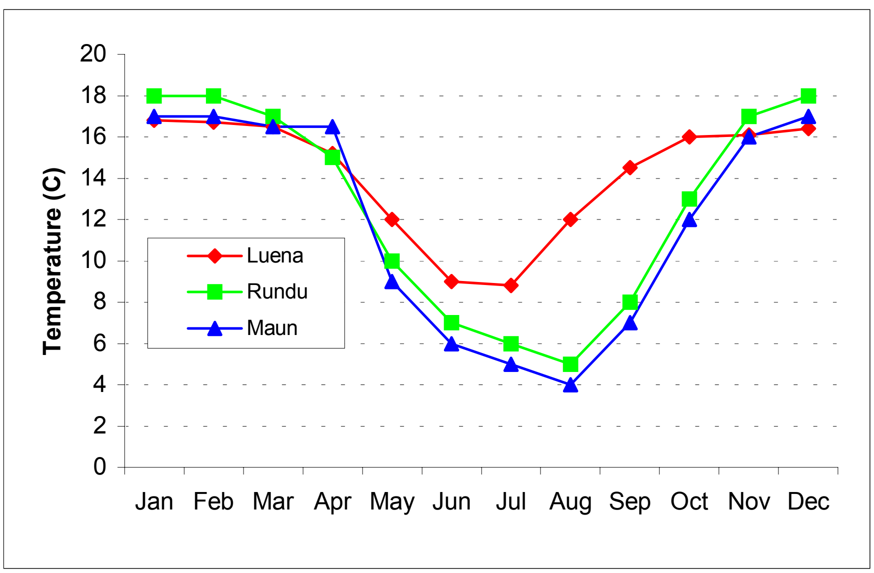


Figure 4.7 : Mean Monthly Minimum Temperature

In the southern part of the catchment the climate is distinctly sub-tropical, with a significant decrease in rainfall and humidity. Night-time temperatures can occasionally fall below zero during the winter months, although this is unusual.

4.3.3.4 Evaporation

Potential evaporation rates are high, especially in the southern part of the catchment. At Rundu evaporation exceeds average annual rainfall by up to five times. This affects crop and grazing production. For example, at Rundu there is a nett water deficit (for plant growth) in all months of the year except February. Nett annual water deficits are in the region of 1200 mm per annum which indicates that dryland crop production is a high risk undertaking even in years of high rainfall

In the northern part of the catchment, higher humidity and precipitation, and fewer sunshine hours lead to lower evaporation figures, but they are still high. However, it was possible to identify average figures which indicate an annual evaporation of around 1900 mm at the Septentrional zone of the basin increasing to the South up to close to 2000 mm at the meridional region. The months with greater evaporation are those pertaining to the end of drought, and the lower evaporation month is February, during the peak of the rain season.

In three localities of the basin, it was possible to identify average records of evaporation and of potential evaporation-transpiration, calculated both through Thornthwaite and Penman methods, as follows:

Pan Evaporation (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue	97	88	91	106	141	157	189	251	294	250	142	118	1924	53/67
Cuito Cuanavale	117	101	109	124	158	164	181	243	295	246	147	126	2011	51/67
Mavinga	131	95	139	174	200	183	199	266	360	319	179	139	2384	53.65
Cuangar	208	174	177	211	262	265	284	404	411	414	329	265	3404	55/67

Potential Evapo-transpiration (Calculated (mm)) (Thornthwaite)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue	100	86	93	77	55	37	37	54	81	111	103	103	937	51/70
Cuito Cuanavale	96	84	90	77	56	40	42	55	89	109	100	103	941	51/70
Mavinga	112	95	100	81	53	34	34	51	86	118	111	113	988	53/70
Cuangar	122	103	105	90	58	31	31	48	83	125	125	133	1054	55/67

Calculated Annual Potential Evapo-transpiration (Penman)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue	161	138	147	134	115	93	101	130	156	182	165	165	1687	53/65
Mavinga	177	156	162	145	117	94	101	130	168	199	178	181	1808	54/65

Figure 4.8 illustrates mean monthly evaporation for a number of locations in the catchment.

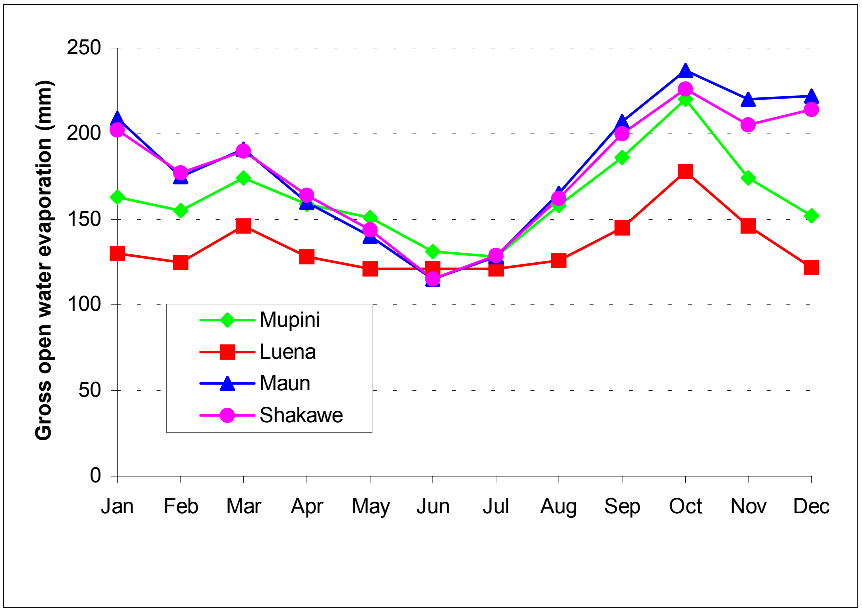


Figure 4.8 : Monthly Gross Open Water Evaporation at Selected Locations

4.4 Human Links with the Basin

4.4.1 Introduction

4.4.2 Data Available

4.4.3 Previous Studies and Research

4.4.4 Overview

5. HYDROLOGY, HYDRAULICS AND GEOHYDROLOGY OF THE OKAVANGO RIVER

5.1 Introduction

National Consultants reports on geohydrology and hydrology in Angola provided valuable information, but at the same time reinforced the fact that there is a major data shortage, no data having been collected since 1975. The hydrology of the river within Namibia has been adequately covered in other studies, including the recent study compiled by Water Transfer Consultants.

5.2 River Morphology

5.2.1 Data Available

5.2.2 Overview/Analysis

The Cubango River rises in the Bié plateau, Angola's hydrographic centre, to the South of Vila Nova, at an altitude of 1800 m, and in its initial track, runs in a north to south direction until Menongue, from where it heads towards the south-east. Downstream of Cuangar, its course evolves changes from west to eastwards and it continues to the Southern Angola/Namibian border until Mucusso, at a stream length of 975 km, in Angolan territory . Its basin in the Angolan territory covers between parallels 12° 20' South and 18° South and between the meridians 16° East and 21°30' East, covering parts of Cuando Cubango, Huambo, Bié, Moxico, Cunene and Huíla Provinces. To the east the catchment is bordered by the Cuando River, the Zambezi River basin to the north-east, the Cuanza River basin to the north and the Cunene to the West, including a drainage area not clearly defined and known as the Cuvelai Delta River.

In Angolan territory, the basin covers an area of 148 860 Sq. Km, of which 60 860 belongs to the basin of its main tributary, the Cuito River.

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

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

Within Botswana, the morphology of the river can best be described in terms of the following components:

- The pan handle where the perennial swamp begins but is confined due to a set of north to north-westerly trending faults.
- The permanent/perennial swamp which is sustained in the alluvial fan by base flow from the Okavango river. This area is controlled by an east-north easterly set of faulting (Mallick *et al* 1981).
- Seasonal swamp, a seasonally inundated wetland which relies on the annual flood from the Okavango river.
- Intermittently flooded areas which fall within the alluvial fan of the Delta. These areas are intermittently flooded to varying degrees during periods of high rainfall in the region (high flow regime).

- The Magwegqana spillway which, during a high flow regime may conduct water through to the Kwando/Linyanti and Chobe river systems which form part of the Zambezi river basin. Thus at times the Okavango is part of the Zambezi river basin and sometimes not. The Modeling which is being developed for the Zambezi river basin action plan (ZACPLAN - a SADC Water Sector Project), excludes the Okavango from the Zambezi basin (Denconsult, 1993).
- The Magwegqana spillway which, during a high flow regime may conduct water through to the Kwando/Linyanti and Chobe river systems which form part of the Zambezi river basin. Thus at times the Okavango is part of the Zambezi river basin and sometimes not. The Modeling which is being developed for the Zambezi river basin action plan (ZACPLAN - a SADC Water Sector Project), excludes the Okavango from the Zambezi basin (Denconsult, 1993).
- Mababe depression, episodically flooded, at present mostly an Acacia woodland
- Lake Ngami is an intermittently flooded area at the south western end of the alluvial fan. When full it forms an open water surface.
- The Boteti river is an outflow from the Okavango Delta. As it transfers water (on an irregular basis) through an arid area, its waters are extremely important in terms of land use, groundwater recharge and maintaining populations of water dependent wildlife ungulates.
- The Boteti flows into an ephemeral freshwater lake called Lake Xau. The channel upstream of the lake has been modified to allow abstraction of the water into a salt pan for storage (now defunct) for use in Orapa and Letlhakane Diamond Mines.
- During extremely high flow regimes water from the Boteti can flow into Ntwetwe Pan, the westernmost sump of the Makgadikgadi Salt Pans.

5.3 Water levels and Runoff

5.3.1 Introduction

Data gathering is by means of automatic stage recorders and periodic flow measurements by current meter. Rating curves are widely used to convert stage into discharge. Where flow measurements are carried out, hydraulic parameters such as depth, width and mean depth are also recorded

5.3.2 Data Availability

5.3.2.1 Gauging Network

A considerable number of gauging stations have been in operation at some time during the last 50 years within the basin. The data recorded at these stations have been collected together for this study. Table 5.1 provides a summary of the major gauging stations which have been operated at some time or another. The positions of the various stations are shown on the satellite imagery in Annex 4, and on Figure 5.1

Table 5.1 does not include stations for which only occasional gauge plate readings were taken, nor does it include the recently added automatic hydrometric stations in the Delta.

A network of new hydrometric stations has recently been put in place in the Delta. The idea behind these stations is that in addition to automatically measuring water levels at useful locations, the data logging system may as well be connected up to an number of climatic sensors (rain etc) as well. 12 new such stations have recently been put in place and there names and locations are provided in the table below. Only a limited amount of data is available from these stations as yet, but they should provide useful; information in the future. In addition, experience with this type of low maintenance station may allow it use elsewhere in the catchment where data are lacking.

Table 5.2 : New hydrometric stations

Id Number	Station Name	Location
1625E	Mohembo	Lat. 18^o 17'; Long. 21^o 50'
1625F	Kwihum	Lat. 19^o 08'; Long. 22^o 37'
6260	Xo Flats	Lat. 19^o 22'; Long. 22^o 52'
16261	Moumo	Lat. 19^o 32'; Long. 23^o 10'
16262	Guma	Lat. 19^o 05'; Long. 22^o 20'
16263	Gaenga	Lat. 19^o 03'; Long. 22^o 50'
16264	Xugana	Lat. 19^o 04'; Long. 23^o 08'
16265	Txaba	Lat. 19^o 22'; Long. 23^o 15'
16266	Shumamorei	Lat. 18^o 22'; Long. 23^o 33'
16267	Zabadanja	Lat. 18^o 35'; Long. 23^o 33'
16268	Sajawa	Lat. 18^o 30'; Long. 23^o 38'
16269	Shaile	Lat. 17^o 58'; Long. 24^o 23'

5.3.2.2 Completeness and Quality of Data

There are a number of factors which affect the usefulness of runoff data. These can be summarized as follows :

i) Completeness and reliability of the raw water level data : If observations are made manually, they must be made frequently and with sufficient care. There is always a danger that the observer was not at his station for a period and simply "estimated" the water levels for this period. In the case of the Okavango Riber stations most stations have been fitted with automatic level recorders.

ii) Recorder Malfunctions and Faulty Calibration : Data may be lost or incorrect due to instrument malfunctions (faulty clock, torn chart, faulty data logger etc). Another problem, perhaps more serious, is the possible faulty calibration of the station. If the recorder has not been correctly calibrated, the recorded water level will not correspond to the level on the gauge plate. These type of errors can be minimized through carefully field checks. (situation in Okavango)

iii) Accuracy of Stage/Discharge Rating : In general, caution should be exercised when using runoff data, especially when it has been indirectly derived. This is generally the case with the gauging stations of the Okavango River Basin. The practice has been to record water levels by means of an automatic level sensor (float and counterweight in the past, sometimes replaced nowadays by a pressure transducer.). Although water level data is in itself often useful for certain applications (areas of inundation, environmental and flood studies), the aim is normally to derive runoff data. In order to derive runoff data it is necessary to have a relationship established between water level (stage) and discharge for each gauging site. Such a relationship can be calculated from theory provided various descriptive parameters are known (river cross section, water slope, manning roughness coefficient etc), but cannot be done very accurately for natural river cross-sections. It is normal practice to carry out “flow” or “velocity” gaugings on a frequent basis, and over the full range of possible water levels. In this way the relationship between stage and discharge is derived empirically. If the cross-section is stable and a unique relationship can be derived then this type of relationship can be relatively accurate, although it must be regularly checked. In assessing the usefulness of runoff data for a particular station, therefore, it is absolutely necessary to know the background to the stage/discharge relationship or “rating”.

Bearing these points in mind, the following remarks may be made with respect to the available data.

i) Angolan Stations : The last data collected on river flow in the basin in Angola was in the mid-seventies. The data collected by the national consultant for this study includes the water level data and stage/discharge rating for many of the stations, although not all. However, it has not been possible to obtain any indication of how the ratings have been derived, whether they have been based on theory or on a number of velocity gaugings at the site. As a result it is difficult to give an assessment of the accuracy of the data. This may be possible once all the sites have been visited, surveyed and new gaugings carried out. It will also be important to source the original cross-section data . If the original gauge plates are still in position it will make it possible to review the old data.

ii) Namibian Stations : Data has been collected continuously at the two stations on the river for around 50 years. The Mukwe gauging station has been successfully rated through extensive speed gaugings carried out at the Divundu cableway gauging site a further 25km downstream. Gaugings are carried out to check the Mukwe rating on a regular basis. In addition, a number of joint gaugings (Crerar and Child; 1991) at both the Divundu (velocity gauging site for Mukwe) and Mohembo have been carried out with the Botswanan Department of Water Affairs and there is agreement between the two countries that the flows gauged at Mukwe are accurate. There is, therefore, international consensus on the volume of water flowing in the Okavango River through Namibia.

Above a discharge of around 1000m³/s no velocity gaugings have been performed. Upstream of the confluence, water levels have been measured at the Rundu gauging site since 1945. The station was rated through a number of gaugings carried out from a hydrometric cableway constructed at Rundu for this purpose. The cableway was, however, dismantled about 20 years ago and there is now some doubt as to the accuracy of the water level/discharge rating, especially at the lower levels. The DWA in Namibia has selected a new site for construction of a cableway and work will start as soon as agreement is reached with Angola, and funding is in place..

iii) Botswanan Stations : There are gaps in the data for all gauging sites, ranging from a few months to years. The data for the Okavango at Mohembo is perhaps the most complete, having a gap of only about 2%.

The Botswanan Department of Water Affairs also operates a gauging site at Mohembo, about 40 kilometres downstream of the Namibian velocity gauging site. The accuracy of this station is suspect at higher levels when water starts to bypass the velocity gauging site on the left bank.

Flow data are of variable quality. The data prior to 1971 are probably the worst in quality. In a study of the flow data for the Okavango at Mohembo, it was found that the records contained many inexplicable observations (Sefe, 1996). Statistical and hydraulic analyses were applied to the data in order to obtain a useable rating curve. However, the methods used could only be applied to the flow data for the two main rivers of the Okavango Delta system: the inflow at Mohembo and the outflow in the Thamalakane at Maun. The methods could not be applied to other gauging stations because data on cross-section surveys and gauging were not sufficient.

5.3.3 Overview/Analysis

5.3.3.1 General

Reference should be made to Figure 5.1, and the annotated satellite images included in Annex 4.

In the following section data available on the river system is briefly analysed so as to provide an overview of runoff, and where possible flood and low flows in the river system. The approach adopted has been to take the system, tributary by tributary, moving in a downstream direction.

5.3.3.2 Cubango River and Tributaries (take down through Angola and include Rundu)

The Cubango River rises as one of four main tributaries which run parallel with each other from north to south in the north-western side of the catchment. From west to east these four are the Cubango, Cutato, Cuchi and Cacuchi Rivers. All four of these rivers have been gauged at some time in the past (see table 5.3) although no data are available for the Cacuchi River .

Table 5.3 : Runoff in the Cubango, Cutato, Cuchi and Cacuchi Rivers

River	Station	Catchment Area (km²)	Period of Record	MAR (Mm³)	Unit Runoff (mm)
Cubango	Chinhama	1799	63/64 – 68/69	751.5	418
Cubango	Cuvango	7185	63/64 – 69/70	1877.0	261
Cutato	Cutato	3683	63/64 – 69/70	934.2	253
Cuchi & Cacuchi	Cuchi	9214	63/64 – 69/70 67/68 missing)	1837.4	199
Cacuchi	Camue				

In view of the fact that these MARs have been derived from concurrent record periods, their comparable magnitude may provide a reasonable comparison of the potential of the streams. However, in order to derive a long term mean annual runoff, or other useful long-term runoff statistics, it is necessary to extend the records to at least 40 years. This would be best achieved through a detailed analysis of catchment rainfall records, physical catchment characteristics and the longer runoff records available for the Namibian stations. This type of modelling requires a large amount of time and will certainly form part of the environmental assessment. At this stage long term mean annual runoffs for all the Angolan river stations have been calculated through simple comparison with the records at Rundu and Mukwe in Namibia. These values are presented in table 5.12, and represents a useful point of departure for an overall understanding of the basin hydrology.

Further downstream the Cubango River is joined by the Cuelei and Cuebe Rivers. The Cuelei is gauged about 40km to the west of Menongue, and the Cuebe is gauged at Menongue. A small tributary, the Luahaca is also gauged just before it joins the Cuebe. The Cuebe is gauged again near to its confluence with the Cubango at Capico, and the Cubango itself, is also gauged just upstream of this confluence at Caiundo. Downstream of the confluence the Cubango has been gauged at Mucundi, then at Foz de cuatir (downstream of the confluence with the Cuatir River, and then at Rundu and at Sambio. Rundu, which has been gauged by the Namibian authorities since 1949 can be regarded as the master station for the Cubango and its tributaries.

Table 5.4 : Runoff in the lower Cubango River and Tributaries

River	Station	Catchment Area (km²)	Period of Record	MAR (Mm³)	Unit Runoff (mm)
Cuelei	Cuelei	5839	66/67	751.5	418
Luahuca	Menongue 1	976	64/65 – 68/69	67.9	69
Cuebe	Menongue 2	4295	63/64 – 69/70	934.2	253
Cuebe	Capico	9758	63/64 – 69/70	1837.4	199
Cubango	Caiundo	38486	63/64 – 69/70	5716.0	148
Cubango	Mucundi	50135	63/64 – 69/70	6470	129
Cubango	Foz de Cuartir	68357	65/66 – 69/70	6842	100
Cubango	Rundu (Namibia)	92250	49/50 – 96/97	5390	58
Cubango	Sambio	93475	63/64 – 69/70	6250	66

The runoff of the Cubango River at its confluence has been estimated (WTC Crerar) at 5390 m³/s.

Some in depth analyses on low flows in the Cubango River at Rundu have been performed for various projects. The 51 year record from 1945/46 to 1995/96 was utilised for the analysis. Minimum flows with return periods of 2 (median), 5, 10, 20, 50 and 100 years were calculated. Table 5.5 provides the data including an analysis of annual maxima.

Table 5.5 : Rundu Monthly low flow extremes (m³/s)

Month	Return Period (Years)					
	100	50	20	10	5	2
Oct	13.1	14.6	17.1	19.6	23.3	32.2
Nov	12.5	14.0	16.6	19.2	22.9	32.1
Dec	14.8	17.1	21.3	25.8	32.7	51.1
Jan	21.6	26.2	34.8	44.7	60.6	108.5
Feb	35.1	43.2	58.0	72.4	98.0	171.3
Mar	52.5	63.2	83.0	105.3	140.9	245.7
Apr	95.6	108.7	131.0	154.5	188.9	277.3
May	60.2	67.9	81.0	94.5	114.2	163.7
Jun	43.7	48.5	56.5	64.7	76.2	104.4
Jul	33.6	37.3	43.6	49.9	59.0	81.0

Aug	27.1	29.9	34.6	39.4	46.0	61.9
Sep	18.5	20.4	23.8	27.2	31.9	43.5
Annual	**11.9**	**13.2**	**15.3**	**17.5**	**20.6**	**30.0**

In recent years, some doubt as to the validity of the stage/discharge rating for the Rundu station has been raised with the suggestion that it may be slightly overestimating, especially at low and very low flows. As a result the Hydrology Division in the Department of Water Affairs have tentatively re-calculated the rating.

From the table it is clear that flow in the Okavango River reaches very low levels during October and November.

For a more detailed discussion of the Okavango River as gauged at Rundu see Section 5.3.3.4

5.3.3.3 Cuito River and Tributaries

The upper tributaries of the Cuito have been gauged at three locations, on the Luassinga River at Luassinga, the Longa River at Longa, and on the Quiriri River at Quiriri. Only two or three years of record are available. The data must therefore be used with great care. Further downstream the Cuito River itself, has been gauged at Cuito, Cuito Cuanavale and Ponto Passagem. Table XX provided station details and the MAR for the record periods.

Table 5.6 : Runoff in the lower Cubango River and Tributaries

River	**Station**	**Catchment Area (km²)**	**Period of Record**	**MAR (Mm³)**	**Unit Runoff (mm)**
Luassinga	Luassinga		65/66 – 66/67	70.5	
Longa	Longa	1122	64/65 – 66/67	125.3	112
Quiriri	Quiriri	1769	65/66 – 66/67	251	141
Cuito	Cuito	15193	65/66 – 66/67	2708.5	178
Cuito	Cuito Cuanavale	22198	66/67	3344	151
Cuito	P. Passagem	25351	63/64 – 66/67	3998	158

The mean annual runoff of the Cuito River at its confluence with the Cubango River was calculated from a model based on daily runoff volumes recorded at Rundu and Mukwe,. The derived value for the defunct Dirico station is 4367 Mm^3/a. Although there is no record available for the Cuito River at its confluence (Dirico) with The Okavango River, although at least one gauging was carried out by the Namibian Department of Water Affairs in the early seventies.

A simplified hydrological model based on the Rundu and Mukwe observed record was drawn up to create a synthetic record for the Cuito River at Dirico. It is believed that the monthly runoff figures derived are a good estimate, within an accuracy of 2 to 3 per cent. The full monthly runoff record is included in Annex 5. Because of the fact that the estimate of the lag time between Rundu and Mukwe is fundamental to the model, and that this lag time fluctuates depending on the level of discharge, the accuracy of the flood peak estimates and to a lesser extent, of the minimum discharges, will not be quite so good.

Table 5.7 : Runoff Statistics for the Cuito River at Dirico (Synthetic record).

Parameter	**Annual Runoff Volume (Mm^3)**	
	Dirico	**Rundu**
Seasons*	45	45
Mean	4484	5391
Median	4494	4962
Coefficient of Variation	0.14	0.22

*For the sake of comparison only the concurrent Cuito and Rundu records have been used. This corresponds to the period during which the Mukwe station has been open.

The mean annual runoff at Mukwe for this period is 9875 Mm^3. Approximately 45,4 % of this is contributed by the Cuito River. Despite the similar mean annual runoff (MAR) values, there is a significant difference in seasonal flow regimes of the two rivers. This is further illustrated in Table 5.8.

Table 5.8: Comparison of some runoff parameters

Parameter	**Rundu (Okavango)**	**Dirico (Cuito)**
Month with highest mean discharge	April	April
Mean discharge for above month	401	175
Maximum Flow recorded (m^3/s)	962	550 - 600
Date of maximum flow	April 8	February 3*
Minimum Flow Recorded (m^3/s)	11.1	64
Month of Minimum Flow	November 17 - 20	October 24

It can be seen from the above that the peak discharge in the Cuito River is normally during April. Average discharge for this month is 175 m/s. This is also true of the Okavango River at Rundu where the average discharge for April is much higher at 393 m/s.

However, in the Cuito River the peak is often only recorded in May and hence the average discharge for May is still as high as 172 m/s and for June still 167 m^3s. In the Okavango the average for May is already down to

258 m^3/s and to only 139 m^3/s in June. The reason for this is that despite its shorter mainstream length, floods in the CuitoRiver are significantly attenuated due to the presence of wide flood plains in the lower part of the catchment. Only a very large flood such as the one of February 1968 would be relatively unaffected by these flood plains. A comparison of the average monthly flow volumes at both stations in shown in Figure 5.2. It is interesting to note from this graph that on average the runoff in the Cuito is greater than that of the Okavango for 7 months of the year.
Figure 5.*3* illustrates a comparison of the maximum and minimum monthly volumes.

The 1968 flood which produced a peak of between 550 and 600 m^3/s in the Cuito River was as an unusually early flood in both tributaries. At Rundu 909 m^3/s were recorded and the resultant peak at Mukwe on only February 7 was 1473 m^3/s, the highest on record. It seems that the flood in the Cuito was an extreme event, having a return period in excess of 50 years. Under more normal circumstances the peak discharge in the Cuito occurs in April or May.

Figure 5.4 shows a comparison of the season total for both rivers for the period 1949 - 1993. It is interesting to note from this graph that there are 17 seasons (marked with x), where the seasonal runoff volume in the Cuito River at Dirico was greater than that of the Okavango River at Rundu. Of particular interest is the fact that for all ten of the lowest seasons recorded at Rundu, the runoff volume of the Cuito was higher.

5.3.3.4 Okavango River

The Okavango River, as it is known in Namibia both upstream and downstream of its confluence with the Cuito River has been gauged at Rundu and Mukwe. It is also gauged at Mohembo at the top of the panhandle in Botswana.

Table 5.9 : Annual Runoff Statistics for Gauging Stations on Okavango River

Parameter	Runoff Volume (Mm^3)			Seasonal Max. Discharge (m^3/s)		Seasonal Min Discharge (m^3/s)	
	Rundu	Mukwe	Mohembo	Rundu	Mukwe	Rundu	Mukwe
Seasons	51	46	64	51	46	51	46
Mean	5263	9876	9935	527.8	701.1	29.7	133.1
Median	4765	9461	9455	485.4	644.0	27.9	134.0
Standard Deviation	1920	2158	2230	208.7	262.7	10.1	19.6
Coefficient of Variation	0.36	0.22	0.23	0.40	0.38	0.34	0.15

The Mohembo data is derived from three different periods(Manley; personal correspondence, 1997). From 1932 to 1946 the data were measured as levels at an unknown site near to the present one. From 1947 to 1965, Namibian data (mainly Mukwe) were used. From 1966 to date, the current site was used. The discharge values for the early period are based on a rating derived by Manley, rather than that originally derived by the Botswanan Department of Water Affairs.

Table 5.10: Monthly Discharge Statistics for Gauging Stations on Okavango River (all records)

	Mean Monthly Flow Volume (Mm^3)			Mean Monthly Discharge (m^3/s)			Median Monthly Flow Volume (Mm^3)			Minimum Observed Monthly Flow Volume (Mm^3)		
	Rundu	Mukwe	Mohembo	Rundu	Mukwe	Mohembo	Rundu	Mukwe	Mohembo	Rundu	Mukwe	Mohembo
Oct	107	398	431	40	149	161	112	391	429	57	288	268
Nov	115	387	431	44	149	161	116	379	429	42	232	242
Dec	255	544	574	95	203	215	210	532	555	58	353	277
Jan	482	770	814	180	288	304	420	737	760	114	413	392
Feb	671	986	1022	277	404	382	602	871	901	213	363	404
Mar	950	1351	1397	354	505	522	893	1261	1326	251	633	626
Apr	1019	1504	1500	393	584	560	964	1388	1323	379	786	777
May	689	1277	1223	257	477	457	663	1267	1168	310	653	640
Jun	358	855	820	138	330	306	365	845	814	157	463	392
Jul	265	692	674	99	258	252	275	687	665	138	418	349
Aug	206	574	571	77	214	213	219	563	552	115	391	308
Sep	144	472	475	56	182	177	153	460	470	69	333	265

Note: Rundu record starts 1945/46; Mukwe record starts 1949/50; Mohembo record starts 1932/33

At Rundu, October and November are the worst months, with median flow volumes of 100,5 and 105,4 Mm respectively. The minimum monthly flow volume measured at Rundu is 34,2 Mm^3. At Mukwe, November is the worst month with a median monthly flow volume of 379 Mm, and a minimum observed monthly volume of 232 Mm□. There is clearly a much larger quantity of water downstream of the confluence than above, *especially during the critical low flow periods of the year.*

For Mohembo, the median monthly volume for November is 428,5 and the minimum monthly volume is 242 Mm. From these simple comparisons and a close examination of Table 3.2 it can be seen that there are some apparent discrepancies between the Mohembo and Mukwe data with neither one being consistently higher than the other. With the stations being so close together, it could be expected that the monthly volumes between the two would be comparable. In order to make a more useful comparison of the volumes recorded at each station, only the record for the period 1966/67 to date is now analysed since this corresponds to the period of concurrent record for all three stations.

Looking at only this concurrent period, the mean annual runoff figures for Mukwe and Mohembo differ by less than 0,5%. In view of the level of inaccuracy inherent in discharge measurements (+/- 2%) on a single well-conducted gauging, this can not be considered as a major difference. However if the monthly totals are looked at as indicated in Figure 3.2 there are clearly some bigger differences for some months than for others. This can largely be explained by lag factors.

During the months where the hydrograph is generally rising (December to March), the Mukwe volumes are marginally higher. For the other months the Mohembo volumes are higher. This is exactly what would be expected. The conclusion is that there is no significant difference between the flow recorded at Mukwe and Mohembo. Evapotranspiration and seepage losses between the two stations are probably more than made up for by direct rainfall onto the river and local runoff during intense rainstorms. This conclusion is supported by the results of combined gaugings carried out by the Namibian and Botswanan water authorities. These are provided in Table 5.4.

Table 5.4: Joint Discharge Measurements carried out by Namibian and Botswanan Authorities (Hatutale 1994)

Date	Mukwe Gauge Plate Reading (m)	Gauged at Mukwe (Divundu) (m^3/s)	Gauged at Mohembo (m^3/s)	Mukwe Stage/Discharge rating (m^3/s)
24 May 1984	3,59	(N) 552 (B) 567	(N) 550 -	554
20 March 1985	3,18	(N) 364 (B) 358	(N) 361 (B) 354	362
16 October 1991	2,48	(N) 117	(B) 109	118
18 November 1992	2,55	(N) 127	(B) 127	137
10 November 1993	2,47	(N) 107 (B) 110	(N) 115 (B) 117	117

Note: (N) means gauging carried out by Namibian team
(B) means gauging carried out by Botswanan team

In modelling inflow into the Delta it is recommended that Mukwe flow record be used with attention paid to the small time lag. The rating of the Mohembo station is suspect at higher levels. If it is desired to use the Mohembo record because of its early starting date, it is recommended that the Mukwe record be used on a monthly basis for checking purposes.

5.3.3.5 Inflow: Okavango at Mohembo

Inflow into the Okavango Delta is via the Okavango River. Flows are measured at the top of the 'Panhandle', a relatively narrow defined channel. River gaugings at Mohembo started on a more or less regular basis in

1974. There are irregular data dating as far back as the 1930's (SMEC, 1987). Data of variable length are available on the following parameters: stage, discharge (gauged or estimated from rating curve), cross-sectional area, surface width, mean velocity, mean depth, and maximum depth. Discharge is gauged with an OTT current meter from a boat, with velocity in the vertical measured by a combination of the single point and two-point methods. The discharges were calculated using the mid-section method (Morsley and McKerchar, 1993). Although the number of verticals varied, the reliability of the gaugings was not assessed.

5.3.3.6 Outflow Rivers

The Okavango Delta system is highly unstable and many tributaries and distributaries have been blocked and reopened repeatedly. Numerous studies detail the shifting and changing channel systems (IUCN, 1992). The current main outflow channels are discussed in this section. The river gauging network in the Okavango Delta Region is shown in Figure 5.6 and information on the gauges is provided in Table 5.12. The individual rivers are discussed below.

Boro River

At present, the Boro River is the main channel that transmits flow out of the Delta. The Boro is a tributary of the Jao which is itself a tributary of the Ngogha. The Boro flows through the Xo Flats where the flow disperses and its channel becomes undefined. A clear channel emerges in the vicinity of Xakue, where the flow is gauged, and it joins the Thamalakane near Maun. Of all the outflow tributaries, the Boro floods first and recedes slowest.

The Boro is gauged at two places: Xakue and Junction (also known as Pontoon). The Xakue gauging site is about 75 km northwest of Bokwi. The Junction gauging site (Gauge Station No. 7412) is the main gauging site on this river. Discharge data are available for the Boro at Junction from 1970/71 hydrological year .The flow usually peaks in July or August. Figure 8 illustrates the distribution of mean monthly flow in the years 1970 to 1996. Monthly flow is very variable from year to year, especially during the low flow months. The coefficient of variation exceeds 100% for seven months (December to June). In certain years no flow has been observed from one to six months. Information on mean, median, minimum and maximum observed flows are summarised in Table 5.13. In addition to the gauging station at Junction, there are a number of staff gauges for stage measurements at Thokatsebe, Malakgaga and Mporota (Figure 5.6). There are no reliable data for these stations as they are no longer in use.

Santantadibe River

The Santantadibe River is also part of the Ngogha River system. It is a tributary of the Mboroga which is itself a tributary of the Ngogha.

The Santantadibe flow has not reached the Thamalakane since 1981. However, water has ponded up at a point on both sides of the Kunyere Faultline at and near Daonara. This has been the case since 1981. Within the Okavango Delta Region, the river is gauged at Malalakgaka (Gauge Station No. 7512), south of Daonara and at Ditshipi (also known as Ditshiping). Useable data from Ditshipi were available from 1985/86 onwards

The flow regime of the Santantadibe is different from all the other outflow rivers of the Delta in that flow is fairly uniform throughout the year, showing no apparent response to the flooding of the Delta (see Figure 9).

While discharge is generally uniform from month to month, there is considerable variation from year to year as shown by the summary statistics in Table 9.

Shashe River

The Shashe River is a tributary of the Thamalakane. This river has not shown a recorded flow since December 1989. In fact, since October 1984, this river has shown recorded flows in 1987 (one month) and 1989 (seven months). However, flow may have occurred in some of the reported no-flow years but did not reach the gauging site because of channel losses.

The Shashe River is gauged at Shashe Bridge (Gauge Station No. 7722) on the old Maun to Toteng Road. The data retrieved from the DWA archives started from 1970/71 hydrological year that flow is highly variable from year to year, with the coefficient of variation exceeding 100% for all months and reaching 461% for how the distribution of mean monthly flows in the years 1970 to 1996. In years with flow, the river peaks in July or August.

Kunyere River

The Matsibe, Marophe and Xudum Rivers converge to form the Kunyere River. This river provides the link between the Okavango Delta and Lake Ngami. Like the Shashe River, the Kunyere River ceases to flow for several months each year and did not flow for five of the years between 1969 and 1985 (i.e. 1971, 1972, 1981, 1982 and 1985). In recent years the river last flowed in 1992. Like the Shashe, some flow may have occurred in the reported no-flow years.

The Kunyere River is gauged at Toteng (Gauge Station No. 7712). The monthly flows are listed in Appendix 10 and the distribution of mean monthly flow in the years 1968 to 1996 is shown in Figure 11. The Kunyere exhibits a high flow variability, with the coefficient of variation exceeding 100% for all months and reaching 496% for April. In years with flow, this flow is concentrated between June and September, with the peak usually occurring in July or August.

Thamalakane River

The Thamalakane River flows along the Thamalakane Fault in a southwesterly direction, acting as a collector channel for several rivers that receive outflow from the Okavango Delta (Gomoti, Santantadibe, Boro, Shashe and the Nxotega). Currently, the major flow to the Thamalakane comes from the Boro.

The Thamalakane has a long gauging history. Between 1921 and 1933 annual maxima, and between 1933 to 1948 monthly water levels, were recorded by Government officials. From 1952 to 1960 the Witwatersrand Native Labour Association maintained a staff gauge. However, it was not until 1968 that discharges and water levels were systematically measured following the re-establishment of the gauge during the UNDP/FAO Bot/67/501 project.

Monthly discharges of the Thamalakane at Maun Bridge (Gauge Station No. 7812) are listed in Annex 5. and Figure 5.8 shows the distribution of mean monthly flow in the years 1969 to 1996. Flow is concentrated between June and September, with the peak normally occurring in July or August. During years of exceptionally heavy rainfall, such as 1974 and 1978, a second flood peak may develop earlier in the year, between March and May. In early 1955, following a very high regular flood in 1954, the heavy rains produced the highest flood level ever recorded at Maun. Flow is variable from year to year, with the coefficient of variation exceeding 100% for many months (November to June) (Table 12).

5.3.3.7 Conclusions

Table 5.12 provides a summary of preliminary Mean Annual Runoff values for the Okavango River Basin. These values have been derived through simple comparison of concurrent records for the period 1949/50 to 1994/95 using Rundu, Synthetic Dirico, Mukwe and Mohembo as the master stations.

Table 5.12

River	Station	Catchment Area (km²)	MAR (Mm³)	Unit Runoff (mm)
Cubango	Chinhama	1799	612	
Cubango	Cuvango	7185	1528	
Cutato	Cutato	3683	760	
Cuchi & Cacuchi	Cuchi	9214	1495	
Cacuchi	Camue			
Cuelei	Cuelei	5839	1118	
Luahuca	Menongue 1	976	45	
Cuebe	Menongue 2	4295	760	
Cuebe	Capico	9758	1495	
Cubango	Caiundo	38486	4652	
Cubango	Mucundi	50135	5265	
Cubango	Foz de Cuartir	68357	5372	
Cubango	Rundu (Namibia)	92250	5390	
Cubango	Sambio	93475	5085	
Luassinga	Luassinga		68	
Longa	Longa	1122	123	
Quiriri	Quiriri	1769	243	
Cuito	Cuito	15193	2627	
Cuito	Cuito Cuanavale	22198	3162	
Cuito	P. Passagem	25351	3646	
Cuito	Synthetic Dirico	60600	4484	
Okavango	Mukwe		9875	
Okavango	Mohembo		10036	

5.4 Erosion, Sediment Loads and Sedimentation

5.5 Groundwater

6. WATER QUALITY AND CHEMISTRY OF THE OKAVANGO RIVER SYSTEM

6.1 Introduction

Detailed studies on water quality in the Angolan and Namibian portions of the catchment are lacking. A 1984 survey measured a range of chemical parameters at 35 mainstream and 10 backwater sites along the river in Namibian territory. Other water quality data are available from The Division of Water Environment within DWA Namibia.

A certain amount of detailed work has been carried out for the Delta in Botswana.

6.2 System Variables

The water quality of the water in the Okavango rivers measured in Namibia is relatively good). The range in certain chemical concentrations measured at 35 mainstream and 10 backwater sites during a survey in 1984 are presented in table 6.1.

Table 6.1 : Chemical Concentrations of Okavango River Water from various sites in Namibia

Parameter	Unit of Measurement	Mainstream sites	Backwater sites
Conductivity	Siemens/cm	30 - 45	45 - 205
pH		6.8 - 7.2	6.7 - 7.5
TDS	mg/l	25 - 42	30 - 172
Alkalinity	as $CaCO_3$ m/l	10 - 20	20 - 95
Na^{++}	mg/l	1 - 3	3 - 10
K^{+}	mg/l	1 - 2	1 - 3
Ca^{++}	mg/l	6 - 16	7 - 46
Mg^{++}	mg/l	3 - 8	6 - 22
SiO_2	mg/l	8 - 15	9 - 36
Cl^{-}	mg/l	0.5 - 1.0	1.0 - 5.6
Total N	mg/l	0.1 - 1.5	0.1 - 6.2
PO_4 - P	mg/l	0.01 - 0.07	0.02 - 0.15
Org P sol	mg/l	0.01 - 0.10	0.02 - 0.32
Total P	mg/l	0.01 - 0.15	0.04 - 0.37

The water is typically soft, with very low conductivity. Chemical and nutrient concentrations are low.

Within Botswana the system variables can be summarized as follows:

pH

The pH of the Okavango surface water varies between 5.9 to 7.6 (SMEC 1987 and Cronberg et al 1995).. The largest variation in pH is found in the groundwater and ranges from 6 to 9.8 (Maun Groundwater Project 1996).

Water Temperature

The temperature of inflowing Okavango water varies seasonally and ranges from 18°C in July to 29°C in January. Temperatures were generally found to be 3 to 4 degrees higher at the distal end of the Delta ranging from 22°C in July to 32°C in January.

Dissolved Oxygen (DO).

Dissolved Oxygen content throughout the flowing waters of the Okavango is generally high and near saturation conditions (UNDP 1997). From a small number of measurements in October 1975, the dissolved oxygen content appeared to be variable. The waters of the Okavango have variable DO content. Studies by Cronberg et al 1996 stated that the DO content of water was below, or substantially below, saturation and reflected stagnant conditions throughout the wetland. Such variations in results possibly reflect the relative stages of flood progression in study areas

6.3 Non-toxic Inorganics

Most detailed work has been carried out in Botswana :

Total Dissolved Solids

Most work on non-toxic inorganics has concentrated on the Boro river within the Delta. The water has been characterized as a calcium-sodium-bicarbonate, with moderate alkalinity and moderate to high amounts of silica (Sawula and Martins 1991, Cronberg et al 1995, McCarthy and Metcalfe 1990).

Mean values of the total dissolved solids of the Boro river range from 30mg/1 to 120mg/1. General ionic concentrations are shown below,

Ca^{-2} 4.8 mg/l
Mg_2^- 1.3 mg/l
Na^- 1.9 mg/l
K^- 2.7 mg/l
CI^- 1.Omg/l
HCO_3^- 27mg/l
SiO_2^- 38mg/l

(After Sawula and Martins 1991)

Trends of TDS

The TDS show a distinct increase in concentration from proximal to distal regions of the Delta. Inflow values ranged from 25mg/1 at Seronga to 95mg/1 at the outflow near the Boro and Thamalakane river junction. This trend is proposed to be a result of evaporational and transpirational water losses (SMEC 1989, Sawula and Martin 1991).

The individual dissolved ion concentration was shown to be inversely proportional to flow (Sawula and Martins 1991). This relationship was found to be more noticeable for Na^{+}, Mg^{+2}, Ca^{+2} and less obvious for K^{+}. Dissolved silica also shows a distinct increase in concentration from inflow to outflow regions (McCarthy and Metcalfe 1990).

Sources of TDS

Surface waters of the Jao/Boro system are essentially of rainwater type with a small proportion attributed to rock dominated origins. (Sawula and Martins 1991) This is as expected, considering that rainfall in the Angolan highlands is the principle source of floodwater for the Okavango. Rainfall within the Okavango contributed up to 35% of the total water input into the system (SMEC 1989).

The chemical content of TDS in rainwater generally includes: sulphate, nitrate, chloride, ammonium, calcium, magnesium, sodium and potassium (UNDP 77). The TDS amounts in rainwater are commonly in the range of Img/1 and rainfall itself accounts for approximately 35% of local input into the system ($4 \times 10^{9} m^{3}$ in volume, SMEC 1989).

Predicting the mass of TDS added to the overall system by rainfall is limited by seasonal variability in volume, distribution, infiltration and runoff. However, rainwater TDS mass is around 3% of floodwater mass derived from the Angolan mountains, so a crude estimate would be in the range of 8 000 to 10 000 tonnes of TDS and therefore could have a significant input on water chemistry/quality. Little to no work has been done on rainwater chemistry.

6.4 Mass Balance, Salininty And Carbonate Formation

Approximately 96% of the water entering the Okavango Delta is lost through evapotranspiration. Two percent leaves via groundwater paths and two percent leaves via surface flow (Wilson & Dincer 1978).

The mass of TDS of inflow water to the Delta is approximately 400 000 tonnes. The outflow is only 30 000 tonnes (SMEC 1989). It has been shown by McCarthy & Metcalfe 1990, that precipitation reactions resulting from increased transpirational water losses account for "fixing" a large percentage of the missing mass of TDS. However, the occurrence of saline surface water is rare.

It has been shown by McCarthy et al 1991, that through transpirational processes the sodium bicarbonates are confined to island centres. The precipitating salts are then flushed from the system during the rainy season which prevents the sustained accumulation of salts in surface water. Although this process occurs throughout the Delta, the formation of carbonates does not fully explain mass deficiencies of TDS.

McCarthy et al 1989 and McCarthy and Ellery 1993 have also shown the importance of vegetation effects on water chemistry. Increases in salinity from transpiration in seasonal swamps are offset by fixation of some metals in the peat. Thus, vegetation related effects on TDS may play a more important role in mass balancing in the Okavango than is presently understood.

6.5 Groundwater Salinity

Studies by the Maun Groundwater Project 1997 (MGP) have shown that groundwaters are of a similar composition to floodwaters in the distal portion of the Okavango. Oxygen and Deuterium isotopic signatures of groundwater suggest that most groundwater samples represent water recharged from infiltration of surface water.

From 18 brothels in the upper Boro, upper Thamalakane and lower Thamalakane Valley regions, the TDS concentrations indicate good water quality. The Department of Water Affairs designate a cut off of 1000 mg/1 TDS for drinking water. The lower Thamalakane Valley brothels north-west of the fault, range from 333 to 408 mg/1 with the other areas fluctuating between 102mg/1 and 2016mg/1. There is obviously distinct lateral variation in TDS, which has also been shown to increase with depth (MGP 1997).

Aquifer depth ranged between 29 to 95m. One borehole at 40m had a TDS concentration of 13 700mg/l The MGP recommended that regular monitoring of well field groundwater quality should be continued to provide early warning of saline water intrusion.

6.6 Toxic Constituents

Work on toxins, nutrients, plankton and organic contents of water in the Okavango Delta has been limited to work by Cronberg et al 1992, 1995 and 1996. Thus, sections 2.5 to 2.7 of this review summarize that work.

Inorganic and organic toxic constituents of water in the Okavango Delta are present in low values and represent mostly natural background accumulations. It is important, however, to establish a baseline of present concentrations, should the concentrations change through later development.

6.6.1 Inorganics (Trace elements)

Iron and magnesium concentrations were low 12.8 g/1 and 3.5 g/1 respectively. At these concentrations (determined from 299 samples), there would be no toxic effect on biota but may be moderately toxic to aquatic plants (Cronberg et al 1995).

The Aluminum ion can be extremely toxic. Within the Okavango, concentrations were generally low 2.5 g/1, and well below recommended concentrations for protecting aquatic biota or human consumption. Aluminum in the Okavango mainly exists as an aluminize ion $Al(OH)_4$ but it may also occur as colloidal $Al(OH)_4$ and as stable complexes with various ligands (Cronberg et al 1995).

Chromium was present in 10 out of 12 samples from the Boro junction in the Thamalakane, in average concentrations of 0.3 g/1. Cd, Pb, Ni, Zn and Co were analysed from samples in the upper Delta and at the outlet of the Boro River (Table 1), and with the exception of Zn, the trace metals concentration can be assumed to reflect background levels.

6.6.2 Organotoxins

As yet no work has been done on polycromatic hydrocarbons or organochlorines. Effects of insect spray programmes on fish fauna were documented by Matthiessen in 1982, however, organic contamination of water or soil has yet to be evaluated (Cronberg et al 1995).

6.6.3 Biotoxins

Algal blooms have been found within the Delta and Linyanti systems and consisted of *Microcystii* and *Cylindrospermopsis*. A few toxin producing species *Microcystii acroginosa* have also been found within the Delta and particularly in Kings Pool.

6.7 Nutrients

Nitrogen and total Phosphorous

The concentration of Nitrogen components and total Phosphorus from Cronberg et al 1995 and 1996 study (Fig 1) are given in Appendix D.

Inorganic nitrogen (nitrate and ammonium) constitute 25 to 35 percent of total nitrogen. The concentration of organic - N and ammonium - N were moderate to high 0.95 and 0.07mg/1 respectively. The concentration of Nitrate - N 0.07mg/1 and total phosphorus 0.064mg/1 were within the observed range of similar wetland systems (Cronberg et al 1996).

Care must be taken with interpretation of data as variation coefficients of 92% to 177% were recorded by Cronberg et al 1996.

Trends in Nutrients

i) Inflow

N & P exhibited a seasonal fluctuation similar to that of other solutes i.e. concentration increases with discharge at low levels of discharge and decreases concentration as the discharge levels increase. This suggests a flushing effect on solutes. (Cronberg et al 1996). Concentrations of N & P downstream of the inflow lost this relationship.

ii) Intra Delta

Total N and nitrate - N exhibited high variability in both perennial and seasonal swamps, whereas total P showed the highest variability in seasonal swamps. Ammonium - N concentrations exhibited similar variations in both seasonal and perennial swamp. Cronberg et al 1996 observed the largest variation of N and P in the seasonal swamps. This would be expected as the process affecting Nitrogen and Phosphorus formation (ammonification, nitrification, denitrification and algal uptake) would be more variable as they are regulated by other variables including: water temperature, oxygen availability and pH which are likely to fluctuate locally in seasonally inundated floodplains.

iii) Isolated Pools

These environments were found to have different chemical and biological characteristics compared to the rest of the Delta.

High average concentrations of ammonium (560µg/1) total N (2400µg/1) and total P (195 g/1) were observed while Nitrate - N concentrations were relatively low (40µg/1). The high concentrations of ammonium in the Okavango can in part be attributed to biological inputs from waterfowl and mammals and in part from anaerobic decomposition of soil organic matter. (Reddy & Patrick 1984). The high concentrations of P were probably due to desorption of P from flooded soils and peat areas.

iv) Outflow

Concentrations of Nitrogen at distal regions range from 150 to 180 mg/m/year and about 8 to 10 mg/m/year of Phosphorous.

v) Nutrient Export Comparisons

Nutrient export comparisons with other catchments are difficult due to variations in peak flow and sediment loads. However similar papyrus systems, where data is available i.e. Lake Maivasha (Gauged 1979) generally correspond to studies on the Okavango. Similar wetlands in Africa e.g. The Sudd, Lake Chad, Middle Zaire and Bangweilu have not yet been assessed for nutrient flows (Cronberg et al 1996).
Compared to Zimbabwean catchments, the Okavango has similar total P exports, but 5 times more total Nitrogen export (Thornton 1986).

6) Nutrient Summary

The present results on the nutrient concentrations indicate that nutrient accumulation is mostly controlled by effects of flood and discharge. Biological effects are difficult to distinguish due to overprinting of physical effects.

River Channels are mainly oligiotrophic, swamps and floodplains vary between oligiotrophic and mesotrophic, with isolated water bodies varying between mesotrophic to eutrophic.

6.8. Plankton, Bacteria And Dissolved Organic Carbon

Plankton and bacterial assemblages often reflect levels of N and P. Wetland functions are also extensively regulated by microbiota (Cronberg et al 1995), thus records of bacterial and plankton quantities and types, besides being the fundamentals of the food chain, are of importance in the overall chemistry of Okavango waters.

Phytoplankton

In general, phytoplankton biomass was low in river channels, less than 1mg/1, but never reached higher than 45mg/1 in swamps. The major groups of phytoplankton include diatoms of the genus *synedra* sp, cryptomaonads and dinoflagellates of the genus peridinium. These groups increased in abundance in channels connected to lagoons with higher N and P.

The Aleal flora of the Okavango is similar to other wetlands including Lake Shiva, Lake Bangwela in Zambia (Thomasson 1957), and the Aligator River in Australia (Ling and Tyler 1986).

Zooplankton

Identification of zooplankton was based on 35 samples by Cronberg et al 1996.

River channels with low N and P levels were essentially devoid of zooplankton (282 numbers/l) whereas distal regions with higher N and P levels contained large numbers, (up to 2800 numbers/l). Very few species differences were found across the surveys. Rotifera and Navplius larvae were the dominant taxa found.

Bacteria

Environmental factors and water chemistry variables that affect bacterial abundance are presently unknown (Cronberg et al 1996). Thus, variation in bacterial counts at this time has unknown use in providing insight into water chemistry or water quality changes.

Based on 55 samples of surface water by Cronberg et al 1996 the total bacterial numbers (TBN) counts range from 0.07 to 3.89 x 10^6 cells/ml. There appeared to be no variation in TBN between seasonal and perennial swamps but variation between sites did occur.

Dissolved Organic Carbon (DOC)

The concentrations of DOC within the Okavango are high to extremely high in some isolated pools and lagoons, 16 to 285 mgC/1. (Cronberg et al 1996). The increase in DOC is proposed to occur via "flushing" of the swamps and floodplains with flood cycles. DOC concentrations also increase downstream via evaporational process similar to those described in Section 6.4.

DOC concentrations were found to be higher in seasonal swamps than in the perennial swamps possibly as a result of both the above processes.

Average concentrations of DOC throughout the Delta are:

- 7.7rmg C/1 in the upper Delta (Moshapatsila)
- 10 mg C/1 intra Delta (XO flats)
- 16,7 mg C/1 lower Delta (Thokatsebe)

This pattern suggests that although the central swamps of the Delta have relatively low water velocities, it is still a region of efficient mixing. This supports the findings of McCarthy et al 1991 regarding the distribution of carbonates and salts formed through transpiration and precipitation processes.

DOC Mass Balance.

Less than 25% of the input mass of DOC is exported out of the Okavango (Cronberg et al 1996), The Okavango has high DOC retention rates and high turnover rates, which may indicate that DOC is efficiently utilized. However, it is not yet known how DOC is transformed into biomass or respired as $C0_2$ thus information on production and decomposition of aquatic plants is necessary (Cronberg et al 1996).

6.9 Water-borne Diseases; Health Hazards

6.9.1 Introduction

A NCR was commissioned to look at water-borne diseases within Botswana and Namibia and to make some assumptions on the likely situation within Angola.

6.9.2 Data available and review of previous and present studies

There is little published literature on water-borne diseases and few unpublished reports.
The only comprehensive and reliable survey of bilharzia in the Okavango Region of Namibia was that of Geldenhuys *et al* (1967), thirty years ago. Another was carried out in 1983 by La Grange & Steyn but this used biased sampling methods and crude diagnostic techniques (Schutte 1997). Statistics from three clinics in the Okavango Region of Namibia for 1996 were obtained from the Ministry of Health and Social Services (MOHSS) and are presented in Curtis (1997 (page F-14 of vol. 4 part 3; copy of this "Table 1" included at end of report). A preliminary report to the MOHSS by Dr CJH Schutte on urinary bilharzia was also undertaken in October 1997 shows an exceptionally high incidence of urinary bilharzia at three schools in the Okavango Region. The final report will be available once the survey is completed after May 1998. There are no data available on livestock diseases in Namibia (Tolmay, *pers. comm.*).

Little is known of the situation in Angola. The World Health Organisation (1987) map of the distribution of bilharzia in Africa shows that both urinary and intestinal bilharzia occur in the Cubango and Cuito catchment areas, but there are no statistics as to how serious the situation is. Looking at the climate and geomorphology of the river, it

6.9.3 Analysis

Dando (1976) reported that malaria was a particular problem in the Delta but that bilharzia had only become a problem since 1973. Annual reports for 1986 and 1987, which are available from the Ministry of Health in Botswana, showed that both malaria and bilharzia were a problem. The 1995 annual report mentioned the problem of malaria but did not mention bilharzia.

The MOHSS in Namibia is currently involved in a comprehensive survey of bilharzia in school children from the Okavango, Omusati and Caprivi Regions (Schutte 1997).

None of the diseases caused by bacteria and other micro-organisms appears to be a problem in the Okavango River either in Namibia or Botswana (Curtis 1997). Malaria is a widespread and very serious problem in both countries, but is not restricted to the river. Rainwater pools and any man-made structures which hold water are sufficient to ensure the continuation of the problem without the river.

The most serious problem associated with the river is bilharzia or schistosomiasis. Both species of human bilharzia known from southern Africa are alive and well in the Okavango River in Namibia, along with their snail intermediate hosts. The MOHSS recognises this as a problem and is now initiating a control programme. Of concern with this control programme is the use of molluscicides to kill the intermediate hosts. The poisons are not species specific and could have a detrimental effect on the other aquatic fauna. A preliminary report to the MOHSS by Dr CJH Schutte on urinary bilharzia was also undertaken in October 1997 shows an exceptionally high incidence of urinary bilharzia at three schools in the Okavango Region. The final report will be available once the survey is completed after May 1998.

Botswana has undertaken an extensive snail eradication campaign in the past with the result that the disease is virtually unknown in Ngamiland at present. Very few intermediate host snails were found during the 1996 survey (Curtis 1997).

A potential cause of concern is the presence of a large and healthy population of blackflies, *Simulium damnosum* (Simuliidae), which was found in February 1997 at the Andara weir. These tiny flies are vectors for a small parasitic Nematode worm which causes onchocerciasis or river blindness (Chutter 1997). These parasites are a severe problem in west Africa. In the past, neither the parasite nor the vector was present in Namibia or Botswana. With the spread of the vector it is not impossible for the parasite to be spread to the Okavango as well. This could pose a serious new threat to the health of the population living along the Okavango River. Simuliid larvae and pupae attach themselves to rocks in swiftly flowing water and this species is typical of impoundment outlets. Because of the lack of rocky outcrops in the Okavango in Botswana, blackfly are unlikely to spread into Botswana.

Looking at the climate and geomorphology of the river, it would appear that conditions would be ideal for the existence of bilharzia. With a mean annual temperature of 18 - 20 °C in the highlands and 20 - 22 °C in the lowlands, both parasites and snails would thrive. The gentle gradient of the river and numerous meanders are ideal for the presence of floodplains and quiet backwaters in which snails breed. Figure 3.6a in the IUCN report on Angola (1992) (copy of this figure included at end of report) shows floodplains along the Cubango and Cuito Rivers only where they border with Namibia and a bit further north. The area near Huambo where the Cubango River starts is shown as swamp, which could be ideal for bilharzia snails.

One factor which may lessen the likelihood of bilharzia, is the low human population density. Around Cuito-Cuanavale the river appears to meander a lot and there are many settlements, so this could be an area of concern. There is a high population density around Huambo where the Cubango starts and where the swamps mentioned above occur. This is a potential site of high infection. For most of their course, both the Cubango and Cuito appear to flow through an area of low population density, however, this is probably misleading since the population is probably concentrated along the river. If the incidence of bilharzia is high in Namibia, it is likely to be as high in Angola.

Malaria is probably rife in Angola, but like Botswana and Namibia it is unlikely to be dependent on rivers. Being a more tropical and much wetter country there could be other water-borne diseases which are unknown in Botswana and Namibia.

7. THE OKAVANGO RIVER ECOSYSTEM

7.1 Introduction

An attempt has been made to take an ecosytem approach for the system as a whole starting by looking at primary production, then at secondary production and then at how the two interact by considering habitat. This allows a logical lead on to the condition of habitats and how the activities of man may affect them.

7.2 General Approach/Main Ecosystem Sub-divisions

7.3 Primary Producers

7.3.1 Introduction/General

Data on primary producers within Angola is extremely lacking, no new work having been done there for more than twenty years. The national consultant had extreme difficulty in locating the old studies which were done. Within Namibia more work has been done and a recent updating exercise on mapping of the Okavango Region using aerial photography may be useful for vegetation and land-use studies.

Within the Delta are, a considerable amount of work has been done and research is ongoing.

7.3.2 Data Available/Previous work

Few studies relating to the classification of Angola's floral biodiversity have been carried out. No new data have been collected since the mid-seventies, and much of the potentially useful references were not found in Angola or the other two riparian states. The satellite imagery bought for the Preparatory Assessment Study, which dates back to August 1993, covers the entire basin in Angola and provides a good picture of the existing land cover. These images, once ground-truth will be useful for the up-dating of vegetation maps etc. keeping shown in Appendices CC. Based on the bibliography consulted, the studies conducted by Castanheira Diniz (1973 & 1991), and those by Quintela Góis (1973), provide a better clarification of the flora of the Cubango (Okavango) Basin.

The IUCN report (October 1992) refers to the study by Barbosa (1970) which subdivided Angola's vegetation into 32 mapping units.. It has not been possible to obtain an original copy of this map. The black and white photocopy is relatively useless.

Little detailed work has been done on the vegetation of the Okavango River system in Namibia and most of the descriptive material for the various vegetation units is derived from the following studies. Page (1980) provided a broad overview of the vegetation of the previously defined Kavango area. This study describes 10 units within which are 19 sub-units. The description of the riverine units are cursory. Correira & Bredenkamp (1987) proposed a classification of 15 land-use units on the basis of vegetation composition and structure. Hines (1987) in a paper on the avifauna of the eastern Kavango gave a brief overview of the principal vegetation types of the region. Bethune (1991) describes 5 main vegetation zones associated with the Okavango River. These broad descriptions are accompanied by a detailed checklist of all plant species known or expected to occur along the river. Hines (1996a) provides a detailed account of the vegetation associations in the planned Okavango National Park (comprising the Mahango Game Reserve and the Buffalo Section of the Caprivi Game Park). Classification systems proposed in the above references differ considerably but most reflect the influence of the river and the Kalahari sands as broadscale determinants of the composition, structure and distribution of the major units. No studies have been carried out in the Namibian sector of the river which detail the determinants and processes involved in defining the principal riverine and associated vegetation units (such as those of McCarthy *et al.* 1993). The importance of plants in the hydrological and biological cycles of the river has not been studied in any detail.

A large number of studies have been carried out focussing on the Okavango River Delta. A full annotated reference list is included in the NC's report. Some of the key information available is as follows:

In their *Central District Planning Study* (1990), Aquatech The first major GIS based planning study in Botswana. The GIS contains all major themes mapped at 1:250 000 or 1:500 000. Some primary data collection was undertaken, eg, vegetation mapping, and a number of new themes were generated eg, agro-ecological zones. A very useful source of digital information. In *The ecology of Chief's Island and the adjacent floodplains of the Okavango Delta, Botswana., (1979)* Biggs describes (in detail) five main wetland vegetation types based on water availability and subdivides them into 20 plant communities. He uses Tinley's classification for the dryland plant communities. The vegetation section is from page 37-105. The rest of the thesis examines animal populations and animal interaction with vegetation.

In *Northern State Lands, Botswana: Land Resources Study No. 5,* Blair Rains, A. & A. McKay describes land systems and vegetation communities in the Chobe and Ngamiland Districts. In *An Ecological Survey of North-eastern Botswana: Report to the Government of Botswana*, Child, G. Contains a mixture of useful ecological and economic information and serves as a "baseline" of the ecological functioning of north-eastern Botswana. Contains sections on vegetation (particularly the Chobe floodplain), forestry, the influence of fire and recommendations for its management, tsetse fly, tourism and management recommendations for the Chobe National Park. The "elephant problem " and their impact on vegetation is highlighted.

In a study of *the vegetation of the seasonal swamps,* Heemstra H.H provides a good description of the vegetation of the seasonal swamps. During his development of the classification of communities he was assisted by P. Smith. His work has been largely superseded by the Ecozoning report.

Forest inventory and management in the Baikiaea forests of north east Botswana Henry, P.W.T, There is background information concerning the Baikiaea forests (legal ownership and usage). An estimation of wood resources in Chobe, Kasane, Kazuma and Maikaelelo Forests. Recommendations cover further inventory requirements and agreements for exploitation of the forest.

In his study on *The composition, condition and utilization by large herbivores of the grasslands in Savuti, Chobe National Park., BSc (Hons) thesis* Joos-vandewalle, M.E. Savuti is an ephemeral wetland attached to the Linyanti system located within the Mababe depression. The vegetation types and plant community descriptions from this work were used in developing the Chobe National Park

Masundire, H.M., Eyeson, K.N. & S.F. Mpuchane (Eds.) (1995) Includes papers on the ecology, management and conservation of wetlands in Botswana, utilization of economic resources, and community-based fisheries and wildlife resource management (Proceedings of the Conference on Wetlands Management in Botswana)

In his *Field investigation into the mokoro industry* (1988) Murray-Hudson, M Tree species used in the construction of mekoro in Northern Botswana were identified. Trees preferred by mekoro operators are

Mukwa, Mokusi and Moporota. Over 100 mekoro were examined in the study and age estimates attained. Factors adding to longevity of these crafts were identified. The required supply of mekoro for the tourism industry and the availability of trees was assessed.

In *Chobe Forests Inventory and Management Plan,* (1992) Norwegian Forestry Society provides A detailed enumeration study which used both remote sensing (data manipulation with the use of IDRISI) and field samples to provide an estimate of wood resources. The management plan is made up of a number of volumes and annexes. There is a detailed wood resource inventory (annex 4 pp 182) and a number of management options, some of which are linked to livestock grazing in the areas. Discussion on extensive impact of fire and elephant on the woodlands.

A Detailed Vegetation Study on the Chobe River in North East Botswana, Simpson, C. D. The vegetation survey was carried out as part of a population ecology project on the Chobe Bushbuck Tragelaphus scriptus ornatus Pocock, 1900. The survey covered 32 km west from the eastern Chobe National Park boundary, including river frontage and the floodplain south to the sand ridge. Habitats and vegetation physiognomy were mapped in detail for a 98,3 Ha intensive study area.

In their ,Southern Okavango Integrated Water Development: Phase I; Final report environmental impact study; Annex ** SMEC Contains detailed descriptions and mapping of vegetation in the seasonally inundated areas of NG 30 and the lower Boro river. Impacts to vegetation are described. In the Southern Okavango Integrated Water Development, Phase 1: Final Report Environmental Impact Study - Vol III Sukwane Reservoir Impact Assessment. The study assessed the impacts of a dam at Sukwane (lower Boteti river). Vegetation is described as well as other issues such as wildlife/agricultural clashes and the use of the river bed for melapo farming.

In his *Draft list of indigenous grasses* (1988), Smith, P. A. List of grass species of Botswana together with a key to the tribes of indigenous grasses (adapted from the key in "Genera Graminum" W.D. Clayton & S.A.

In their *Programme for the planning of resource utilization in the Okavango Delta region: Volume I: Natural resource and utilization inventory*, (1989), Swedeplan produced a desktop compilation of data for the area. Largely outdated by the publication of the Ecozoning report.
In *The primary productivity of African wetlands, with particular reference to the Okavango Delta.,* Thompson, K Outlines the main African herbaceous wetlands. Discusses primary productivity in terms of certain wetland plant species, nutrient availability and water availability. Concludes that there are considerable differences between potential and actual productivity. Provides figures of productivity which are the upper limits

In a study of *Abundance and distribution of large herbivores in relation to environmental factors in Savuti, Chobe National Park, Botswana (1988).* Vandewalle, M.E.Joos Contains detailed descriptions of vegetation within the Savuti marsh and Mababe depression areas. These data are recorded in the Chobe National Park Management plan (Deloitte & Touche, 1992, Volume 1). The *Provisional Vegetation Map of Botswana (1971),* by Weare, P.R. & A. Yalala A physiognomic description of general vegetation types and dominant species is provided for the

7.3.3 Analysis

7.3.3.1 (Major) Components of the System

a) Basin Within Angola

From a physiographic point of view, the catchment within Angola has been divided into three regions, corresponding to Regions 3, 4 and 5 of Diniz's (1991) classification. These are shown in Figure 7.1

These regions can be described as follows:
Diniz (1991) categorized the vegetation into 39 phytogeographic zones, of which zones 3, 4 and 5 relate to the Cubango (Okavango) Basin area.

Region 3

The Central Zone of Angola (High Cubango) covers an area of 33 600 km^2. The climate is humid to sub-humid, with prolonged rains for 6 to 7 months of the year during the hot, dry season. The soil is a ferric-clay type. The predominant vegetation is open forest of *Julbernadia*, *Brachystegia* and *Isoberlinia*.

Region 4

The Middle Cubango Zone covering an area of 79 900 km^2, makes up most of the Basin. The climate is humid to sub-humid, and in the transitional strip it is sub-humid to dry, with 5 to 6 months of rain a year. The soil is influenced by the sandy coverage of the Kalahari. The vegetation is varied, open forest prevailing to the north and savanna forest to the south, both essentially of *Brachystegia sp*, *Julbernadia paniculata*, *Guibourtia coleosperma* and *Pterocarpus angolensis*.

Region 5

This region corresponds to the Cubango Lowland, and covers an area of 36 200 km^2. It has a semi-arid climate, with a short rainy season and an uneven distribution of rainfall. The soil is mainly sandy, and alluvial in the river lowlands. The vegetation is dependent on soil characteristics.

Alluvial Plain Areas

In these areas which are submerged during flooding periods, the vegetation typically consists of *Vetiveria nigritana*. During the dry season, graminoid plants such as *Phragmitis mauritanus* are found around the edges of small lakes and depressions.

Lowland Terraces (lombos)

These zones consist of rarely flooded areas alternating with small depressions which are usually ancient or fossil river beds. The vegetation consists of trees such as *Acacia tristis*, *A. giraffae, A. mellifera, Peltophorum africanum, Terminalia sericea* and *Combretum* spp. After major floods, these areas become inundated with grass cover such as *Themeda, Aristida, Tricholaena, Heteropogon, Loudetia* and *Tristachya*..

High terraces

As flat elevated terraces these areas are free from flooding. In these flat areas, the vegetation is that of savanna consisting of ***combretum imberbe, acacia sieberana*** var. ***Woodii, peltophorum africanum*** and ***ficus gnaphalocarpa***.

Riverside Slopes

A transition from alluvial plain to the Kalahari platform occurs along these areas. The vegetation consists of *Acacia giraffae, Peltophorum africanum, Combretum imberbe* and *Strychnos*.

Kalahari Platform

The highest elevations follow the valleys of Cubango and Cuito. The vegetation is that of tree savanna, consisting of *Baikiae plurijuga, Guibourtia coleosperma, Pterocarpus angolensis, Burkea africana, Erythrophleum africanum, Dialium engleranum, Pseudolachnostylis maprouneifolia, Terminalis sericea, Combretum zeyheri* and *C. psidioides.*

In the depressions shrubby communities of *Diplorhynchus condylocarpon*, *Swartzia madagascariensis* and *Strychnos* spp are to be found.

In the drier areas, there are communities of closed or thick forests of *Croton, Grewia*, *Terminalia* and *Combretum*.

According to Barbosa's classification (1970), Angola's vegetation is grouped into 32 phytogeographic units (Map 5), corresponding to the Cubango (Okavango) Basin from north to south, the units 15MS, 22gM, 29g and 23Wg. Diniz (1991) categorised the vegetation into 39 phytogeographic zones, of which zones 3, 4 and 5 relate to the Cubango (Okavango) Basin area . Part of this map is reproduced in Figure 7.1

Insert Figure 7.1

b) Basin Within Namibia

The Riverine System

The Okavango River is a perennial endorheic system subject to annual floods of varying intensity. These floods seasonally inundate large areas of lands adjacent to the main river channel and the wetlands associated with them vary in size from 119 km^2 in the dry season to about 430 km^2 during annual floods (van der Waal, 1990). The riverine component is the most important area in terms of supporting human activities, with most human settlement, arable agriculture and livestock being centred on this part of the system. There are a number of well defined units within the riverine system. These are:

Open Water Habitats

This comprises the main channel (50-200 m) wide and the narrower side channels which remain flowing through the year. The substrate is usually sandy or rocky (e.g. in the Mukwe-Andara-Popa area) and water depths vary from 0.5-8.0m. These areas are some of the most important fisheries areas. They are, however, relatively unimportant grazing areas and the vegetation is uniform and dominated by floating macrophytes such as species of *Potamogeton, Lagarosiphon, Nymphaea* and *Trapa.* The river channel margins are generally dominated by *Phragmites* spp. and *Vetiveria* spp., which are both important species in the construction of local houses. These reed-grass fringes can be quite extensive, and form important fish breeding areas during periods of high water. In the lower reaches of the river, below Andara, the reeds are often replaced by dense, floating mats of papyrus *Cyperus papyrus* (Bethune, 1991). Reeds are readily traded and at certain times of year large quantities are stockpiled and sold along the roads between Rundu and Divundu. The reed beds are extensively burnt during the dry season even though they comprise a valuable source of cash.

Floodplains

The floodplain of the river varies considerably in width from a couple of metres to several kilometres wide, but is generally limited in extent. Bethune (1991) and Ellery (1997) map the main floodplain areas in Namibia.

The floodplains can be divided into a variety of habitats the principal determinants of which are thought to be the length of the period of inundation following the onset of flooding and the substrate. The perennial swamp systems on the floodplains are dominated by papyrus *Cyperus papyrus* which are extensively burnt during the dry season. They are largely unaffected by fires and are not heavily utilised by man. Other areas are dominated by *Phragmites* reeds, often with a poorly developed woody component comprising species such as *Syzygium guineense* and *Rhus quartiniana.*

The seasonally flooded areas are far more diverse in composition with soil substrate and the period of inundation being important determinants. On sandy clay soils the tall, unpalatable grasses *Miscanthus junceus* and *Vetiveria nigritana* can form extensive, uniform grasslands in the "wetter" end of the spectrum. Dense floating grass mats form on similar soils where the period of inundation is longer. *Echinochloa* and *Vossia* are the most important grass types here and are very important grazing resources for domestic livestock and for wildlife. Several fish species use these floating grass mats as substrates for egg-laying and protection of young. In areas of relatively short inundation, the grass *Cynodon dactylon* is dominant and the lawns formed by this species are some of the most important grazing resources along the length of the river. They are heavily and consistently grazed throughout the year, being extremely hardy and resilient. In some areas where flooding has become reduced through terrestrialisation of the floodplain, this species has disappeared. On sandy islands and shallow deposits, the vegetation is dominated by woody, perennial grasses which are largely unpalatable and have little value as grazing resources. Characteristic species here are *Chloris virgata, Eragrotis pallens* and *Cymbopogon* spp. The tall grass species of the floodplain habitats are important thatching resources.

The role of fire and frost as determinants of the vegetation units in these seasonally flooded areas is open to question. Fires occur frequently in parts of the system, particularly the *Phragmites* and *Cyperus papyrus* reedbeds but whether these fires alter the structure and composition of these units is unclear. Most of the grasslands (with the exception perhaps of those in the Okavango National Park) remain unburned because grazer pressure on the system as a whole, lowers fuel loads to the point where few fires of any extent are recorded in any one year. No extensive peat beds are reported from along the Namibian sector of the Okavango and so peat fires are not a feature of the functioning of the ecological system.

The small ponds, backwaters and oxbows which form after the floodwaters recede are usually well vegetated and are an important source of fish during the dry season.

The grazing resources of the floodplain (particularly the *Cynodon dactylon* lawns) are some of the most important natural resources within the Okavango River basin. Fish breeding is to a large extent dependant on the integrity of these resources in that they provide important nutrient inputs into the system as well as provide numerous breeding sites for fish. The commercial (and socio-economic) value of these resources as integral support systems for the maintenance of the regional livestock herds has not been studied in any detail, but should not be underestimated. The seasonal floodplain grasslands and grazing resources warrant considerable investigation relative to the utilisation by livestock owners and the stability of the local economy.

Riparian Fringe And Riverine Terraces

Alluvial terraces form on either side of the river and are generally above the level of general flooding. These terraces and the direct riparian fringe have a very distinct assemblage of plant species. These units are characterised by tall tree species such as *Diospyros mespiliformis, Ficus sycomorus, Acacia nigrescens, Garcinia livingstoneii* and *Lonchocarpus capassa*. These trees are generally between 15 and 20 m in height. There is a distinct sub-canopy stratum of trees 4-8m in height characterised by *Croton megalobotrys, Terminalia prunioides* and *Combretum hereroense*. The soils on which these woodlands formed are alluvial loams which represent some of the best soils for arable agriculture along the river. The woodlands have been extensively cleared to make way for fields and the best examples of this vegetation type are now found in the protected areas of the lower reaches between Divundu and Muhembo, although many of these have been severely damaged by elephant in recent years.

In areas immediately adjacent to the river margin, saline accumulation in the soils is characteristic. These soils are largely occupied by palms *Hyphaene ventricosa* and trees such as *Terminalia prunioides.* Very little of this habitat remains, except within the Mahango Game Reserve.

The Aeolian Kalahari Sands

The vegetation of the deep, dystrophic Kalahari sands is generally not affected by levels of flooding and the annual cycle of the river, and so fall outside of the boundaries of this study. The vegetation of the sand areas is characteristically a tall, open woodland dominated by trees such as *Burkea africana, Terminalia sericea, Combretum spp., Ochna pulchra* and a well defined shrub layer. These areas are important wet-season grazing areas and a source of most of the construction wood used in building houses. The lack of surface water in these areas limits the value of the grazing resources, which are not of as high a quality as those of the floodplain areas.

c) Basin Within Botswana

General

The plant habitats of the area affected by the water of the Okavango Delta can be broadly divided into three types of system ie, perennially flooded areas; seasonally flooded areas; intermittently flooded areas. The intermittently flooded areas include the outflows from the Delta. Within each of these broad systems are a number of habitats which are a result of localised factors such as location in the landscape, history (ie, past flood regime), soils and land use. Plant communities within each of these habitats are shown in Table 7.1.

The key botanical studies are indicated in the table below in which plant communities are outlined.

Table 7.1: Plant Communities of the Okavango System.

Major Wetland Systems	Plant Communities	Location Within Study Area (Section Error! Reference source not found.)
Perennial Swamp	A number of plant communities occur, best described by the topographic units ie, channel, lake, channel margin filter communities, rainwater pans (Biggs, 1979; Ellery, 1987; Ellery, 1988; SMEC, 1989). There are some dryland communities that are directly linked to the perennial swamp and occur on islands ie, riverine woodlands and salt tolerant /halophytic species.	i) Okavango river, ii) Pan handle, and iii)Perennial swamp.
Seasonal swamp	The plant communities are divided into two main groups based on duration and depth of flooding ie, **seasonal swamp** (which contains a widespread community with two co-dominants *Schoenoplectus corymbosus* and *Cyperus articulatus*); **flooded grassland** and **rainwater pans** (Heemstra, 1976; SMEC, 1989).	iv) Seasonal swamp
Intermittently flooded areas	These areas are mainly **edaphic grasslands** composed of the "dryer" type flooded grassland which maintain species composition through episodic flooding. In the absence of flooding dryland plant communities establish in these areas. These are dynamic communities as they act as, and are largely composed of wetland species when flooded yet change when dry.	v) Intermittently flooded areas (SMEC, 1989, KGS, 1990). vi) Magwegqana spillway. vii) Mababe depression (Vandewalle, 1988; Deloitte & Touche, 1992) viii) Lake Ngami (SMEC, 1987). ix)Boteti river (SMEC, 1987, Aqua Tech, 1990). x) Lake Xau (SMEC, 1987).
Salt Pan	Salt pan algae community	xi) Makgadikgadi pans (Ntwetwe pan).

Dryland Plant Types	Plant Communities	Location Within Study Area (Section Error! Reference source not found.)
Forest	Riverine forest (SMEC, 1989)	ii) Pan handle
Woodland	Riverine woodland (SMEC, 1989; Heemstra, 1976; KGS, 1991; SMEC 1987;	i) Okavango river, ii) Pan handle, iii)Perennial swamp iv) Seasonal swamp v) Channels in the intermittently flooded areas
	Colophospermum mopane woodland (KGS, 1991). Distribution in SMEC, 1989.	Found in the intermittently flooded areas. Invades into areas where seasonal and intermittent flooding has stopped. To the south and east of the Delta. Important component in areas adjacent to river channels in outflow areas.
	Acacia erioloba woodland (KGS, 1991; Tinley, 1966; Biggs 1976)	Found throughout the wetlands on dryland.
Savannah	*C. mopane* tree and shrub mosaic (KGS, 1991)	Found in the intermittently flooded areas. Distribution in SMEC 1989 and KGS, 1991.
	A. erioloba/Terminalia sericea (KGS, 1991, Deloitte & Touch, 1992)	On major islands of seasonal and intermittently flooded areas.
	Mixed *acacia* spp. on clayey soils	v) Intermittently flooded areas.
	T. sericea/ Lonchocarpus nelsii/Combretum collinum shrub	Dryland areas which contain channel sands from past fluvial activity.
	Hyphaene petersiana	On islands where soils are saline in the seasonal swamp and intermittently

		flooded areas.
Grassland	Island grassland with forbs	Centres of islands in perennial and seasonal swamps. Also occurs in the intermittently flooded areas where heavy grazing has occurred.
	Halophytic	Centres of islands in perennial and seasonal swamps.

The structure of vegetation in the Okavango and a detailed discussion on species-area relationships are described in the Ecological Zoning report (SMEC, 1989). A detailed description of dryland plant associations and the area relations of the associations is given in the Moremi Game Reserve Management Plan, Volume 1 (KGS, 1991). A broad vegetation habitat classification for the Okavango was developed by Smith (in SMEC, 1989) and is shown in

(to be added).

Smith (SMEC, 1989) identified 1061 plant species within the Okavango Delta and considers that the number will increase to about 1200 species. In his floristic analysis he found a species area ratio of 0.0545 per km^2. This is the second highest ratio found for biomes in southern Africa (the highest being the Cape Fynbos with a ratio of 0.1997 per km^2.).

Major Components of the System

The Panhandle and Perennial Swamp

A detailed list of species occurring in the perennial and seasonal swamp areas was developed by Smith (in SMEC, 1989). He found a total of 445 species in both areas with 205 occurring in the perennial swamp and 240 in the seasonal swamp. Specimens can be viewed in the Peter Smith Herbarium in at the Okavango Research Institute in Maun.

The major plant groupings are outlined in Table 7.1 and common plant species detailed in the appendices. Subdivision of the main groupings into discernible plant communities has been undertaken for the Mwanachira river area by K. Ellery 1987, W.N. Ellery 1988. These two studies would be needed if detailed plant community descriptions are needed. There has been considerable work undertaken by Smith (Smith, 1976 & SMEC, 1989) to form the base for further plant community descriptions. The plant communities are grouped floristically around dominant species such as *Cyperus papyrus*, *Phragmites* spp and *Typha*.

Mapping of the extent of the perennial swamp was undertaken during the Ecological Zoning (SMEC, 1989) through the examination of 1:50 000 scale aerial photographs (May 1983). Copies of these maps exist with the DLUPU at Maun. The approximate distribution of *Phoenix reclinata*, an indicator species of the perennial swamp was also mapped. The perennial swamp vegetation forms a mosaic of plant communities making the mapping of individual communities impossible at a useful scale.

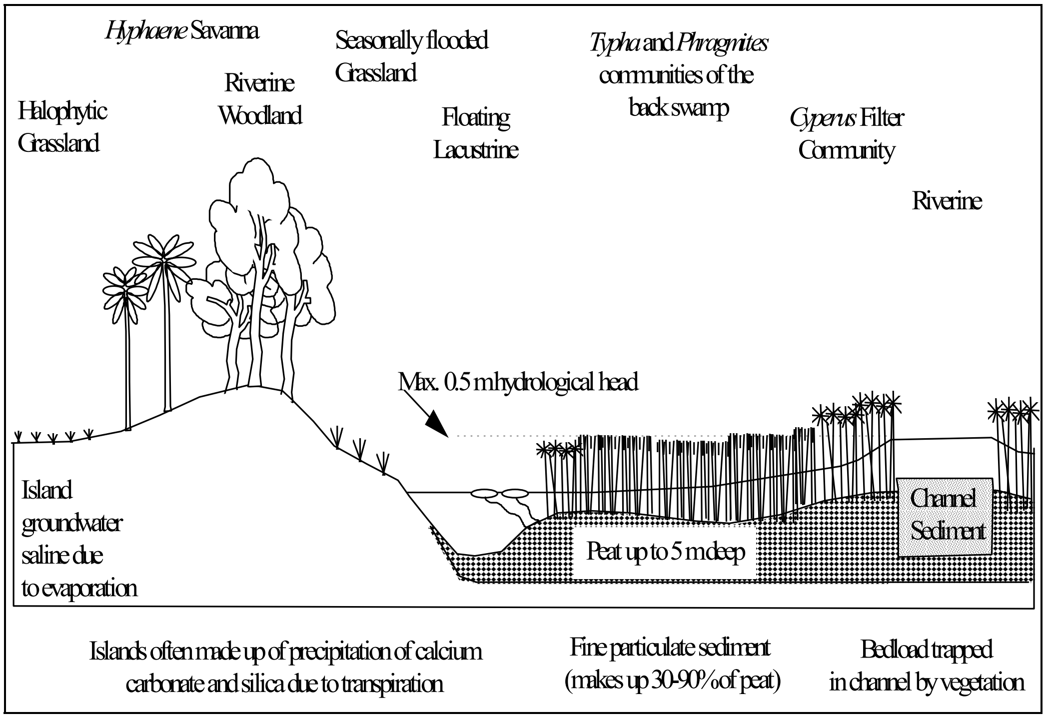
Determinants have been identified as water depth, quality, turbidity, level amplitude and substrate (SMEC, 1989). In addition sedimentation and sedimentation rates, and flow velocity have been identified as important by McCarthy (1992, 1997).

Vegetation has been identified by McCarthy as having an active role in shaping the Okavango Delta. The channel flanking plants such as *Cyperus papyrus, Phragmites australis* and *Miscanthus junceus* form permeable channel margins facilitating the widespread distribution of water while localising the deposition of channel sediments. When channels begin to fail, due to the unstable hydrological gradients caused by the flanking plants, species such as *Vossia cuspidata* grow prolifically. These then entrap floating papyrus and accelerate channel failure. Also important in the channel failure process is the luxuriant growth of *Papyrus* in the moribund section, which prevents avulsion and allows for the formation of a filter area. As a result new channels form at some distance from the failing channel thus desiccating the area and allowing the process of peat fires to occur. The life cycle of a channel from formation to final abandonment appear to be in the order of 150-200 years.

McCarthy also notes that *Papyrus* and *Vossia* do not occur at the distal ends of the swamp where their growth forms could potentially block channels. Rather *Miscanthus* replaces these plants on the margins of channels, stabilising them without posing a threat to flow.

Increases in salts due to evaporation and transpiration are controlled by bacteria living in the peat substrate and by the localisation of salts in island centres through the transpiration actions of riverine vegetation. The vegetation induced swamp abandonment is considered essential to the recovery of island soils from salt accumulation. The role of vegetation in the dynamics of the Okavango is central to preventing the Okavango Delta becoming a salt pan.

Figure 7.4 : Diagram of Perennial Swamp Vegetation.



<u>Seasonal Swamp</u>

The composition of plant species in the seasonal swamp has been described in the above section. In addition to the work carried by Smith, description of plant communities has been undertaken by Heemstra (1976) and Biggs (1979).

The full extent of the seasonal swamp was mapped by Smith (in SMEC, 1989). He was unable to map the boundaries between the main communities (seasonal swamp, flooded grassland and the intermittently flooded areas) and considers that future mapping would entail extensive fieldwork and approximately two years of work. Mapping of the distribution of the main communities of the seasonal swamp by other people has been limited to small areas. These areas are the Xudum - Xwaapa area at 1:50,000 (SMEC, 1987) and the area north and east of Chiefs Island (Biggs, 1979). Island areas within the perennial and seasonal swamps can be reliably identified using the 1969 coloured photomaps (SMEC, 1989).

Determinants of the seasonally flooded areas are primarily flood depth and duration, followed by soil type, fire, herbivory (KGS, 1991). There is also a rapid shift between seasonally flooded and intermittently flooded areas. Large areas of the Delta that were classified, in 1989, as seasonally flooded (based on 1983 photos) are today now only intermittently flooded and have woody encroachment of the flooded grasslands.

Vegetation of conservation importance has been addressed in the discussion on the perennial swamp.

<u>Intermittently Flooded Areas</u>

These areas are made up of dryland plant communities (as described in Table 7.1 and flooded grasslands that are in a constant transition between savannah (due to *Acacia erioloba* or *Combretum imberbe* woody encroachment) and open grassland. In these areas flooding maintains the grasslands which are valuable for herbivore species.

The dryland plant communities that are associated with or adjacent to these areas have been described by Biggs (1979) and KGS (1991) for Moremi Game Reserve. Little descriptive work had been undertaken in the western Delta.

Smith (in SMEC, 1989) has mapped the extent of the intermittently flooded areas and identified the larger stands of dryland vegetation occurring within these and other wetland communities. During the development of management plans for the Multipurpose CHAs (1993 onwards) some detailed mapping of vegetation has occurred.

The major determinants of these communities are flood frequency, and soil types. Fire, frost and herbivory are also important.

Outflows of the Delta

a) The Magwegqana (Selinda) spillway

The spillway links the Okavango system to the Zambezi basin via the Linyanti/Chobe river. Vegetation in the spillway and surroundings has not been well documented. The channel floods episodically. There was at least a 30 year period between flooding early this century and the floods of the 1970's. During the dry periods *Acacia* and *Combretum* tree species invade the channel bed.

Description of plant communities and mapping of these communities is limited to the CHA management plans undertaken by the current leaseholders of the multipurpose CHAs.

b) Lake Ngami

The species composition and plant community descriptions of Lake Ngami have been completed to a limited degree in SMEC, 1987.
The determinants of plant communities in the system is linked to flood frequency (in the lake bed) and the determinants of the dryland plant communities (mainly *Acacia erioloba* dominated) relate to catena position which influences the depth and salinity of groundwater.

c) The Boteti river, Lake Xau and Makgadikgadi Salt Pans

The relatively high frequency of outflows from the Delta that feed the Boteti river has resulted in (wetland) reedbed communities and well developed riverine woodlands in the upper reaches. Further down the river the riverine species composition becomes less varied and a broad *Acacia erioloba* woodland (which changes to a savannah further down the river) exists on either side of the river beyond the riverine woodland. The woodland relies on groundwater from the river channel.

Plant community descriptions and mapping have been done by SMEC, (1987a & b). A broad classification and mapping of communities can be found in the Central District Planning Study which reconciled various earlier vegetation classifications (Timberlake, 1980, Ecosurv, 1988) in Central District and mapped the communities at 1:500,000 (AquaTech 1990).

More recent work was undertaken during the Makgadikgadi/Nxai Pans Management Plan where plant communities and land systems were reconciled and management activities for the land systems identified (IUCN, 1995). The main determinants of vegetation was considered to be the river flow frequency, duration and recharge into the alluvial and lacustrine sands. This controls the depth of groundwater available to the riverine and surrounding *Acacia* woodlands. Plant species variation and condition of the riverine decreases in a downstream direction

Detailed assessment of the Boteti riverine vegetation was undertaken in 1996 by Perkins (in Sefe *et al*, 1996)

The Boteti river area including Lake Xau has been subject to extensive research concerning the process and alleviation of desertification (Arntzen *et al*, 1994). Decreased water supply to the area together with arable farming and high numbers of livestock have started a process of desertification and rapidly changing vegetation.

7.3.3.2 Determinants

No studies have been carried out in the Namibian sector of the river which detail the determinants and processes involved in defining the principal riverine and associated vegetation units (such as those of McCarthy *et al.* 1993). The importance of plants in the hydrological and biological cycles of the river has not been studied in any detail.

In addition to the determinants discussed in the section of the major habitats, the following also applies:

In areas in which flooding occurs, the duration and frequency of flooding are the key determinants, with other determinants such as flow rate and substrate being of lesser importance. The determinants of plant communities that occur in freshwater pans are soil structure, catchment, rainfall and use.

The interface between the wetland communities and dryland can be abrupt as in the case of riverine woodland within perennial swamp, or diffuse, eg, acacia or mopane riverine woodlands fringing intermittently flooded grasslands.

The dryland plant communities are determined by the evolutionary history of the soils. The key determinants are the soil type and depth, depth of the water table and presence of an impermeable soil layer.

The structure and composition of the communities is further modified by fire and frost. The distribution of rainfall determines which annuals dominate the herbaceous layer from one year to the next.

Little is known of the fire history of the Okavango, although man-made fire is likely to have been an important component of the system since the first presence of people in the Delta approximately 10 000 years ago. Naturally-started fires have been part of the ecosystem for considerably longer than this.

Fire is a frequent event in the Delta. The high frequency of fires in an area of such low annual rainfall, and the fact that the fires seem to be independent of annual flood levels and rainfall is thought to be due to the following factors:

i) Most fires that occur in the Delta are the result of human activities. The natural frequency of fire in this environment is likely to be in the order of 20% ie, a given area burns one year in five on average (KGS, 1991). An estimate of the present regime is 75%, or three years out of four.

ii) The dryer (grassy) seasonally inundated community of the floodplain generates sufficient fuel load for fires in most years. The intermittently flooded areas also generate reasonable fire fuel loads, but are more dependent on annual rainfall. The catena position and distribution of the dryer seasonally inundated area (SIA) results in an extensive distribution of what is a relatively small plant community in terms of area (like a fuse).

iii) The relatively low densities of grazer species ensure that much of the grass biomass remains available to fire.

iv) There are also plant communities with surprisingly low fire fuel loads such as:

- The wetter SIA forms part of the aquatic food chain and appears to be utilized during the annual flood, leaving little for fires.
- Many of the dryland communities have very little grass (eg mopane woodlands and pluchea forblands).

This mosaic of plant communities, some with and others without fuel loads, together with the presence of extensive areas of water results in a patchwork of fires which increases the ecological heterogeneity of the Delta.

In addition to the normal bush fires that occur on a seasonal basis, peat fires occur in areas which were formerly perennially flooded, and have dried out. These fires can burn for years in the subsurface peat, with heat from burning drying surrounding peat. This results in collapse and compaction of the peat, thus lowering the surface.

Plant biomass removal by herbivores is limited in importance in the wildlife areas but is important in the livestock areas where grasslands are changed to forblands and where peat soils are lost due to hoof action and wind erosion (western Delta). The plant communities most affected are the upper edge of floodplain grasslands the island short grasslands and riverine woodlands. Warthog root up extensive areas of the floodplain sedgeland after flooding has receded.

The effect of elephant on plants has been extensively documented. The impact of elephant on the Delta vegetation is increasing and will play a major role in woodland and savannah composition and structure in the future.

7.3.3.3 Plants Species and Communities of Conservation Importance

Angola

In the Namibian portion of the catchment, several species, as well as the communities and habitats of which they are a part can be considered of conservation importance The flora is rich in diversity with 869 species of 88 families described in Bethune (1991), but few of the vegetation units or habitats have remained intact following the accelerated clearing and over-utilisation of plant resources in recent years. As such, most habitats could be regarded as threatened to some degree, even those within proclaimed conservation areas which have been severely altered through elephant damage within the last 10 years.

Plant species and communities of conservation importance within the Delta area and panhandle have been identified in the Ecozoning report (SMEC, 1989). These are provided in table 7.2:

Table 7.2 : Plant species and Communities requiring special attention.

Species/Community	Issue	Notes
Eulophia latilabris	overpicking	A showy orchid in peat areas of perennial and seasonal swamp
E. angolensis	overpicking	A showy orchid in peat areas of perennial and seasonal swamp
Zeuxine africana	rare	Known in only one site in the Delta and rare throughout the rest of its range
Habenaria pasmithii	endemic	The only known Delta endemic
Ansellia gigantea (var nilotica)	overpicking	Serious depletion of wild plants
Eleocharis cubangensis	no issue at present	Range limited to Okavango and localities in Namibia
Relic forests	require special protection	These relic forests occur in the panhandle and contain an interesting floral composition
Xaga islands baobabs	vandalism	Protection of specimens from vandalism by tourists

7.3.3.4 Invasive Alien Flora

No invasive aquatic plants have been recorded from the Namibian sector of the Okavango River although considerable potential for infestation exists, as boats are often moved from the Kwando-Linyanti system (which has heavy infestations of *Salvinia molesta*) onto the Okavango River.

A number of alien species found along the Okavango River are listed in Hines *et al.* (1985) and Hines (1996b) but the majority of these are not considered invasive. Species known to be invasive are:

Opuntia ficus-indica which has taken over large areas of rocky outcrops in the Andara area. This infestation could be controlled through the release of cochineal bugs.

Ricinus communis is widespread and occurs on disturbed sites all along the river. The seeds are used for the extraction of cosmetic oil by many local people.

Acacia mearnsii is a highly invasive species currently only known from the old military camp at Picapau south of Buffalo. This population should be eradicated before problems arise.

Sidium guajava is currently fairly limited in its distribution along the river, mostly being found near villages and other settlements. It has the potential to be highly invasive along the river.

Xanthium spinosum is a widespread invasive herb with strong burrs. It is known all along the river.

Lantana camara is planted in many gardens along the river, but it is not known whether the form grown here is invasive. A large stand of this species is known from Buffalo Camp.

Euphorbia tirucali is widely used for live-fencing along the length of the river. There is no evidence that this species is invasive in the Okavango Region but it is thought to be potentially so.

Within the catchment in Botswana the following are to be found:

Invasive Aquatic Plants (Salvinia molesta)

Salvinia is a free floating aquatic fern which reproduces vegetatively. It has a growth rate doubling time of from 3-9 days, depending on nutrient and temperature conditions. The plant produces a large number of sessile sporogonia of which most are empty in the Botswana infestations. (Forno, 1983). Little information on spore survival is available.

The most important criterion for growth of salvinia is the availability of still or slow flowing water habitats. Eutrophic conditions are not essential for plant survival, but speed up growth rates.

Within a river system, once salvinia has been introduced, spreading usually occurs due to passive water flow. Spreading by large herbivores also occurs. Kariba weed spreading between river systems is primarily due to human factors such as discarded aquarium plants or inadvertently on boats. Spreading by waterfowl is possible but has not been proven to occur in any recorded infestations.

The Delta is a highly dynamic ecosystem with seasonal and cyclic changes in water regime. One of the main changes in water movements is due to vegetation blocking channels and then rapidly colonising the blockages. Any outbreak of salvinia in the perennial swamp could alter the frequency and location of blockages and hence the regime of any specific channels. This could have indirect implications on the yield of water from specific channel systems through the Delta.

The plant was first collected from the Zambezi River system at Kazungula Island in 1948 (Mitchell, 1967). By 1967 Salvinia was found throughout the Chobe River system from the Zambezi River almost to Lake Liambezi (Mitchell, 1967).

The first confirmed siting of salvinia in the Delta was at Xini Lediba on the 11th of June, 1986. Xini was the nucleus of the infestation with smaller colonies of plants up to two kilometres away, apparently spread by hippo. As the last salvinia was cleared from Xini by the Aquatic Vegetation Control Unit of the DWA, a second outbreak was identified at the south eastern end of Bodumatau in early July 1988. In August the same year a further area of salvinia was found in the Abaqao Lediba, which is just south of Xini and has now spread to the Mogohelo river system south of Abaqao indicates the present distribution of salvinia in the Okavango.

A biological control programme is managed by the Department of Water Affairs. The control agent, a weevil (*Cyrtobagous salviniae*) has been distributed on all known mats of the weed (Smith, 1993; Forno, 1996).

To prevent further introduction of aquatic weeds and the spread of salvinia there has been an enactment of legislation which controls the import and movement of boats in the country. The legislation limits boats to specific zones unless movement permits are obtained (GOB, 1986).

Invasive Exotic Plants (Dryland Species)

A list of undesirable plants was identified for inclusion into the Moremi Game Reserve management plan (KGS, 1991). A similar set of undesirable plants have been banned from the Photographic CHA's of the Okavango Delta (Ecosurv, 1996). The WMA regulations, that have been developed (but not yet gazetted), also contain a list of undesirable plant species. The list of species is indicated in Table 7.3.

Table 7.3 : Undesirable plant species.

Common name	**Scientific name**
Candelabra tree	*Euphorbia ingens*
Rubber tree	*Euphorbia tirucalli*
Bamboo	*Bambus* spp
Tomato	*Lycopersicon esculentum*
Cassava	*Manihot esculenta*
Pumpkin	*Cucurbita* spp.
Pawpaw	*Carica papaya*
Guava	*Psidium guajava*
Banana	*Musa* spp.
Syringa	*Melia azedarach*
Jacaranda	*Jacaranda mimosifolia*
Port Jackson Willow	*Acacia saligna*

7.3.3.5 Conclusions

7.4 Secondary Producers

7.4.1 Introduction/General

7.4.2 Data Available/Assessment

7.4.2.1 General

As with flora, data on the catchment in Angola is almost completely lacking. The references which are known about date back to the a970s and earlier and could not be located in most cases. For this reason, the information on the different studies has been presented by making reference only to the author of the document.

The study "ANGOLA – Avaliação do estado actual do Meio Ambeinte" (*Assessment of the current status of the environment*), by IUCN, October 1992, mentions the cataloguing of Angola's avifauna, carried out by Taylor (1963). Dean et al (1988) mentions the most complete study, that of Pinto (1993). With regard to pisciculture, the IUCN (1992) study refers to the study of Max Pohl on "Os peixes dos abundantes rios de

Angola" (*The fishes of Angola's abundant rivers*). However, the content of these publications was not accessible.

In considering fauna in Sections 7.4.2.2 to 7.4.2.7 specific data for the Angolan catchment has been mentuioned where possible, but deailed analysis concentrates on the catchment within Namibia and Botswana.

Available data on fauna of the Okavango River and Delta region in Botswana include published and unpublished reports and articles on the studies and surveys listed in Annex A: References. Of the data sources listed, 221 have been located in Gaborone, nine in Maun, and the remaining 53 are available from locations in South Africa, Namibia and Zimbabwe. Details for a large number of other known references have been requested. Amongst those are more recent studies and reports on monitoring the impacts and effectiveness of the Tsetse fly control programme (TFC Unit, Maun).

Twenty-two data sources identified in Annex A include computerised data bases, most of which are in a geographical information systems (GIS) format covering the study area. These data bases include information on large wildlife species densities and distribution (Bonifica, 1992; DWNP, 1993, 1995, 1996, 1997; ULG, 1994b, 1994c, 1994d), physical features, landforms, vegetation types, ecological zoning, land use and natural resources availability, archaeological sites and infrastructure, (Ecosurv, 1994, 1996, 1997a, 1997b; DWNP, 1996; WTC/CSIR, 1997).

Many studies on large animal populations have been undertaken by the Department of Wildlife and National Parks (DWNP) while private research (mainly as part of dissertation studies) has played a very important role, particularly in collecting information on large mammals, fish and fisheries. Both research and population censuses have tended to focus on the larger, commercially important or rare and endangered species. Few data have been collected on species of low tourism, hunting or other commercial value in the Okavango Delta region.

7.4.2.2 Amphibians

The amphibian fauna of the Okavango River basin in Namibia is relatively well known and there have been recent reviews by Griffin & Channing (1991), Hines (1996b) and Jacobson (1997)

Research on amphibians of the Okavango Delta region has apparently been limited. Auerbach (1987) provides maps showing reported distributions for amphibians in the study area and a bibliography listing (mainly regional) publications on research. Zoogeography of herpetofauna in Botswana, including amphibians, has been described (Simbotwe and Gillette, 1990). Research on amphibians in the region has been conducted by D.G. Broadley and W.R. Branch among others. Two collecting surveys were carried out by Auerbach (1987). Some amphibian species were collected and identified following aerial spraying of insecticides for tsetse fly control (Graham, 1964; Russel-Smith, 1976; Douthwaite, 1981; Games, 1982a).

Ecology, management and research recommendations for selected amphibian species are discussed by SMEC (1987a) and SMEC/KCS (1989). N.G.H. Jacobsen carried out a short herpetological survey in Botswana as part of the initial environmental evaluation for the feasibility study on the Okavango River to Grootfontein link of the Namibian Eastern National Water Carrier in December 1996 (CSIR&WTC, 1997).

7.4.2.3 Reptiles

The reptile fauna of the Okavango River basin in Namibia is not as well studied as other vertebrate taxonomic groups. Griffin (1985) compiled an atlas of known records of species in the Kavango area but the results of the update have not yet been published. Recent reviews by Hines (1996b) and Jacobson (1997) provide a list of some 80 species of reptiles which are known or are expected to occur in the basin.

Apart from specific studies on the economically important Nile Crocodile, *Crocodylus niloticus* (Blomberg, 1976; Graham, 1976; Medem, 1981; Simbotwe, 1988; Simbotwe and Matlhare, 1988) little research on reptiles has been documented from the study area. Auerbach (1987) has compiled a relevant guide for Botswana, with maps showing reported distributions for reptiles species and an extensive bibliography of mainly regional publications on research. The zoogeography of herpetofauna (Simbotwe and Gillette, 1990) and general herpetology of Botswana (Simbotwe and Spawls, 1987) have been described.

Most research on reptiles in the region has been conducted by D.G. Broadley, W.R. Branch and M.P. Simbotwe, while R.D. Auerbach (1987) has conducted two surveys of the study area. Ecology, management and research recommendations for selected reptile species are discussed by SMEC (1987a) and SMEC/KCS (1989). N.G.H. Jacobsen carried out a short herpetological survey in Botswana as part of the initial environmental evaluation for the feasibility study on the Okavango River to Grootfontein link of the Namibian Eastern National Water Carrier in December 1996 (CSIR&WTC, 1997).

7.4.2.3 Fish (and Fisheries)

Fish have been extensively studied in the Okavango River over many years (Barnard, 1948; Skelton & Merron, 1984, 1985, 1987; van der Waal, 1991; Hocutt & Johnson 1993). These studies have been focused on the biogeography and breeding biology of species in the system, with almost no work having been done on quantifying the value or scale of the exploitation of the fish populations.

A number of surveys have been carried out on the taxonomy, distribution and abundance of fish fauna of the Okavango River and Delta region (Maar and Dibbs, 1965; Jubb and Gaigher, 1971; Bruton, 1980; Merron and Bruton, 1984, 1986c; Minshull, 1985; Skelton, 1985, 1993; Merron, 1993a, 1993b; Bills, 1996).

Studies of the fish fauna ecology and ecosystem functioning have been conducted (Fox, 1976; Merron, 1991), research has been done on fisheries productivity and development (Gilmores, 1976-79), and proposals for the management and development of fisheries resources have been made (Merron and Bruton, 1988; Merron, 1993b; SMEC, 1987a; IUCN, 1993; CSIR/WTC, 1997).

Feasibility study reports for development and expansion of commercial fisheries on the Okavango River and Delta (based mainly on technology employed in east Africa) were prepared by NORPLAN (1985) and NORFICO (1986-87). Monitoring of subsistence and commercial fishing and development efforts of the Fisheries Unit, Ministry of Agriculture were reported annually (MOA, 1987-93), and community-based fisheries and conservation programmes development has been investigated (Merron and Bruton, 1995).

Impacts on Okavango fish populations of aerial and ground spraying of various pesticides to control tsetse fly have been assessed during various studies (Graham, 1964; Russel-Smith, 1976; Gilmore, 1979; Douthwaite, 1981; Games, 1982a; Fox and Mathiessen, 1982; Merron and Bruton, 1986; Merron, 1986-92).

7.4.2.4 Birds

The avifauna of the Okavango River system in Namibia is relatively well known and several recent reviews (Hines, 1987; Brown & Jones, 1994; Hines, 1996; Allen, 1997) provide detailed information on the distribution and presumed abundances of species associated with the river and adjacent upland sites.

Bird distribution and occurrence has been relatively well documented and specific studies and sightings are quite numerous. Borello and Borello (1997) list 387 references to works and articles on the avifauna of the Okavango Delta and River, 212 references for Lake Ngami and 127 references for the Boteti River. Penry (1994) compiled a bird atlas for Botswana, mainly from data collected by the Botswana Bird Club and affiliates, providing quarter-degree square locations for sightings of 453 species within the study area.

Fraser (1971), Herremans (1993-95) and Allen (CSIR/WTC, 1997) compiled some of the larger individual lists of birds during studies of the Okavango River and Delta, Moremi Game Reserve and Lake Ngami. These areas have been included in extensive (low intensity) surveys conducted annually for economically important, rare and endangered species as part of the African waterfowl census (International Waterfowl and Wetlands Research Bureau, 1983-95; Wetlands International, 1996). A waterbirds survey of the Okavango Delta by DWNP staff has recently begun.

Graham (1964) reported avifauna mortalities following blanket spraying of woodlands near Maun with Dieldrex. Milenski and Campbell (1976) studied bird diversity in relation to vegetation types in the Moremi Wildlife Reserve. Habitat and management requirements for locally rare or endangered bird species meriting special consideration are discussed by SMEC (1987a) and SMEC/KCS (1989).

Distribution data and population estimates for ostrich *Struthio camelus* are available from the series of aerial censuses.

7.4.2.5 Mammals

Recent reviews of the mammalian fauna of the Okavango River basin in Namibia (Hines, 1996b; van Aarde & Ferreira, 1997) Griffin & Grobler (1991) provide a review of wetland associated mammals in Namibia

Large Mammals

Wildlife Population Census

There is a fair degree of understanding of the distribution and seasonal movements of large herbivores. Aerial census data collected between 1975 and 1997 provide information on seasonal distribution and crude population estimates and trends for large wild and domestic mammal species (UNDP/FAO, 1977; KCS, 1984-85; DWNP, 1979-1997; SMEC, 1987; Bonifica, 1989-1991; ULG, 1992-1994).

The DWNP Research Unit consider data from aerial surveys conducted prior to 1989 to be either unreliable, or incompatible with recent (1989-1994) data collected in terms of the methodology employed (ULG, 1994a). However, data from some earlier surveys (e.g. UNDP/FAO 1977 and KCS, 1984-85) has been used in assessing general population trends over the past twenty years. Data from 1995 and 1996 aerial surveys are currently being re-analysed and are also considered unreliable in their current form by some DWNP Research Unit staff.

Ecological Surveys

General surveys of wildlife (mainly larger mammals) in the Okavango Delta region include Smithers' survey of mammals (1971), field surveys of the Moremi Wildlife Reserve (Tinley, 1966; Robbel and Child, 1976) and of Chief's Island (Biggs, 1979), ecological surveys carried out during the UNDP/FAO Investigation of the Okavango Delta (1977), the Southern Okavango Integrated Water Development Project (SMEC, 1986-88) and the Okavango Delta ecological zoning exercise (SMEC/KCS, 1989). A study of the ecology and functioning of perennial and seasonal floodplains at Naraga is being co-ordinated by the Okavango Research Centre in Maun.

Specific Studies

Detailed work on the ecology of individual species has been limited mainly to large mammals. Studies include those on impala (Robbel and Child, 1970), buffalo (Raseroka, 1978; Patterson, 1979), lechwe (Lent 1969; Biggs, 1979), tsessebe (Child, 1972), sitatunga (Games, 1983; Ross, 1991), wildebeest (Williamson, 1985), baboons and wild dogs (University of California, various researchers 1976-1993, and McNutt, 1993-present), zebra and wildebeest (Joos-Vanderwalle, 1993) and lions (on-going). University of Botswana students from the Departments of Biological and Environmental Science are currently conducting studies on grazing trials and behaviour of lechwe, impala and warthog as part of the floodplain ecology study co-ordinated by the Okavango Research Centre.

Elephants have received considerable attention, as their increasing numbers and expanding range in northern Botswana is perceived as a management problem and a threat to biodiversity. Elephant research has focused mainly on the interactions with vegetation in riverine habitats and over the entire range. Although most elephant research has been carried out in Chobe District, a growing number of studies have included the Okavango Delta (Moroka, 1984; Melton, 1980-1984; Work & Owen-Smith, 1986; Calef, 1985-88; Ben-Shahar, 1991 and Torr, 1996). Elephant-vegetation interactions are currently being studied at Savuti (Barnes, in progress).

Environmental Impact Assessments

Impacts on wildlife (with emphasis on larger mammals) have been assessed under the UNDP/FAO Investigation of the Okavango Delta (1977), the Southern Okavango Integrated Water Development Project (SOIWDP, SMEC, 1986-88), the SOIWDP review (IUCN, 1993), the adaptive environmental (modelling) assessment of the Okavango Delta (Wildlife Conservation International, *et. al.*) and the feasibility study on the Okavango River to Grootfontein link of the eastern national water carrier in Namibia (WTC/CSIR, 1997).

Planning Studies and Management Plans

Management and tourism development plans, including proposals for the management of wildlife resources, have been prepared for the Moremi Game Reserve by Anderson (1985), Kalahari Game Services (1991) and DWNP/PADUN (1996). The latest plan, which built upon and updated previous plans, provides for various forms of wildlife and natural resources protection and use by tourists in designated zones within the game reserve.

A study was carried out to identify potential wildlife utilisation pilot projects involving Okavango Delta communities, among others (Cumming and Taylor, 1989). A programme for the planning of resource utilisation in the Okavango Delta region was prepared by Swedeplan (1989), and a land use plan for the Okavango and Kwando Wildlife Management Areas (WMA's) was prepared and approved by the Ngamiland District Land Use Planning Unit (1991). The land use plan resulted in zoning of Controlled Hunting Areas (CHA's) within the WMA's for various forms of wildlife-based tourism. Management and tourism development plans have subsequently been prepared for these CHA's (Ecosurv 1996, OCC, 1995 and various private sector safari operators).

Hunting licensing statistics for Ngamiland District have been collated and computerised by DWNP since 1985.

Small Mammals

Few studies on small mammals have been conducted in the study area. General taxonomy, ecology, behaviour and regional distribution data for large and small mammals of the southern African sub-region are provided by Smithers and Skinner (1990), while DeGraaf (1981) gives more detail on the rodent species. Small mammals were collected as part of a survey of impacts of Dieldrex spraying against tsetse fly by Graham (1964). Limited live trapping of small mammals (mainly rodents and shrews) was carried out as part of the field studies of SMEC (1987a) and CSIR/WTC (1997).

7.4.2.6 Invertebrates

Terrestrial Invertebrates

Research on terrestrial invertebrates in the Okavango Delta region has concentrated mainly on the Tsetse fly *Glossina morsitans centralis* Machado. The ecology of the tsetse fly, local history of sleeping sickness and fly control programmes and effects of control on fly population using various insecticides have been reported (Lambrecht, 1968; Davies, 1981; Davies and Bowles, 1976, 1979).

The effects of insecticides spraying on non-target arthropods (Ali (1976, 1977; Davies, 1980; Games, 1981) and some other terrestrial invertebrate orders (Douthwaite, 1981) have been documented. Other studies on arthropods include collecting surveys for butterflies and dragonflies (Pinhey, 1967-76; Silsby, 1991), monitoring of weevils (*Cyrtobagous singularis*) in the control of *Salvinia molesta* (Procter, 1983) and a survey of tick infestations on African buffalo (Carmichael, 1976). The Crop Protection Unit (MoA) have produced unpublished reports on locust outbreaks and control efforts in the region (MoA, 1978-92).

Research is currently being conducted on *Macrotermes* and *Hodotermes* spp. termite ecology, their role in nutrient cycling and ecosystem functioning in the Moremi Game Reserve (G. Schuurman, in press).

Aquatic Invertebrates

Some sampling of aquatic invertebrates was carried out under the first Okavango Hydrobiological Project (Reavell *et. al*, 1973, 1974). Limnological observations in the upper Okavango Delta at low water levels also involved sampling (Hart, 1986) and later hydrobiological research resulted in more detailed sampling of the Okavango river and upper Delta (Cronberg, 1995). IUCN (1993) carried out extensive sampling on the lower Boro, Thamalakane and Boteti Rivers, and channels and lagoons between Sepupa and Jedibe in 1992, collecting 93 aquatic invertebrate species. Freshwater snails of east Caprivi and the lower Okavango River basin in Namibia and Botswana have been described by Brown, *et. al.* (1992). Research on plankton has recently been initiated as part of the floodplain ecology study co-ordinated by the Okavango Research Centre.

A limited number of aquatic invertebrate species were also collected in the process of sampling non-target aquatic species affected by aerial spraying of insecticides for tsetse fly control (Russel-Smith, 1976; Douthwaite, 1981).

7.4.3 Analysis

7.4.3.1 Amphibians

These reviews indicate that 25 amphibian species are known or are expected to occur within the Namibian section of the basin. Of these, 13 species are largely dependant on riverine habitats, and it is the integrity of these habitats which determines the presence and abundance of these species. Most habitats are extensively degraded, with the exception of the areas within the Mahango Game Reserve. The overall result of this is a markedly impoverished amphibian fauna outside of protected areas. There are however, no Red Data species listed for the study area (Griffin, 1994).

Bullfrogs *Pixicephalus adspersus* are eaten in large numbers by local people, but are not considered threatened. This species is widespread, is a prolific breeder and is not confined to perennial water systems.

Recent reviews by Hines (1996b) and Jacobson (1997) provide a list of some 80 species of reptiles which are known or are expected to occur in the basin. A number (12) of species of reptiles are either entirely dependant on or are most frequently associated with riverine habitats. As with the amphibian fauna, extensive habitat degradation and persecution has lead to an impoverished reptile fauna outside of conservation areas. Several species of tortoise, python and varanid (leguaan) contribute significantly to the protein diet of the rural communities in the basin, and these animals are becoming increasingly rare outside protected areas.

A total of 28 amphibians that have been recorded or are expected to occur in the Okavango Delta, with comments on localities of occurrence (after SMEC/KCS, 1989). Twelve amphibian species restricted in distribution to the Okavango River and Delta and Chobe River systems in Botswana (after CSIR/WTC, 1997).

Five species of frogs are known only from the Okavango River and upper Delta within Botswana, but also occur elsewhere. The yellow swamp toad (*Bufo lemairii*) has been collected at Shakawe and Xugana Lediba. These are the only records for southern Africa south of the Cunene/Zambezi catchments. Collection of the yellow-bellied grass frog (*Ptychadena guibei*) from Gumare, Bocage's reed frog (*Hyperolius benguellensis*) from the Xo Flats, and the pygmy puddle frog (*Phrynobatrachus parvulus*) from the Khwai river are the only records for each species from Botswana. Of these *Bufo lemairii* and *Hyperolius benguellensis* are likely to be important as they represent southward extensions of predominantly tropical species (SMEC/KCS, 1989).

The bullfrogs (*Pyxicephalus adspersus* and *P. edulis*) are collected and eaten by some residents. The current status of amphibian populations is not known. As 'indicator species', amphibian populations tend to react quickly to environmental changes and water pollution. Though some specimens have been collected in a limited number of surveys (Russel-Smith, 1976; Douthwaite, 1981), very little data have been collected on the impacts of large-scale insecticide spraying programmes on amphibians.

7.4.3.2 Reptiles

80 species of reptiles which are known or are expected to occur in the basin. A number (12) of species of reptiles are either entirely dependant on or are most frequently associated with riverine habitats. As with the amphibian fauna, extensive habitat degradation and persecution has lead to an impoverished reptile fauna outside of conservation areas. Several species of tortoise, python and varanid (leguaan) lizards (all listed as vulnerable by Griffin 1994, see Table xx) contribute significantly to the protein diet of the rural communities in the basin, and these animals are becoming increasingly rare outside protected areas.

Table 7.4 : Reptile Red Data Species in the Okavango River basin in Namibia. Status from Griffin (1994).

STATUS	SPECIES	
Vulnerable	Leopard Tortoise	*Geochelone pardalis*
	Hinged Tortoise	*Kinixys spekii*
	Serrated Tortoise	*Psammobates oculifer*
	Bushveld Monitor	*Varanus exanthematicus*
	Water Monitor	*Varanus niloticus*
	African Python	*Python sebae*

Although protected by law, Crocodiles are heavily persecuted outside protected areas and breeding for this species is now largely restricted to the Mahango Game Reserve and perhaps some of the sand deposits on islands between Mukwe and Andara. No egg collections are made in the Namibian section of the basin, but between 3000-4000 eggs are collected annually in the panhandle of the Okavango Delta in Botswana. This species represents considerable economic potential as a commercial enterprise.

67 reptile species of the Okavango Delta are described, with comments on localities of occurrence (after SMEC/KCS, 1989). A total of 64 reptiles that have been recorded or are expected to occur in the Okavango Delta region, together with their habitat requirements (from CSIR/WTC, 1997). Table 3 lists ten reptile species restricted in distribution to the Okavango River and Delta and Chobe River systems in Botswana.

Twelve reptile species, including four terrapins, the Nile monitor, python and five water snakes may be considered aquatic or near aquatic. The largest, and most important of these species in economic terms, is the Nile Crocodile (*Crocodylus niloticus*).

Commercial hunting between 1957 and 1974 decimated the crocodile population of the Okavango Delta (Blomberg, 1976). As the population recovered under protection, predation on livestock (and occasional attacks on people) increased around settlements in the Panhandle, where almost all nesting occurs. Exploitation resumed in 1983 when eggs, hatchlings, sub-adults and adults for breeding were first collected from the wild for stocking of two crocodile farms. Having captured their initial stocks, these farms were meant to breed, rear and sell their own crocodiles.

Population estimates of about 5 000 crocodiles in the Panhandle and 1 600 in the rest of the Delta in 1987 (Simbotwe, 1988b) are based on few survey data. Survival rates and sex ratios are poorly known. Aerial surveys indicated that there are about 100 nests which might be expected to yield 5 600 eggs if all nests are found on ground searches (Simbotwe, 1988a). Quotas for egg collection by farmers have been set on demand, with 3 300 eggs taken in 1995 and 4 200 collected during 1996 (CSIR/WTC, 1997). This level of off-take represents 60-75% of the estimated maximum annual reproduction, and could have significant impacts on crocodile populations if significant numbers of sub-adults are not being returned to the wild. It also indicates that crocodile farms are not sustainable, since they are still removing huge numbers of eggs from wild populations to rear and sell on as 'farmed' crocodiles 14 years after they were established. The Nile crocodile was listed as 'vulnerable' on the world level and 'rare' in Botswana (WCMC, 1991).

The Nile Monitor (*Varanus niloticus*) is also reported to be an important predator on crocodile eggs in the Panhandle (Blomberg, 1976). Monitors, tortoises, terrapins, pythons, crocodiles and their eggs are eaten by some local residents. The current status of these and other reptile species populations is unknown. There is concern that tortoises may be over-exploited, especially where they are collected for use in producing handicrafts.

Based on the very limited information available, no reptile species are yet known to be restricted only to the study area, and none is listed as endangered at present.

7.4.3.3 Fish (and Fisheries)

Eighty three species have been identified within the Okavango system, 71 of which occur in Namibian waters. A comprehensive list is given in Rall (1997). Cichlids (bream species) comprise about 50 % of the species recorded in the system (Tvedten *et al.,* 1994). Fish populations have been broadly divided into three components: resident species, present throughout the year, longitudinal migrant species which move downstream from Angola which return as the floods recede, and, lateral species which inhabit isolated bays and small streams and backwaters on the floodplain (Skelton & Merron, 1985).

In general terms, fish populations are declining in the Namibia sector of the Okavango River. Using an *index of biotic integrity,* Hay *et al.* (1996) were able to show that the system as a whole is deteriorating. The main changes indicated were dwindling fish stocks as a result of high fishing pressures and habitat destruction. Siltation as a result of erosion has also been cited as further exacerbating factor in population declines (Bethune, 1991; van der Waal, 1991). This perception of declines is confirmed through interviews with local people reported in Tvedten *et al.*(1994). The importance of the local fisheries in the subsistence economy of the region is discussed under Fisheries below.

Only one Red Data species has been identified in Namibia (Holtzhausen, 1991). The Broad-headed Catfish *Clariallabes platyprosopos* is only known from the rocky areas around Popa Falls and the Mukwe-Andara area. It has a limited distribution in the Okavango and Zambezi River systems.

Eighty-three fish species have been identified from the Okavango River and Delta in Botswana. Five species are listed as rare (Skelton, 1987). Populations have been broadly divided into resident species, longitudinal migrants which move downstream with floods and return with receding waters, and lateral species inhabiting isolated bays and back waters on the floodplains. There are rarely more than 15-20 species common to any one community, and three or four species often comprise the largest proportion of fish biomass within a community (Skelton, *et. al.*, 1985).

Fish population ecology and reproductive biology have been fairly well studied in the Okavango Delta (Skelton, *et. al.*, 1985; Merron and Bruton, 1988; Merron, 1991, 1993b). Very few data are available on the status of fish populations and their habitat requirements in the Okavango Delta. Harvesting rates and impacts on fish populations have received little attention. During normal to high flood level regimes prevailing when much of the initial research was being conducted, over-harvesting was not perceived as a potential problem. There is now concern that Okavango Delta fish populations may be declining due to fishing pressure under current conditions. An estimated 2 000 - 4 000 residents of the Delta and neighbouring villages were fishing for home consumption and about 750 fished commercially in 1987 (Skjonsberg and Merafe). Merron (1991) estimated subsistence yields at about 1 000 tonnes, commercial fisheries yields at 1 200 tonnes and the recreational harvest at about 800 tonnes, for a total of 3 000 tonnes per annum.

Annual inundation of extensive shallow floodplains results in a nutrient pulse into the aquatic system from detritus, animal dung and vegetation, etc. This is probably the most important factor influencing fish productivity in the Okavango Delta (Merron and Bruton, 1988). Drought and low flood levels during the past decade must have adversely affected fish stock production as the extent of shallow feeding, breeding and nesting areas has been reduced for extended periods.

Use of insecticides in controlling tsetse fly has also had negative impacts on Okavango fish populations. Endosulfan and Deltamethrin were found to be highly toxic to fish species at all concentration levels, and misapplications have resulted in substantial fish kills being documented (Douthwaite, 1981; Merron, 1986).

Another threat to fish populations is that posed by introduced or exotic aquatic plants. Spreading mats of *Salvinia molesta* reduce photosynthesis by algae and submerged macrophytes, lowering productivity (Merron, 1993). Few data are being collected on the impacts of these processes.

Reductions or major changes in the structure of fish populations will also have impacts on populations of fish predators. The largest and most significant of these in the Okavango Delta is the Nile Crocodile (*Crocodylus niloticus*).

7.4.3.4 Birds

A total of 430 species has been recorded along the river and adjacent woodlands representing some 68 % of the birds recorded in Namibia, making the region the most diverse in terms of birds in the country. However, extensive degradation and alteration of riverine habitats, particularly the loss of riparian forests, has reduced the ranges of many of the species to relatively well protected sites between Mukwe and Muhembo. This includes species such as Pel's Fishing Owl and African Fish Eagle.

Ninety-four species occurring in the region are listed by Brown (1993) as Red Data Species. The majority of these species (54) are not discussed here as they are designated as *Amber* [species requiring regular monitoring because of low numbers, restricted distributions, specialised requirements or because insufficient information is currently available to class them in another higher category]. Of the 25 species designated *Rare*, the majority could be considered peripheral (Table xx) and not seriously threatened by activities along the Okavango River in Namibia. The remaining rare species are all water dependant or dependant on riverine habitats for breeding and have highly restricted ranges within Namibia as a result of the general habitat degradation along the length of the Okavango River.

Ten species are regarded as vulnerable of which both species of pelicans, Black Stork, the two species of flamingo and Black Sparrowhawk can be viewed as marginal species with their major strongholds elsewhere in the sub-region. White-headed Vulture, Bateleur and Ground Hornbill are species of woodland habitats and not specifically associated with the river, although Ground Hornbill may breed in large trees on the riparian fringe, and thus may be affected through loss of breeding habitat. African Goshawk is strictly associated with the riparian fringe forests and has undergone marked declines in numbers because of habitat loss. The Okavango basin as a whole is the global stronghold of Slaty Egret. However, only relatively small numbers occur in the upper Delta and the Namibian sector of the river, because of a lack of suitable habitat. Even so, this species should be considered as of the highest conservation concern in Namibia.

Of the seven species considered *Endangered*, the Cape Vulture can be considered marginal or vagrant and is not of concern here. The remaining species are all associated with wetlands or riverine habitats and have undergone considerable reductions in range and numbers in recent years, as a result of the widespread damage to and loss of riverine habitats. Most of these species are now restricted to the short stretch of river between the Mukwe-Andara islands and the southern boundary of the Mahango Game Reserve at Muhembo. The continued occurrence of these species (and Slaty Egret) in the Namibian sector of the river is entirely dependant on the adequate conservation of the limited remaining habitat.

Table 7.5 : Bird Red Data Species in the Okavango River basin in Namibia (Status from Brown (1993).

STATUS	SPECIES
Rare (peripheral)	Marabou Stork, Sacred Ibis, Glossy Ibis, Hadeda Ibis, Hooded Vulture, Cuckoo Hawk, Tawny Eagle, Ayre's Hawk Eagle, Martial Eagle, Black-bellied Korhaan, Grey-headed Gull, Cape Parrot, Narina Trogon, Pygmy Kingfisher, Arnot's Chat, Natal Robin, Coppery Sunbird, Purple-banded Sunbird
Rare	Bittern, African Fish Eagle, African Marsh Harrier, Red-winged Pratincole, Wood Owl, Greater Swamp Warbler, Yellow-billed Oxpecker
Vulnerable	White Pelican, Pink-backed Pelican, Black Stork, Greater Flamingo, Lesser Flamingo, Slaty Egret, Black Sparrowhawk, White-headed Vulture, Bateleur, African Goshawk, Ground Hornbill
Endangered	Saddle-billed Stork, Cape Vulture, White-backed Night Heron, Western Banded Snake-Eagle, Wattled Crane, African Skimmer, Pel's Fishing Owl.

A list of the 280 bird species recorded during the CSIR/WTC survey of the Okavango in Namibia and Botswana (after CSIR and Water Transfer Consultants, 1997).

Penry (1994) lists 453 species recorded within the 34 quarter-degree squares including the Okavango River and Delta region, making it the richest mosaic of habitats for avifauna biodiversity in the country (496 species are verified and 59 others may occur in Botswana). Penry (SMEC, 1985) lists 45 species from the Okavango Delta region which are classified as 'threatened' or 'vulnerable' in southern Africa. About half of them are dependent on wetland or tropical habitats. The Okavango system represents a southern intrusion of wetland and tropical habitats into the Kalahari, extending the range of many species and supporting a large number of resident and migratory species.

Birds considered important in a local, regional or international context, based on their very limited distribution and breeding localities, or conservation status include the Pink-backed pelican (*Pelecanus rufescens*), Marabou stork (*Leptoptilus crumeniferus*), Yellow billed stork (*Mycteria ibis*), Open bill stork (*Anastomus lamelligerus*), Saddlebill stork (*Ephippiorhynchus senegalensis*), Rufous bellied heron (*Butorides rufiventris*), White backed night heron (*Gorsachius leuconotos*), Pygmy goose (*Nettapus auritus*), Western banded snake eagle (*Circaetus cinerascens*), Pel's fishing owl (*Scotopelia peli*), Blue quail (*Coturnix adansonii*), Wattled crane (*Grus carunculatus*), Ross's lourie (*Musophaga rossae*), Narina trogon (*Apaloderma narina*), African skimmer (*Rynchops flavirostris*) and Carmine bee-eater (*Merops nubicoides*).

The Slaty egret (*Egretta vinaceiqula*) deserves special mention as the rarest heron in the world with its range limited to the Okavango Delta, Linyanti-Chobe system and Lake Bangweulu in Zambia. It has only been recorded breeding in the Okavango Delta. Very little is known of its ecology or the details of its habitat requirements.

Among bird species which are of economic importance as potential pests of small grain crops are red-billed quelea (*Quelea quelea*), cape turtle dove (*Streptopelia capicola*) and the spurwing goose (*Plectropterus gambensis*).

7.4.3.5 Mammals

116 mammal species have been recorded or are expected to occur in the area. This represents about 57 % of Namibia's terrestrial mammal species. However, the extensive alteration of the riverine strip, especially floodplain and riverine fringe forest habitats has led to the majority of these species being restricted to areas afforded some degree of protection in conservation areas or on isolated islands. Much of the reduction in range and numbers (particularly of large mammals) has taken place in the last 25 years. Long-time residents of Rundu still recall species such as Elephant, Impala and Greater Kudu being abundant within 30 km of Rundu in the early 1970's. Large mammal populations are now restricted to the Mahango Game Reserve area.

Griffin & Grobler (1991) provide a review of wetland associated mammals in Namibia and 31 of the 38 species identified by them occur within the Okavango System. Only one species, Shortridge's Mouse *Mastomys shortridgeii*, is found only in this part of Namibia. It is, however, also known from Botswana, Zambia and Angola. None of the species occurring along the Okavango River are endemic to Namibia (Griffin 1996).

A number of Red Data Species occur within the Okavango River basin in Namibia and these are given in Table 7.6. The majority of these do not occur in any significant numbers outside the small conservation area of the Mahango Game Reserve, the Buffalo area of the West Caprivi Game Park and the islands and woodlands in the Andara-Mukwe area.

Rodent populations in the areas fringing the river can cause significant losses in stored grain crops and are also agents for the dispersal of plague, which although rare, occurs from time to time in the Okavango Region. The majority of these mice are thought to be of the genus *Mastomys*, the multimammate mice. These mice are well known for their eruptive populations following good rain seasons. There are no systematic control mechanisms in place to eradicate plagues of these mice, except at the local village level.

Other problem animals include crop-raiding elephants and occasional stock-raiding lions, in the Divundu-Muhembo area. These animals take refuge in the Mahango Game Reserve by day and leave the park at night. This has resulted in considerable tension between park authorities and the local population resident immediately outside the park.

Table 7.6 : Mammal Red Data Species in the Okavango River basin in Namibia

STATUS	SPECIES
Vulnerable	Aardwolf, African Wildcat, Bateared Fox, Brown Hyaena, Cape Clawless Otter, Cheetah, Chobe Bushbuck, Elephant, Giraffe, Hippopotamus, Lesser Bushbaby, Lion, Red Lechwe, Reedbuck, Roan Antelope, Sable Antelope, Sitatunga, Spotted Hyaena, Tsessebe.
Indeterminate	Serval, Large-spotted Genet, Water Mongoose
Indeterminate (Endangered)	Spotted-neck Otter
Indeterminate (Rare)	Civet, Selous' Mongoose, Striped Weasel
Endangered	Wild Dog
Extinct	Black Rhinoceros, Waterbuck, White Rhinoceros

Large Mammals

Thirty-three large mammal species known to occur in the Okavango Delta region are listed in Annex A, Table 1. Conservation status (IUCN) and Trade Schedules (CITES) listings have been included.

Large mammals potentially occurring in the Okavango Delta are also listed in the NCR report. Water requirements for each species and sections of the Delta from which they have been recorded are included (after CSIR and Water Transfer Consultants, 1997).

The NCR report 3 lists numbers of mammals counted as part of a survey conducted by DWNP over the Okavango Delta during 1992, and Table 4 provides density estimates for large mammals based on surveys conducted during 1992, 1994 and 1996 by DWNP (both after CSIR and Water Transfer Consultants, 1997).

With the notable exception of elephant, declines in populations of most large mammals have been reported during the past twenty years.

Analysis of the most recent reliable aerial census data for the Okavango Delta region (DWNP & ULG, 1989-1994) indicates the following shorter-term trends for selected large mammal populations:

African Elephant *Loxodonta africana*
The elephant population of northern Botswana has increased significantly over the past several decades, and by nearly 10% per annum since 1989. In addition to high reproduction and low mortality, this rate of increase indicates recruitment from Caprivi and Zimbabwe, and aerial surveys in those areas support this case. The 1993 population estimate was over 79 000 with an increasing proportion occupying the Okavango Delta region. There is concern that the increase in elephants may be at the expense of other species as indicated by the changing ratio of elephant biomass to that of all other large mammals. It appears that the increasing elephant population could be having an impact on biodiversity. There is also a growing fear of epidemic disease sweeping through the elephant population at this density. There is a nominal hunting quota of 61 elephant for all the community-managed CHA's in Ngamiland during the 1997 season.

African Buffalo *Syncerus caffer*
The buffalo population of Ngamiland comprises about 90% of the national herd. Though annual estimates have varied considerably due to the difficulty in counting the species in clumped herds, the population may have declined by almost 19% per annum between 1987 and 1994. Hunting quotas for 1997 are less than 10% of 1984 off-take levels, but reducing quotas had no impact on the rate of decline. Despite improved law enforcement efforts by DWNP and the BDF, poaching may still be a factor, as buffalo meat is highly prized. The Okavango Delta buffalo population was last estimated at between 12 000 and 15 000.

Burchell's Zebra *Equus burchelli*
Overall zebra populations are currently declining by about 4% per annum, though the Okavango sub-population appears to be recovering following large die-offs during the 1980s drought (current estimate is about 20 000). The Makgadikgadi - Nxai Pans population, which relied on the Boteti River during dry seasons, was the hardest hit by drought and still seems to be declining. Hunting quotas for 1997 are about 4% of the legal off-take in 1984.

Blue Wildebeest *Connochaetes taurinus*
The Ngamiland wildebeest population, which is concentrated in the Okavango Delta and Moremi Game Reserve, seems to have increased significantly since 1989. The total hunting quota for Okavango and Kwando CHA's during 1997 is 107 wildebeest.

The overall national wildebeest population continues to decline. Both the Makgadikgadi-Nxai Pans wildebeest, and the Kalahari wildebeest and hartebeest populations were decimated by the 1980s drought when access to surface water (including traditional sources on the Boteti River and at Lake Ngami) was restricted by veterinary cordon fences, or supplies were diverted and finally dried up. Neither wildebeest nor hartebeest appears to be recovering outside protected areas in the south-western system.

Other Ungulates
Roan and sable antelope, sitatunga and eland populations have declined significantly, while waterbuck, tsessebe and hippopotamus also appear to be declining at slower rates. This is contrasted with a marked increase in lechwe populations in the Okavango Delta (about 14% between 1987 and 1993). Other large mammal species populations appear to be stable or increasing slightly (which is also possibly an artefact of better survey methodology).

Large Predators

Aerial census data on large predators are very inaccurate. With the exception of wild dog, systematic species-specific surveys have not been conducted in the Okavango region. Reductions in many prey populations and the few age structure data available from safari hunting records suggest that lion populations (and to a lesser extent, leopard) are declining. Leopard, cheetah and brown hyaena are listed as 'vulnerable' by IUCN. The wild dog is an endangered species whose numbers have been greatly reduced through habitat displacement and livestock predation control. [McNutt's data]

Small Mammals

Ninety-eight small mammal species known to occur in the Okavango Delta region are listed in Annex A, Table 1. Conservation status (IUCN) and Trade Schedules (CITES) listings have been included. Table 2 also includes small mammals potentially occurring in the Okavango Delta (after CSIR and Water Transfer Consultants, 1997).

The majority of small mammals is represented by the three orders Carnivora (24 spp.), Rodentia (32 spp.) and Chiroptera (28 spp.). While the general distribution of small mammals has been recorded, their status in the Okavango Delta region is not known.

7.4.3.6 Invertebrates

Terrestrial Invertebrates

Apart from the tsetse fly (*Glossina morsitans*), the butterflies and dragonflies (Pinhey and Balinsky, 1967-76; Silsby, 1991), the introduced weevil (*Cyrtobagous singularis*) and termites, little is known of the status of most terrestrial invertebrate populations of the study area.

The tsetse fly has long affected the ecology and economy of the Okavango Delta, preventing permanent settlement and the keeping of domestic livestock throughout much of the region. Expensive long-term eradication programmes failed and the tsetse fly is currently re-invading many areas.

Other insects of economic importance as predators of cultivated crops are the red locust (*Nomadacris septemfasciata*) and African migratory locust (*Locusta migratoria migratorioides*), the American bollworm (*Heliothis armigera*), Spotted stalkborer (*Chilo partellus*), Army Worm (*Spodoptera* spp.) and Sorghum midge (*Continaria sorghicola*).

Insects which are locally important as a human protein supplement include the mophane worm (*Imbrasia belina* larva) and termite allates (mainly *Macrotermes* and *Hodotermes* spp.).

Termites are also very important for their major role in the ecology of savanna ecosystems. Their huge populations are involved in energy and nutrient circulation, have important effects on the functioning of the Delta, and provide or modify habitats for a large number of other species. Research is currently being conducted on *Macrotermes* and *Hodotermes* spp. termite ecology in the Moremi Game Reserve (G. Schuurman)

Dragonflies and butterflies are better known for the study area than other groups of invertebrates of similar numbers. According to Pinhey (1967-1976), 114 species of dragonflies are thought to occur in Botswana of which 84 are to be found in the Okavango Delta region. There are 29 species of damselflies (Zygoptera) from five families and 55 species of Anisoptera from four families, giving rise to the statement that the Delta is "one of the richest and most interesting Odonata ecosystems in southern Africa" (Pinhey, 1976b). Pinhey has also compiled a checklist of 123 species of butterflies (9 families) from the Okavango Delta.

Non-target arthropod specimens were collected, but not all were identified beyond sub-order, following aerial spraying of insecticides to control tsetse fly (Ali, 1976, 1977; Davies, 1980; Douthwaite, *et. al.*, 1981; Games, 1981, 1982a).

3.1.7 Aquatic Invertebrates

93 aquatic invertebrates were collected and catalogued during sampling of the Lower Boro, Thamalakane and Boteti Rivers and channels and lagoons between Sepupa and Jedibe (after IUCN, 1993). Table 2 lists 25 species of freshwater molluscs collected from the Okavango River in Namibia and Okavango River and Delta in Botswana (after CSIR/WTC, 1997).

No detailed systematic surveys of the aquatic invertebrate fauna of the Okavango Delta region appear to have been undertaken. SMEC (1987a) recorded eight snails during a brief investigation of the snail hosts of schistosomes.

IUCN (1993) carried out more extensive sampling on the lower Boro, Thamalakane and Boteti Rivers, and channels and lagoons between Sepupa and Jedibe in 1992, collecting 93 aquatic invertebrate species. Freshwater snails of east Caprivi and the lower Okavango River basin in Namibia and Botswana have been described by Brown, *et. al.* (1992).

More recent surveys of the Okavango River in Namibia and Okavango River and Delta in Botswana yielded 15 snails, one limpet and seven bivalve species. Four snail species collected are of medical (bilharzia host) or veterinary (liver fluke host) importance. One bivalve (*Ceratophallus natalensis*) was collected for the first time from the Okavango River during this survey (CSIR/WTC, 1997).

A limited number of aquatic invertebrates were also collected (but not classified in detail) in the process of sampling non-target aquatic species affected by aerial spraying of insecticides for tsetse fly control (Russel-Smith, 1976; Douthwaite, 1981).

7.5 Fauna and their Habitats

7.5.1 Introduction

Once again, the relationship between fauna and their habitats has not been studided in recent times within Angola, although it would be useful to obtain copies of any old studies since they would provide information on how the situation could be once normality returns to the catchment within Angola. At present, the habitats of the basin within Angola have been left much to themselves with the exception of the fact that much of the edible fauna has been killed or chase away from centres of population or areas of human activity (roads etc).

Within Namibia population pressures within and along the margins of the flood plains have transformed these habitats, and according to local inhabitants game is almost totally absent. It is not clear whether it has been destroyed or chased away to other areas, including perhaps the Mohango Game Reserve. Even hippopotamus and crocodiles, also dependent to some extent on the riverine vegetation are apparently ever scarcer.

Along with generally lower flood regimes, flow changes in the Okavango Delta have resulted in drier conditions in the south-east (the Santantadibe and Gomoti River floodplains are receding), while relatively wetter conditions prevail in the northeast. Blockage of the Nqoga River (considered the most important distributary in the Okavango) is causing increased flow into the Khiandiandavu River and beyond into the Maunachira and Khwai Rivers. The Khwai River channel has higher water levels further to the east now with more sedge communities being established along the Mochaba River and generally higher wildlife densities. The Tsam Tsam molapo has also been developing as a northern arm of the perennial swamp for the past 15 years. This has resulted in the formation of a large dryland area south of the old Nqoga channel at the top of Chief's Island. These hydrological changes have influenced the dry season distribution of all water-dependent species.

In the following sections the relationships between fauna and habitat are discussed in some depth since an understanding of these relationships is fundemental to an undrstanding of how man’s activities, as well as existing and future developments may affect habitats and all that are dependent on them.

7.5.2 Mammals

7.5.2.1 Large Mammals

Most large mammal species are highly mobile and therefore may occur in more than one ecological zone, often being found in a variety of habitats. All species display preferences for certain habitat types. The major habitat types in the Okavango Delta region are summarised and the different habitat types used by large mammals are indicated in Table 1 (after SMEC/KCS, 1989). Table 2 shows numbers of large herbivores per km^2 by habitat and season in the southern Okavango Delta (After SMEC,1987).

Perennially Inundated Areas

1. Madiba (lakes)
2. River channels
3. Perennial swamp

Seasonally Inundated Areas

4. Seasonal long grass/sedge floodplains (wet and dry)
5. Seasonal short grass floodplains (wet and dry)

Intermittently Flooded Areas

6. Occasionally inundated grassland

Dryland Associations

7. Riverine Woodland
8. Island grassland
9. Scrub communities
10. Mixed woodland / savanna
11. Mophane woodland / savanna

12. Terminalia woodland / savanna
13 Pans (wet and dry)

Table 7.7: Use of different habitat types of the Okavango Delta by large mammals (after SMEC/KCS, 1989)

Species	1. HABITAT TYPE 1	2	3	4	5	6	7	8	9	10	11	12	13
Baboon				X	X	X	X	X	X	X	X	X	X
Brown Hyaena									X	X	X	X	X
Spotted Hyaena				X	X	X	X	X	X	X	X	X	X
Cheetah				X	X	X		X	X	X	X	X	X
Leopard				X	X	X	X	X	X	X	X	X	X
Lion				X	X	X	X	X	X	X	X	X	X
Wild Dog				X	X	X		X	X	X	X	X	X
Antbear					X	X	X	X	X	X	X	X	
Elephant		X	X	X	X	X	X	X	X	X	X	X	X
Zebra				X	X	X		X	X	X	X	X	X
Warthog				X	X	X		X	X	X	X	X	X
Hippo	X	X	X	X	X	X		X					X
Giraffe							X		X	X	X	X	X
Duiker								X	X	X	X	X	
Oribi				X	X	X							
Steenbok						X		X	X	X	X	X	
Kudu				X	X	X	X	X	X	X	X	X	X
Sitatunga		X	X			X	X						
Bushbuck						X	X	X	X				
Impala				X	X	X	X	X	X	X	X	X	X
Reedbuck				X	X	X							
Waterbuck				X	X	X	X	X					
Lechwe			X	X	X	X							X
Gemsbok									X	X		X	X
Sable					X	X		X	X	X	X	X	X
Roan					X	X	X	X	X	X	X	X	X
Eland									X	X	X	X	X
Buffalo	X	X	X	X	X	X	X	X	X	X	X	X	X
Wildebeest				X	X	X		X	X	X	X	X	X
Hartebeest										X		X	
Tsessebe				X	X	X	X	X	X	X	X	X	X

Table 7.8: Number of large herbivores per km^2 in different habitats and seasons in the southern Okavango Delta (After SMEC,1987).

Survey	Floodplain			Island		Land
	Permanent Swamp	Sedgeland	Grassland	Fringe	Wooded Grassland	Grassland
April	0.12	17.68	2.69	3.17	3.10	3.60
July	0.05	15.81	4.01	3.14	2.57	3.68
August	0.05	5.48	4.34	3.38	2.39	2.21
November	0.08	11.43	2.90	1.63	2.91	2.86
Average	0.08	12.60	3.46	2.83	2.74	2.84

Floodplains and ecotones with riparian woodland habitats on river channels support the highest large mammal biomass in the Okavango Delta. Availability of surface water and flooding of floodplains for fodder production affect the dry season distributions of most species. The availability of dry season floodplain grazing, especially in the sedge communities, is the major limiting factor to large mammal population levels in the Okavango Delta (SMEC/KCS, 1989). Floodplains are grazed during the wet season (low water period) and are normally protected from heavy grazing during the high water period (dry season). The permanently flooded perennial swamp supports very low mammal biomass.

About 50% of the distributional range of the red lechwe (*Kobus leche*) extends over the Okavango Delta (Smithers and Skinner, 1990).

With a rapidly growing population of elephant in northern Botswana, there appears to be a general shift of the centre of distribution westwards into Ngamiland, with large herds concentrated in the perennial swamp ecotones in the Moremi Game Reserve and surrounding CHA's during the dry season. Resulting severe impacts on riparian woodland habitats will affect their use by a large number of other species (mainly birds, small mammals and reptiles).

The declining Buffalo population of Ngamiland, comprising about 90% of the national herd, is concentrated in the Okavango Delta and on the Kwando River during the dry season. During the 1993 dry season, about two-thirds of the Okavango population was found in the Moremi Game Reserve. Buffalo are now confined to a very restricted range. Distribution to the west, north-west and south of the Delta has been blocked by veterinary cordon fences and settlements. Elsewhere the range is restricted by availability of receding surface water supplies. There is concern that large numbers of buffalo have been fenced out of essential habitat in the process of erecting the growing network of veterinary cordon fences for disease control in cattle populations (DWNP, 1994).

The Makgadikgadi - Nxai Pans zebra population relied on the Boteti River during dry seasons, and was decimated during the 1980's drought after this water supply failed. There are indications that part of this remnant population now migrates to the Okavango Delta in the dry season.

The Kalahari wildebeest population (and to a lesser extent, hartebeest) historically relied on the Boteti River and Lake Ngami for water during drought years. Populations have suffered massive mortalities since migrations to surface water have been impeded by veterinary cordon fences during droughts since the 1960's (Child, 1972a; Williamson, 1985). Diversion of water from Lake Xau resulted in higher wildebeest mortalities during the last drought between 1981 and 1988 (Parry, 1987; Williamson and Mbano, 1988).

The impact of changes in the Okavango River system on Kalahari wildlife populations emphasises the importance of this system at a regional and national scale. The extent of the density distributions for Botswana buffalo, lechwe, sitatunga, tsessebe and wildebeest populations, is shown in the Density Distribution maps of these large mammals.

Within the Okavango Delta region the interrelationships between the recent declines in many large mammal species populations and increases in others (elephant, lechwe, wildebeest) are not well understood, but may relate to shifting biomass ratios. Incidence of fire, long-term desiccation in some areas and inaccessibility of traditional ranges are also likely to be factors. Reductions in the size of wildlife habitats is bound to lead to reductions in potential population levels.

7.5.2.2 Small Mammals

Floodplains and riparian woodland habitats probably also support the highest small mammal densities in the Okavango Delta. While the majority of small mammals are not dependent on surface water, the seasonal flooding of floodplains is essential for maintenance of preferred habitats for many species.

One wetland-associated rodent species, Shortridge's mouse (*Mastomys shortridgei*) occurs only in the Okavango River system in Namibia and Botswana. Brant's climbing mouse (*Dendromus mesomelas*) and the Groove-toothed mouse (*Pelomys fallax*) occur only in the Okavango River system within Botswana, but are found elsewhere in South Africa and Zimbabwe.

Four species of bats: the Midas free-tailed bat (*Tadarida midas*), the Butterfly bat (*Chalinolobis variegatus*), Ruppell's pipistrelle (*Pipistrellus ruppelli*) and Rendall's serotine bat (*Eptesicus rendalli*) are also confined to the Okavango Delta in Botswana, but also occur in Namibia, southern Angola and Zambia. Likewise the range of the white-tailed mongoose (*Ichneumia albicauda*) extends from southern Angola and Caprivi into the Delta.

The distribution of various other wetland-associated species within Botswana is confined to the Okavango, Kwando, Linyanti and Chobe River systems.

7.5.3 Fish and Fisheries

General and breeding habitat preferences for fish species of the Okavango Delta have been analysed (CSIR/WTC, 1997).

In terms of distribution, fish populations have been broadly divided into resident species, longitudinal migrants which move downstream with floods and return with receding waters, and lateral species inhabiting isolated bays and back waters on the floodplains. Certain species are distributed throughout the Delta while others have more specialised habitat requirements. Duration and timing of floods and water levels, together with habitat preference and food supplies are the main factors affecting fish distribution.

The flood cycle also appears to have a major influence on breeding seasons for most species. Apart from directly stimulating spawning, it provides shallows for nesting sites and seasonally inundated littoral areas for nurseries. Many floodplain breeders spawn when higher temperatures are experienced (September to December). Excessively cold periods are known to cause significant fish mortalities, particularly in shallow water (Merron and Bruton, 1988).

Factors resulting in lower than expected fish productivity in the Okavango Delta include: nutrient deficiencies, habitat unpredictability, predator imbalances, delayed flood cycles in relation to the best season for fish breeding and growth, and the poor growth of algae and phytoplankton in Okavango waters. Previous dredging also reduced fish stocks creating sterile channels which most species could not use as habitats (Fox, 1976; Merron and Bruton, 1986a). More recently the widespread use of insecticides in controlling tsetse fly has also impacted on Okavango fish populations (Merron and Bruton, 1986a).

Merron and Bruton (1988) describe five major divisions of the Okavango Delta ecosystem in terms of fish fauna habitat:

1) Riverine Panhandle
2) Upper swamp
3) Lower swamp
4) Drainage rivers
5) Sump lakes

They estimated that the most productive perennial water areas comprised approximately 4 000 km^2 within the Delta in 1988.

7.5.4 Birds

A checklist of birds recorded from the Okavango Delta and Lake Ngami area, and a descriptive list of ornithological habitats associated with the checklist has been drawn up. (after SMEC/KCS, 1989). Numbers of bird species and their major activities in the various habitat types in the Okavango River and Delta systems have been included (after Swedeplan, 1989).

Tinley (1966), Jackson (1969) and Fraser (1970, 1971b, 1971c) did some early work on bird distribution and habitat preferences at Lake Ngami (in flood), in the Moremi Wildlife Reserve and on the Khwai River. Milenski and Campbell (1976) carried out a more detailed survey in Moremi Wildlife Reserve in 1975. Numerous researchers have documented distributions for certain water bird species, especially herons and heronries, and limited information is available for raptors and game birds. Few distribution data or information on habitat preferences are available on species of the largest order, Passeriformes.

In a Botswana context, several species occur only in the Okavango Delta region, although they may be more or less widespread regionally or internationally.

There is a general preference by waterbirds for seasonally inundated areas at the swamp margins. This probably relates to richer nutrient cycling and fluctuating conditions associated with seasonal wetlands. (These habitats are most likely to be adversely affected by any manipulation in water levels resulting from abstraction of water from the Okavango River). Seasonal wetlands also provide resting and feeding habitats for a large number of inter-African and palaearctic migrant species.

Highest (non-waterbird) resident species densities occur in riparian woodlands and on island fringes. The destruction of these habitats by growing numbers of elephant in the eastern Okavango Delta could displace numerous bird species. The perennial swamps support fewer species but may be used seasonally for nesting by a few species.

7.5.5 Reptiles

The few distribution data available for reptiles in the Okavango Delta region (apart from the crocodile) are provided by Auerbach (1987). Simbotwe and Guillette (1990) discuss the zoogeography of reptiles of Botswana and management implications.

The distribution of the Nile crocodile is better known than that of any other reptile species in Botswana (Blomberg, 1976; Simbotwe and Guillette, 1990). Crocodiles are distributed throughout the Okavango River and Delta in permanent swamp, rivers, madiba and seasonal swamp. However, nearly all nesting sites are found in the Panhandle above the Delta between Shakawe and Seronga (Graham and Simbotwe, 1988). Extensive movements may take place (up to 200 kms) but nearly all individuals eventually return to the Panhandle to breed. This section of the river also supports large human and livestock populations, and there are inevitable conflicts here with crocodiles taking livestock, and residents hunting or snaring crocodiles and raiding of nests (Skjonsberg and Merafe, 1987).

The Pelomedusidae (terrapins) show interesting diversity in the Okavango Delta, where four of five Botswana species are recorded. The eastern striped swamp snake (*Limnophis bicolor bangweolicus*) is an Angolan/Zambian species recorded only from Maun and Xugana lediba. The Barotse water snake (*Crotaphopeltis barotseensis*) and the western green snake (*Philothamus angolensis*) are confined in Botswana to the study area.. Four of the five Botswana records for the eastern rufous beaked snake (*Rhamphiophis oxyrhynchus rostratus*) are from the Okavango Delta (SMEC/KCS, 1989).

Twelve reptile species, including the Nile crocodile and monitor, python, five water snakes and four terrapins may be considered aquatic or near aquatic, and are restricted in their distribution to areas in/near perennial surface water. Distribution of reptiles which are not dependent on water mainly reflects their dietary preferences and the abundance of prey or plant food species. Very few data have been collected on the habitat requirements of other reptiles in the region.

7.5.6 Amphibians

The few distribution data available for amphibians in the Okavango Delta region are provided by Auerbach (1987). Simbotwe and Guillette (1990) discuss the zoogeography of amphibians of Botswana and management implications.

The inventory of amphibians and what is known of their distribution highlights the importance of the Panhandle and distributary systems towards the east and south east. The Okavango River and the Nqoga, which is the main distributary, are of major importance in influencing distribution of amphibians (SMEC/KCS, 1989). Recent hydrological changes have also limited their distribution, particularly in the south and south-east parts of the Delta.

Only two amphibian species (*Xenopus laevis* and *X. muelleri*) are fully aquatic. Most species appear to select habitats including perennial water supplies where possible, and require standing water to complete their life cycles, but they have adopted strategies of hibernation or aestivation to survive temporary and seasonal desiccation of habitats.

Findings of a recent survey in the Okavango Delta indicate a patchy distribution for many amphibian species, even on a small scale in what appear to be suitable or similar habitat types (CSIR/WTC, 1997).

Very few data have been collected on the habitat requirements of amphibians in the region.

7.5.7 Invertebrates

7.5.7.1 Terrestrial Invertevrates

Little research has been done on the ecology and habitat requirements of terrestrial invertebrate fauna in the Okavango Delta, or elsewhere in Botswana. A few economically or ecologically important species have been studied in some detail, including the tsetse fly (*Glossina morsitans*), the mophane worm (*Imbrasia belina* larva) the silkworm moth (*Gonometa postica*) and termites (*Macrotermes*, *Hodotermes* and other genera). Records of occurrence and limited information on distribution have been collected for species of the Orders Lepidoptera (butterflies) and Odonata (dragonflies) from the study area (Pinhey, 1967-76). A considerable body of information is available from South Africa, Namibia and Zimbabwe, particularly on species of economic importance.

Tsetse Fly

Environmentally and economically expensive control measures, including game destruction, bush clearing, tree felling and extensive ground and aerial pesticide spraying programmes conducted over the past 40 years, have failed to eradicate the tsetse fly from the Okavango Delta. Tsetse fly ranges are again reported expanding to the east and south-east from residual foci on the north-east side of Chief's Island (P. Smith,*pers. comm.*).

Butterflies

Pinhey (1967-1976) has produced a checklist of the butterflies of Botswana from which it has been possible to select several that seem to be of importance within the Okavango Delta region. *Eurema hapale* (Pieridae), which was collected at Muhembo, shows an interesting disjunct distribution with the nearest populations being found in eastern Zimbabwe and northwards into East Africa. *Acraea acerata* (Acraeidae) has only been collected at Shakawe/Muhembo south of the Zambezi / Cunene system, while *Acraea onerata* is only known from one type collected on the Okavango River. Other species limited in distribution by their associations with swamp habitats include *Sallya amulia intermedia* (Nymphalidae), *Borbo micans* (Hesperiidae) and *Mylothris bernice attenuata* (SMEC/KCS, 1989).

Dragonflies

Owing to the interest of taxonomists, this order is better known from the Okavango Delta than any other group of invertebrates of similar numbers. Pinhey listed 114 species of dragonflies expected to occur in Botswana of which 84 are found in the study area. There are 29 species of damselflies (Zygoptera) from five families and 55 species of Anisoptera from four families, giving rise to the statement that the Delta is "one of the richest and most interesting Odonata ecosystems in southern Africa" (Pinhey, 1976b).

Termites

A number of termite species occur in abundance in the Okavango Delta region. Some (especially *Macrotermes* spp. and *Hodotermes* spp.) are of great importance in nutrient and energy cycling and ecosystem functioning. Research is currently being carried out on the ecology of these Genera in the Moremi Game Reserve.

7.5.7.2 Aquatic Invertebrates

Very little research has done on the ecology and habitat requirements of aquatic invertebrate fauna in the Okavango Delta, or elsewhere in Botswana. General distribution information have been collected for a number of species in the study Recent hydrological changes in distributary systems of the Okavango River must have also affected the distribution of aquatic invertebrates.

7.6 Environmental Water Demand

7.6.1 Data Available/Work done

Other than the generalised evaluation of environmental water requirements given by Ellery (1997) there have been no other attempts in the past to quantify or qualify environmental water demand within the Namibian section of the Okavango River.

Within the Delta, work carried out by SMEC/KCS, (1989) and Murray provides a useful overview of the environmental water demand s of fauna.

7.6.2 Analysis (Flora and Fauna combined)

Within Namibia Ellery (1997) estimated that about 15 120 m^3/km/day of water is lost along the section between Rundu and the Cuito confluence with most losses going in the form of evaporation from the water surface and transpiration by riparian and floodplain vegetation. The amount of water lost as groundwater recharge is unknown, but Simmonds & Schumann (1987) and Namibian Groundwater Development Consultants (1991) felt that groundwater aquifers were largely unaffected by recharge from the river.

The amount of water required to support the natural vegetation, wildlife and processes of the riverine system needs to be clarified, especially in the light of planned water abstraction from the system. Given the high degree of dependency of the human population along the river, there is also a need to evaluate the domestic and livestock demand for water and the long-term projected trends in these demand patterns.

Within Botswana, the water-supply related determinants of plant communities have been identified. These are flood duration, depth, frequency and flow rates. Directly linked to water are the particulate and dissolved solids transported by the water ie, particulate bedload (type and volume), suspended solids (type and amount) and dissolved solids (types and concentrations). Water requirements of plant communities should therefore relate to the above variables.

It has also been shown that there is considerable variation throughout the system resulting in relatively rapid and frequent changes in plant communities. This variation occurs even in the perennial swamp where major river channels are expected to have a life span of between 150-200 years. In the evolution of such channels the system can vary from dryland to perennial swamp. It has also been indicated that the mechanisms that maintain the variability are essential to preventing the Okavango Delta becoming a saline system. Thus environmental water requirements include water quality and transported particulate matter.

The Delta outflows at its distal end have a high natural variation in water supply. Modelling these outflows has proved to be extremely difficult. McCarthy (1997) found that a regression based on rainfall and inflow into the Delta, for the three previous years, most successfully predicted outflow to the Boteti river.

Even though some of the outflows have experienced periods of up to 30 years of no flow, the system relies on the episodic flows to maintain productivity and recharge groundwater for plant and human use. In this arid system the flooding has disproportionately high ecological and productivity results. This is borne out in the Boteti area where reduced flooding of the river and Lake Xau at the distal end are directly linked to the desertification process occurring (Arntzen *et al* 1994).

In the outflow systems from the Delta, groundwater recharge will be a major component of environmental water requirements as annual evaporation is far greater than rainfall.

Long and short term changes in the extent, duration and timing of annual flooding and consequent changes in dependent habitats affect productivity of the Okavango Delta and the ecology and distribution of fauna. Productivity has apparently been reduced through the period of extreme low water levels experienced during the past decade and further reductions in inflow resulting from abstraction above the Delta can only exacerbate this situation. Cosnidering the environmental water requirements of the fauna in more detail:

Mammals

Table 7..9 indicates that the majority of large mammal species (particularly ungulates) of the Okavango Delta region rely on perennial surface water supplies, resulting in large concentrations of certain species at the (dynamic) river channel and perennial flood ecotones in the Delta during the dry season. Three (semi-aquatic) species remain on the ecotones throughout the year. Though species termed 'water-independent' can normally meet their water requirements through food supplies, all will drink if given the opportunity.

Large daily water and fodder demands keep the growing elephant population in or near the ecotones during the dry season. As they expand further west into the Delta, they are impacting on riparian woodlands, ecotone and island fringe vegetation communities, and altering or destroying the habitats of a number of smaller wildlife species (Ecosurv, 1996).

Table 7.9: Water utilisation by large mammals of the Okavango Delta (After SMEC/KCS, 1989).

Semi-aquatic	Water Dependent	Water Independent
Hippo (G)	Buffalo (G)	Antbear (I)
Lechwe (G)	Baboon (O)	Cheetah (C)
Sitatunga (G)	Bushbuck (B+G)	Duiker (B)
	Elephant (B+G)	Eland (B+G)
	Impala (B+G)	Gemsbok (G)

Oribi (G)	Giraffe (G)
Reedbuck (G)	Hartebeest (G)
Roan (G)	Brown Hyaena (C)
Sable (G)	Spotted Hyaena (C)
Tsessebe (G)	Kudu (B)
Warthog (G)	Leopard (C)
Waterbuck (G)	Lion (C)
Zebra (G)	Springbok (B+G)
Wildebeest (G)[1]	Steenbok (B+G)
	Wild Dog (C)

NOTE: G = Grazer
B = Browser
C = Carnivore
I = Insectivore
O = Omnivore

Note 1: The wildebeest of the south-western (Kalahari) system require supplementary surface water only when fodder moisture levels are low during drought periods.

Fish and Fisheries

Impacts on fish populations and distribution in the Okavango Delta resulting from drought and natural or artificial reductions in seasonal flood levels include:

* Reductions in areas of seasonally inundated swamps will limit available habitats and food supplies.
* Impacts of subsistence and commercial fishing will also be increased as inaccessible habitats are reduced or eliminated.
* Shallow floodplain pools necessary for the completion of breeding cycles of some species will be reduced in extent or eliminated over large areas.
* Seasonal migrations and movements to deep channels may be impeded by lowered water levels.
* Changes in species composition may occur with selective mortality in isolated pools between flood events.
* Changes in population size and structure will affect major fish predator population dynamics (e.g.. crocodile).
* Decreased water levels could accentuate the effects of insecticide spraying programmes aimed at controlling tsetse fly.

Most significant impacts are anticipated in the lower reaches of the seasonal swamps and in the south-eastern quarter of the Delta where the perennial swamp has receded to the upper sections of the Boro and Santantadibe River channels.

Birds

Low flood regimes and hydrological changes also affect the ecology, distribution, food supplies and breeding success of many waterbird species. Disturbance at heronries and other nesting sites is reported to be on the increase as growing numbers of tourists travelling in mekoros are concentrated into shrinking perennial swamp habitats and along river channels (T. Liversedge, *pers. comm.*).

Five of 26 ornithological habitats described by Plowes for the Okavango Delta in SMEC (1987c) are not associated with perennial or seasonal swamps, floodplain ecotones or riparian woodland (*C. mopane* woodland and scrub, *Terminalia* thickets and *Acacia erioloba* woodland). The latter type often borders swamp ecotones inland, and is the most heavily used 'dryland' habitat type (q.v. Annex D, Table 2).

Reptiles

Twelve reptile species, including the Nile crocodile and Nile monitor, python, five water snakes and four terrapins may be considered aquatic or near aquatic, and are restricted in their distribution to areas in and near perennial surface water.

Crocodile distribution, habitat preference and reproduction are closely linked to flood regimes and water levels as they affect food supplies, nest site selection and availability, cover requirements and hatchling survival rates (Graham and Simbotwe, 1988).

Retarding of flooding and causing water levels to recede further under dry season conditions, with potential changes in plant community composition, could affect habitat suitability and availability of food supplies for water-dependent species.

Amphibians

Water demand by most amphibian species is obviously high. Even those which do not rely on perennial water supplies, and aestivate or hibernate through dry periods, must have access to open water pools to complete their breeding cycles.

Some of the potential impacts on amphibian populations in the Okavango Delta resulting from drought and natural or artificial reductions in seasonal flood levels are similar to those listed for fishes:

* Reductions in areas of seasonally inundated swamps will limit available habitats and food supplies.
* Shallow floodplain pools necessary for the completion of breeding cycles will be reduced in extent or eliminated over large areas.
* Reduction in the number and extent (of 'edge') of ephemeral pools which provide habitats for many amphibian species.
* Changes in species composition may occur with selective mortality under drier conditions.
* Gradual changes in the composition of plant communities may occur, with direct or indirect changes in food supplies and habitat suitability.
* Decreased water levels could accentuate the effects of insecticide spraying programmes aimed at controlling tsetse fly.

Most significant impacts are anticipated in the lower reaches of the seasonal swamps and in the south-eastern quarter of the Delta where the perennial swamp has receded to the upper sections of the Boro and Santantadibe River channels.

Terrestrial Invertebrates

Long-term changes in flood level regimes could result in gradual changes in the composition of plant communities and thus (directly or indirectly) in food supplies and habitat suitability for terrestrial invertebrates. Soil moisture levels (affected by vegetation they support) also affect habitats of ground dwelling and nesting species (most notably termites and their role in ecosystem functioning).

Aquatic Invertebrates

Recent hydrological changes in the distributary systems of the Okavango River have also affected the distribution of aquatic invertebrates.

Impacts on aquatic invertebrate populations and distribution in the Okavango Delta resulting from drought and natural or artificial reductions in seasonal flood levels include:

* Reductions in areas of seasonally inundated swamps will limit available habitats and food supplies.
* Shallow floodplain pools necessary for the completion of breeding cycles of some species will be reduced in extent or eliminated over large areas.
* Changes in species composition may occur with selective mortality in isolated pools between flood events.
* Changes in population size and structure may also affect predator population dynamics.
* Gradual changes in the composition of plant communities may occur, with direct or indirect changes in food supplies and habitat suitability.
* Decreased water levels could accentuate the effects of insecticide spraying programmes aimed at controlling tsetse fly.

Most significant impacts are anticipated in the lower reaches of the seasonal swamps and in the south-eastern quarter of the Delta where the perennial swamp has receded to the upper sections of the Boro and Santantadibe River channels.

7.7 Functioning of the Ecosystem

7.8 Ecosystem/Flood Regime Interaction

7.9 Influence of Man *be completed*

The vegetation of the Okavango River valley is heavily utilised both as a grazing resource for domestic livestock and for other domestic uses. The extensive alteration of much of the riverine terrace system in recent years from woodlands to agricultural fields, and the lack of active management practices to improve or maintain production levels means that more and more natural vegetation is being lost. This has important implications in the maintenance of stock numbers and the relative (economic) cost of domestic wood and construction materials.

According to recent studies (IFAD, 1996) range inadequacy can be attributed mainly to the scarcity of forage within the floodplain component during the peak of the dry season. In the wet season range inadequacy is not a problem. Given the loss of *Cynodon* lawns and the conversion of some grazing lands to agricultural fields, there is undoubtedly some reduction in the extent of the high value floodplain grasslands. The significance of these reductions over time, compounded by a slowly increasing regional livestock herd, has not been evaluated and warrants further research in the future.

8. MAN AND THE OKAVANGO RIVER BASIN

8.1 Introduction

8.2 The People and Their Socio-economic Stucture

8.3 Asset Ownership and Legislation

8.4 Water Demand, Supply and Resource Development (take this section from Rui marques)

8.4.1 Current Situation

8.4.2 Potential Develoment

8.5. Land Use

8.5.1 Data assessmnet and availability

8.5.2 Overview

8.5.2.1 General

8.5.2.2 Protected Areas, Wildlife Management and Controlled Hunting Areas

8.5.2.3 Agriculture

8.5.2.4 Tourism

8.5.2.5 Mining

8.5.2.6 Fisheries

8.5.2.7 Urban and Industrial

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8.6 Natural resource Economics

8.6.1 Data Assessment and Avaialability

8.6.2 Overview

8.6.2.1 Natural Vegetation

8.6.2.2 Fisheries

8.6.2.3 Arable Agriculture

8.6.2.4 Livestock

8.6.2.5 Wildlife and Lanscape

8.6.2.6 Transport

SECTION B : DIAGNOSTIC ANALYSIS

1. INTRODUCTION

The aim of Section B of the Transboundary Diagnostic Analysis is identify what is lacking in terms of what is known about the Okavango River Basin and to identify in broad terms the tasks that need to be carried out in the environmental assessment and towards the Integrated Management Planning for the basin as a whole.

It should be stressed that while the environmental assessment should be as wide-ranging and complete as possible, the work must still be carried out in full cognizance of the focus of the study, which is water, and more specifically, runoff (in all its dimensions) , water quality and sedimentation. This focus is illustrated in Figure 1.1, which is a schematic representation of the processes which have a bearing on the outputs, and their inter-linkages.

It must be remembered that the detailed design of the SAP will be driven by the consultative process which will form the overarching sub-programme driving the remaining processes. The purpose, therefore of this document is not to finalise the detail of the work that will have to be done, but to motivate an outline Strategic Action Plan and to derive a cost estimate for the project.. The Strategic Action Plan, will ultimately have to ensure the integration into national and regional development agendas, programmes, plans and agendas. This will be effected largely the continuation and evolution of a consultative process established during the PDF phase.

2. APPROACH

2.1 Stakeholder Consultation and Participation

2.1.1 The Need for Stakeholder Consultation and Participation

During the PDF stakeholders, especially within the Namibian and Bortswanan portions of the catchment were visited in order to introduce the project and its aims. This has been discussed in Section A. In Angola the work was more limited, and essentially aimed only at making OKACOM and the project known to as many people as possible through the mass media.

In the meetings with traditional and regional leaders and communities the desire to be kept informed was strongly expressed. A frequently asked question was, how they would be informed. It would appear that based on past experience they feel that they have either not been properly consulted or have not had the findings or outcome of studies conveyed to them such that they felt that they were not in the picture about events. There was a feeling that they had lost control over events and developments that affect their lives. This is the clearest possible expression of interest in being involved from the grass roots level. It was

The scope of the communication and consultation component of the Strategic Action Plan should not be underestimated, especially when it comes to involving communities and interest groups. These are key players in the process and much of the success of the exercise will depend on them as much as on the efforts of government and specialists. In this regard it is considered important that education is incorporated into communication. Attitudes and practices can be changed through education and it is through this that an integrated basin management plan can best and most successfully be implemented **.**

It is clear that from the outset, the consultative process developed during PDF activities will have to be used and elaborated to involve basin stakeholders etc. to refine the outline SAP through consultative public meetings, reviews and seminars and that special emphasis must be given to activities in Angola. This process is at the core of the design of the alternative course of action and the achievement of global environmental objectives.

Consultation should include the involvement of interested and affected parties from the development of the terms of reference of individual study modules, through the selection of specialists, the management and the review of their work.

Stakeholders have all expressed their desire to be involved and more especially to be consulted. However care will need to be exercised in order to achieve an acceptable level and balance of involvement of the groups. This is an aspect which will need to be given some detailed thought. Workshops and interviews of key informants will have to be the principal means of communication. A balance between involving the general public and those who represent particular interest groups will need to be struck. Over all this the process of consultation and communication must be seen as being constructive and transparent by all parties involved. The effort required to achieve this should not be underestimated and it is likely to generate a considerable amount of work.

Some interest groups, especially the environmentally inclined ones, have expressed a desire that they play a direct role in studying certain aspects which fit in with their remit. An example of such organisations is the Okavango Research Centre. Others have expressed a willingness to fulfil a peer review role or to assist with the community consultation and dissemination, such as the Kalahari Conservation Society. All are open to suggestions and it would be beneficial once there are more concrete ideas as to what is to be undertaken, in sitting down with them to explore mutually beneficial co-operation.

2.1.2 Work required

2.1.2.1 Introduction

The work that needs to be carried out with respect to Stakeholder Consultation and Participation falls into two main categories,

- A high intensity effort during the first 3 to 6 months of the project during which time the Strategic Action Plan will be elaborated
- A continuing effort in which the main aim will be to maximise interest and input from all stakeholders.

2.1.2.1 Start up Phase

The main activities are seen as:

- Drawing up of publicity material and dissemination to all stakeholders, bioth locally, regionally and internationally
- Workshops/meetings with :

i) Government
ii) Local government and Community leaders, including teaching community
iii) Public meetings
iv) Meeting with appropriate NGOs and groups interseted in having an input to the Strategic Action Plan and/or partcipation in the Environmental Assessment and Integrated mangement Plan
v) Meetings with the scientific and technical community to review the TDA, its specialist inputs and other relevant studies

- Inventorizing of all issues, concerns and ideas. Formulation of a draft elaborated Strategic Action Plan will follow from these meetings and workshops.

- The final step in the Start-up Phase of the consultation process will be the presentatiion of the elaborated Strategic Action Plan for discussion and "finalisation". It should be noted that a key part of the strategic Action Plan will be the inclusion of an "education" element.

2.1.2.2 During the Environmental Assessment and Integrated Management Plan

- Regular Meetings with those actively involved in the work. Such meetings will be both informal and informal and will involve members of the PMU, national specialists, NGOs and other groups who are playing a part in the implementation of the Strategic Action Plan.

- Annual (or perhaps more frequent) workshops should be held, open to all the stakeholders in order to keep everybody informed with the progress of the project.
- The existing website on the internet should be continued and expanded, and continually updated with feedback from the ongoing research and the feedback on the outcomes of the various meetings and workshops.
- Extremely important will be the implementation of an education programme. It is recognized that this is an indispensable tool in the implementation of the project.

A programme providing the necessary background for a good understanding of the Okavango River basin should be worked into the school curricula in the region. If this can not be done in formal way it could be achieved in the form of school projects or similar approach. In this way school-leavers will be a a position to participate more effectively ij the stewardship of the river basin. At the same time specialists could be required to prepare material in a popularised style for schools and museums and to present lectures as part of their contract.

The collection of rainfall data from simple daily-read gauges by volunteers should be promited and the project could consider employing a certain number of school leavers from the region who would be tasked to assist the various specialists in their work especially where data gathering is concerned. School leavers would have to receive training and this would have to be incorporated into the brief of the specialists and researchers. They could also assist with providing feedback to local communities as well as liaising with schools.

A certain number of bursaries could be made available to the most able of the school leavers to enable them to study further. It is also proposed that a small number of suitably qualified graduates, preferably from the region, could be employed alongside the school leavers in order to strengthen the capabilities.

This approach is strongly recommended and should be considered as a priority. Previous experience has shown that this type of project can often attract funding for PhD and post-graduate studies, and this sort of support should encouraged, but not at the expense of the education of the grass root stakeholders.

3. GENERAL CATCHMENT INFORMATION

3.1 Climate

3.1.1 General

As has been stated there are virtually no up to date climatic data for the basin within Angola. Within Namibia there has been a gradual decrease in the number of rain gauges operating in the area. Within Botswana, efforts have recently seen the installation of a number of automatic weather stations, but data collection and processing is not yet fully operational. As can be seen from the process model in Figure 1.1, climate is a key and perhaps one of the most important determinants in the model.

3.1.2 Information Gaps

Rainfall data for the period since the mid-70s is virtually non-existent for the Angolan portion of the catchment. Within Namibia and Botswana daily rainfall records of a sufficient length to calculate long term means and to provide an overview of the spatial and temporal variation of dry and wet periods are available. New stations set up within the delta area should provide useful rainfall data including data on intensities, but in general rainfall intensity data is lacking for the entire catchment.

3.1.3 Work Required

3.1.3.1 Investigations and Data Collection

According to UNESCO/WMO standards, a density of 1.25 recording (i.e intensity) and 6 non-recording precipitation stations per 10 000 km² is recommended. This would imply a total of 19 recording and 90 non-recording gauges in the Angolan portion of the catchment alone. In view of the fact that the majority of the runoff is measured in the upland areas, it may be justified to reduce the number of stations in the lower reaches to more affordable levels. A more realistic target would be 10 to 15 recording gauges and 70 – 90 non-recording gauges.

In view of the possibility of combining rain sensors into total weather stations (Data capturing platforms (DCPs) with the resultant rationalisation of data recording equipment and costs as well as the possible combining of raingauges at river water level gauging stations it should be feasible to put 15 recording gauges into operation in the Angolan portion of the catchment. These can be supplemented by 4 recording gauges in the Namibian portion of the catchment of which two can be combined with the water sensor gauges at Rundu and Mukwe. In Botswana, allowance should be made for two further recording gauges to be combined with water level stations.

The need for a relatively dense network of non-recording rain gauges can be achieved at a relatively low cost by involving the local communities. Manually-read rain gauges cost only a few dollars and observers can be trained in a matter of minutes. It is suggested that as part of the stakeholder participation process, schools, police stations, government and non-governmental offices be involved in the rainfall data collection programme. All gauges and observers can be visited twice a year for an inspection of the equipment and collection of the data. (Include further details under the education etc programme description)

It is also necessary to collect evaporation data from all parts of the catchment. This is especially true for the Angolan portion of the catchment for which no recent data exist, and for the Okavango Delta, where accurate evaporation data are needed for a better understanding of the delta area. UNESCO/WMO recommendations are for 3 non-recording stations per 100 000km². It is recommended that 4 are positioned in the Angolan portion of the catchment to cover the different topographical and climatic types. A further station at Rundu and one in the M Game Reserve or at Shakawe. In the Delta area itself three evaporation pan at serviceable locations should be set up.

Measurements of other climatic data, such as temperature wind and humidity can be made at the proposed DCPs

3.1.3.2 Research and Analysis

With improved precipitation data, it will be possible to obtain a much better understanding of the spatial and temporal variations of rainfall which will be very useful for the agricultural sector. Improved rainfall and evaporation estimates will also be critical in improving the accuracy and usefulness of any water balance model of the system and inn particular the Okavango Delta.

The development of a rainfall/runoff model will require a number of years for calibration, and for this good rainfall data are required. Once calibration of the model is achieved the process of extending runoff records and improving estimates of runoff statistics can begin.

The accurate estimate of evaporation from both open water and vegetated water is also very important and can be problematic. It thus requires some careful data collection and research.

3.2 Physical Catchment Description

3.2.1 General

In Section A the Physical Description of the catchment was discussed under a number of headings including topography, geology, geomorphology, soils, vegetation cover and even land-use. In the following section much of these themes have been combined because of the fact that many of them overlap, at least with respect to the data that would have to be collected and the work that is required. For example, digital satellite imagery would provide a useful basis for the work for many of the parameters, with the same scene being analyzed in a number of different ways. A section entitled "Satellite Imagery and Remote Sensing" has been included paragraph 3.2.2 and 3.2.4 to cover the applications and recommendations of satellite imagery in general, even those beyond the Physical Catchment.

Discussion on information gaps and work required with respect to vegetation is deliberately limited since the subject is discussed in further detail in Section 6, The Okavango River Ecosystem.

3.2.2 Applications of Satellite Imagery

3.2.2.1 Introduction

Key issues to be considered in the preparatory phase were :

i) The essential role of remote sensing in environmental assessment projects, the type of remote sensing data most suitable for the OKACOM project and the form of data that can be derived from Remote Sensing data sets.

ii) The role of a Geographic Information System/s (GIS) in Environmental Assessment.

iii) The importance of effective remote-sensing, to GIS links.

iv) An overview of GIS and image processing (IP) systems (for processing satellite and airborne imagery) currently in operation in the Botswana/Namibia region, including current operator expertise, and limited information on data availability.

v) Guidelines for the implementation of a centralised Remote Sensing data repository and GIS database for the Environmental Assessment Project.

3.2.2.2 Applications of Remote Sensing for the Environmental Assessment

World-wide, remote sensing is recognised as being a significant source of data for environmental analysis and assessment projects. Projects of this nature benefit from the unique advantages of remote sensing, many of which are fundamental to the successful outcome of environmental projects. Some of these advantages, pertinent to the OKACOM Environmental Assessment are:

- Regional coverage at adequate mapping resolutions. Landsat TM 180 x 180 km per scene at 30m resolution and SPOT Panchromatic imagery at 10m resolution 60 x 60 km per scene are recommended. These datasets provide the lowest cost per square km for base-mapping and for extraction of a multitude of derived datasets.

- The multi-spectral nature of remote sensing data such as Landsat TM, Landsat MSS, or Spot XS (20m resolution) permit image processing (IP) applications, allowing extraction of data from singe datasets for multiple applications. Environmental applications that can benefit directly from or obtain evaluation data from these datasets are:

- Land use mapping and planning;
- Vegetation cover mapping and vegetation classification maps;
- Hydrological mapping and planning ;
- Land degradation mapping;
- Infrastructure mapping, to update outdated infrastructural and topocadastral maps;
- Geological mapping and mineral potential identification;
- Agricultural production mapping, resource identification, and planning;
- Human settlement mapping and planning.

The extraction of applications data from remote sensing data for the above mentioned studies is automated via standard IP procedures in IP software packages.

- Remote sensing data provides the most current information on an area available, as opposed to aerial and ground-based surveys or existing topocadastral data which is rapidly outdated. This function of remote sensing data has particular importance to the OKACOM project in terms of gathering data about areas where access is denied, or difficult, due to political conflict or instability in certain regions covered by the project.

- Continuous collection of remote-sensing data ensures that environmental planning is based on current data. Comparison of data obtained at different dates during the Environmental Assessment permits time domain analysis, enhancing the quality of:

  - Vegetation studies;
  - Land degradation monitoring projects;
  - Infrastructural development assessments;
  - Human resettlement/movement studies.

- Sophisticated IP procedures can be conducted on remote-sensing data, integrated with other environmental datasets (digital rainfall maps, temperature surfaces, topographic maps etc.) to derive information important for environmental planning. Examples are:
  - Biomass estimation (for use in vegetation monitoring, commercial forestry);
  - Grazing capacity information (effective use of grassland resources);
  - Soil moisture mapping (agricultural planning and monitoring);
  - Habitat mapping and species site matching (locating those areas most favourable/suited to specific agricultural or forestry activities, or requiring preservation status);
  - Infrastructural routing and human settlement site planning;
  - Erosion potential mapping.

Cost effective use of remote sensing data for the above mapping, planning and modeling operations requires integration with other environmental datasets. This necessitates the use of a Geographic Information System (GIS) which is fully integrated with a Remote Sensing and Image Processing System (*see later section*).

3.2.2.3 Role of A GIS in the Environmental Assessment phase

The implementation of a GIS in any environmental assessment project should be carefully planned with the project objectives dictating the manner in which data is collected, processed and stored from the outset. A goal-driven approach to GIS implementation avoids the problems commonly experienced with many GIS projects such as:

- Unnecessary and expensive duplication of data collection efforts;
- Collection of data in formats unsuitable for, or not convertible into formats suitable for analytical procedures required during the project;
- Collection of superfluous data which does not add value to the project outcome;
- Insufficient data collection resulting in incomplete information at crucial stages of the project, or models based on incomplete, outdated or inaccurate data.

A GIS, from the outset, should be seen as having a multifaceted function in the environmental assessment and management program. The GIS is useful for:

i) **Data Collection**, preferably into a central repository to which all project specialists are afforded easy access.

ii) **Data Transformation** and Integration; by this is meant that data from diverse sources can be unified in terms of formats, spatial extents and information content. Data standards need to be specified to meet project requirements and goals. The GIS is a vehicle for upgrading datasets to meet required standards of quality and information content.

iii) **Data Generation**: The GIS is a vehicle for deriving additional data required by specialists through merging, mathematical or statistical operations on existing datasets. An example of this would be the creation of a soil erosion hazard potential map by derivation (GIS analysis and combination procedures) from soil, geological, topographical, vegetation and rainfall datasets.

iv) **Modeling:** the GIS should permit the use of datasets to model outcome scenarios. Given the available input data, if certain parameters are changed, what is the effect going to be on certain outputs? An example pertinent to the OKACOM study - if a dam were built at a certain locality what would the effects be on environmental parameters above and below the dam. The GIS should, in this case, be capable of providing information on (for example):

- The dam's capacity;
- Given certain rainfall scenarios the total water budget for the dam's catchment area and downstream expected water availability;
- Model impacts of changed water budget in the catchment area below dam wall;

Thus, just as a spreadsheet is used by financial analysts, environmental specialists should be able to formulate models using the GIS in terms of the spatially collated environmental data stored in the GIS, and be able to test their models.

v) In the longer term the GIS is an archive of Spatial Data. With time a carefully archived and well-maintained GIS provides a digital historical record against which the results of management plans and environmental policies implemented can be compared in order to evaluate results and guide further environmental management.

3.2.2.4 Effective Remote Sensing to GIS Links

Historically, Geographic Information Systems technologies, and Image Processing systems designed for Remote Sensing applications, have evolved into separate specialist fields and software technologies. Specialist personnel qualify as either GIS practitioners or Remote Sensing / Image Processing specialists. Recently there has been recognition of the important contribution of Remote Sensing to GIS in that:

- Data from satellite sensors provides unique input into a GIS system. The infra-red and thermal data from multispectral sensors allow for detection and mapping of features that no other method can provide data on. Examples are the early detection and mapping of crop diseases, or mapping of soil moisture content.

- Remote Sensing is the only cost-effective method of mapping large areas in a reasonable time frame. The data obtained from remote sensing for regional studies needs to be incorporated into a GIS database if the GIS project is of a regional scale.

- Time domain analysis or change mapping is best effected on large areas by utilisation of remote sensing data. The costs of collecting multi-date data over anything but the smallest area (a single site), using any other method, is prohibitive. GIS, on the other hand, is the only effective technology for objective comparison and statistical analysis of multi-temporal data, given the huge volumes of data involved. Standard GIS procedures can be applied to multi-temporal remote sensing data to quantify change and analyse the direction of change and rate of change.

With this in mind, efforts at merging the technologies have increased in recent years, to the extent that most GIS practitioners now make routine use of digital satellite or aircraft acquired data in their projects, and software products designed for GIS applications incorporate methods of acquiring and utilising remote sensing data.

The effective link between the two technologies cannot be overemphasised. Effective linking of GIS and Remote Sensing encompasses three important considerations.

i) Software considerations. Traditionally, powerful GIS systems have tended to be **Vector**-based systems, especially those developed for urban and engineering applications. Image Processing systems are by nature image or **Raster** oriented systems. Two approaches have been adopted by software vendors in order to provide 'effective links' between GIS and Remote Sensing.

a) A partnership between a Raster-based product (IP/RS) and a Vector-based product (GIS). Two separate software products are used in parallel with a data link between, used mainly to pass Vectorised interpretations from the IP system to the GIS system.

b) Single product solutions, in which one software product handles both image and Vector data, provides functions for changing from Raster to Vector formats and vice versa, and has both IP and GIS functionality built into a single product.

In terms of cost, reliability, ease of data maintenance and most effective linking of GIS and Remote Sensing technology, option (b) is the most desirable.

ii) Data Analysis Considerations. Environmental data collected for a environmental assessment project such as the OKACOM project will typically be of two forms:

a) continuous data - maps of variables that change in continuous fashion over the region, have intermediate values between sampled locations, which values can be interpolated from known data values. These datasets are best stored as Raster data sets, and analysed with Raster GIS tools. Examples are:

- Satellite data sets;
- Digital topographic models (DEMs, Slope, Aspect models);
- Climatic data sets (Rainfall surfaces, temperature surfaces).

b) ***categorical or discontinuous data*** - Data sets (maps or theme coverages) of discrete areas or lines that have a single property or attribute assigned to them. Examples are:

- Soil maps (polygons of discrete soil type & properties);
- Vegetation maps;
- River maps (lines with discrete attributes of names, flow volumes and other chosen attributes);
- Point Sample maps (hydrological monitoring stations, soil samples);
- Land use maps.

Such datasets can only be stored efficiently as Vector datasets with attached attributes in a linked database.

The need for effective GIS - IP links becomes apparent when data stored in formats a) and b) above need to be integrated for essential management functions. An example, pertinent to the OKACOM project, would be an implementation of the UNIVERSAL SOIL LOSS equation, to evaluate potential soil loss at any position within the catchment area.

Other applications related to effective IP and GIS links within the OKACOM project are:

- The production of cartographic quality (Vector) maps from satellite or aerial photograph interpretation. This requires that IP methods applied to digital image data, have outputs in quality Vector format.
- Application of Raster data-sets to Vector data-sets to solve / answer certain key questions.
- Application of a Vector data-set to extract information from a Raster data-set.

The above routine GIS tasks are highly likely to be encountered during the OKACOM environmental assessment study, and effective IP (Raster and Remote Sensing) to GIS (Vector database) links will be essential for these assessments. A GIS strategy incorporating seamless integration of Raster and Vector datasets is essential to the successful outcome of the Assessment study.

iii) Data storage and Maintenance Considerations. The third aspect of efficient Remote Sensing / IP to GIS linkages relates to effective data storage and retrieval, and ease of maintenance of the OKACOM database. Particularly if it is desired that a central data repository ultimately be set up for OKACOM managers and specialists to access as needed, consideration needs to be given to the following aspects:

- Will Raster and Vector data-sets be stored entirely separately from each other and in different system formats, or together within one portable and accessible file structure?

- Will specialists require one software product to access and **analyse** Raster data-sets (including satellite data), and another software product to access **and** **analyse** the Vector data-sets? The **and analyse** underlined is important here as some GIS software may allow access to, but **not** analysis of, a format for which it is not specifically designed. An example are desktop mapping systems ("Vector"-based) which allow Raster images or data-sets to be accessed as "backdrops" but not to be manipulated or analysed to any useful extent.

- Particularly if remote access of the central data repository is required, how many files, file formats, file locations (directories) and file linkages will have to be managed in order for database integrity to be maintained?

- How easy will it be for specialists to obtain the data they require? Issues of data format, data locality and correct data linkages also need to be considered here.

- How will updating of data sets be accomplished? If specialists use the latest satellite data (Raster IP) to update the land-use map (Vector GIS), how efficiently will this process be in terms of number of file formats used, and software products used, and how easy will it be to ensure adherence to data standards in such a process?

Clearly, in relation to the above points, the fewer software products used and the less the number of file formats used the more manageable the above tasks become. This is not to suggest that specialists involved in the OKACOM project all be required to use one standardised file format and/or software product. At the specialists site they should be free to use the product they are most familiar with. At the central database location, however, a single file / database format is recommended, one which is carefully selected to be compatible with all formats submitted / required by various specialists. This single format central database is then efficiently maintained, and requests for data, or submissions of data from specialists, are translated into and out of this central data structure via efficient export / import procedures.

3.2.2.5 GIS and IP Systems currently in operation in Botswana and Namibia

A survey of persons / agencies engaged in GIS / IP work of relevance to the OKACOM study was conducted. Limited responses to the questionnaire were received and more detailed follow-up on this aspect is required. Those responses that were received give some insight into the systems in use, data sharing philosophies and data availability.

It was concluded that :

i) Sufficient expertise exists in the region to undertake satellite data processing and GIS tasks related to natural resource mapping (vegetation, agricultural, habitat, water resource mapping), though most of this capability is within private consultancies who would need to be contracted to assist with management of OKACOM GIS data-sets.

ii) Little experience in the use of GIS/IP for interpretation and mapping of infrastructural networks was reported, though consultancies such as Windhoek Consulting Engineers are known to have this capability.

iii) A wide range of software systems are in use within the region, ranging from powerful integrated GIS/IP systems (TNTmips and to a lesser degree IDRISI) through combination or linked GIS/IP systems (ArcInfo and ERDAS) to specialised, more limited systems (REGIS - a system most suited to urban applications and ILWIS a powerful, but difficult to use GIS system). Several respondents make use of Desktop Mapping Systems (not GIS senso stricto) such as ArcView.

iv) Few respondents gave information about available data-sets, which may indicate that either there is a lack of data available **or** that data is proprietary and there may be some reluctance to make these data available for the OKACOM project. Further investigation is required on this aspect.

3.2.3 Information Gaps

3.2.3.1 Catchment Topography

Topographical mapping of the Angolan portion of the catchment is old, and even though some maps are dated in the early eighties, the content is often older. Mapping at a scale of 1 : 500 000 of most of the catchment was obtained, but it will be necessary to obtain 1: 100 000 maps for the environmental assessment. It is not known whether all this mapping is available. Detailed (a scale of 1 : 100 000 or better with 10m contour interval or better) mapping is probably not easily available for the whole catchment.

The 1 : 50 000 mapping for much of the catchment within Namibia has recently been updated although it is not all yet available in hard copy. What has not been mapped recently is available in the 19xx series. Digital versions of the recent mapping are available. The entire catchment within Botswana is available at a scale of 1: 250 000, and the river and delta area at 1 : 50 000 dated 198 ???

A gap therefore exists in that good and up-to-date topographical mapping is missing for many areas in the catchment

3.2.3.2 Catchment Geology, geomorphology and Soils

The diagnostic assessment reveals an incomplete picture of soil resources of the Okavango River basin. The lack of a coherent regional soils database in which information is based upon standard procedures, mapping scales and survey intensity frustrates any attempt to provide a systematic assessment based on comparable soil attributes and parallel definitions.

A wealth of applicable information can be obtained for Botswana. Information has been correlated and standardized using FAO guidelines, and has been reproduced at several scales of resolution for national, regional and local planning purposes.

In contrast, directly applicable material cannot be easily obtained for Namibia and Angola.

In the case of Angola, material is old and archives are scattered from Lisbon to Lubango. Angolan soils data correlated to the FAO Legend has recently become available at a scale of 1 : 2 500 000 which is inadequate for both environmental assessment and river basin management purposes.

The utility of available Namibian information is compromised by a serious soil classification incompatability with data from Botswana, which cannot easily be resolved.

3.2.4 Work required

3.2.4.1 Satellite Imagery and GIS

a) Satellite Imagery

As presented in Section A, Landsat TM coverage (1993) for most of the the hydrologically active catchment (18 images) has already been purchased. Landsat MSS imagery from 1973 has also been acquired and processed for the same eighteen scenes. These scenes could be supplemented by imagery already existing within government archives in Namibia and Botswana to provide coverage of all the topographical catchment (a further +/- 20 scenes).

- Allowance should be made for a further 5 scenes to fill gaps in coverage of the remaining topographical catchment

A TM scene from August 1997 has also been purchased. This covers the Menongue area in Angola. As discussed under 4.2.2, it will be necessary to acquire a number of other scenes, including some high resolution scenes of key areas.

Add here final detail on what scenes should be allowed for

b) GIS

Implementation of a centralised GIS/IP database would require the following steps:

i) A clear definition of the data required by the Assessment project in order to attain the goals of the Environmental Assessment phase. This requires input from project specialists on the datasets they would require to have access to from the GIS database in order to successfully implement their respective assessments.

ii) This needs to the followed up by negotiations with contributors to the OKACOM project Consultants and Government agencies, in order to obtain actual data-sets as determined in i). above, in whatever format they are available.

iii) Once data-sets have been obtained, to collate these into a single, widely accessible format. During this process, attention must be given to data quality standards, and substandard data rejected or upgraded. Some Vector data may, at this stage, require standardisation in terms of the attribute data attached i.e. standard codes and database table constructs. All Vector data obtained in non-topological formats, should wherever possible, be upgraded to full topological format to facilitate proper GIS neighbourhood and contiguity analysis and minimise spatial data errors. This is particularly true of data received from desktop mapping systems (ArcView and MapInfo) which use a CAD-like, free-form topology system.

iv) At this stage a decision on the system and file structure to be used in the central data repository will have to be made. In the light of the foregoing sections it is recommended that:

- A single, easily maintained and portable file structure be used;
- The file structure should guarantee that project data components remain together and do not become separated, for e.g. the Landsat imagery and Vector maps derived therefrom are always accessible together;
- The file structure / system chosen supports import from and export to ArcInfo, ERDAS, IDRISI, ArcView, ILWIS and REGIS, even if via an intermediate format, so as to allow current users of these systems to contribute and receive data from the central database;
- The central system chosen should support integrated analysis of Vector and Raster (image) data;
- A powerful Vector and Raster editing, and or Raster IP function, must be part of the centralised system to facilitate cleaning, editing and processing of contributed data-sets in these both these formats;
- The central GIS/IP database software should support links to fully relational databases in the most commonly used formats and/or be able to import from external databases into a proper relational database format. At very least ASCII, DbaseIV and INFO tables should be accommodated by the systems in a two-way data-flow, to and from the GIS.

- The centralised system must have the capability for generating customised reports, including summary statistics, from Vector and Raster data-sets, for use by project specialists. These reports need to be, at very least, in digital ASCII format, but preferably in a wide range of database formats;

- The centralised system should have some mechanism for low-cost, platform independent, view-only access or query of the centralised database. This will allow for all users of the OKACOM project data to have at least visual access to the datasets;

- The centralised system should permit network access to the central files/GIS database from remote terminals, even if only for data viewing operations. Preferably it should also permit easy access to a specific dataset/s, extraction thereof, and download to a remote site for further processing/analysis;

- As far as possible, the centralised data repository should deploy the fewest number of different software solutions possible in order to minimise maintenance costs, and complex data translation/linking issues.

v) following selection of a centralised database software, undertake import of the datasets and organisation into a workable and accessible data structure, with procedures put in place for addition of new data as it becomes available during the Environmental Assessment phase. GIS consultants would have to be called in to assist in the implementation of this phase, guided by **the project's** chosen software requirements, data-sets and format, and accessibility requirements. It is essential that the database setup meets the project's data requirements and data exchange needs, and not visa versa, that is, that these are made to fit into any existing software dictated formats.

vi) Simultaneous to the setting up of the centralised database, those involved in the OKACOM project who require access to the central GIS/IP database, and who are not already equipped with software and hardware to do so, be supplied with the necessary system/s most compatible with the central database system. For those equipped with their own systems, mechanisms for data query, data translation to the format of their choice, and data delivery mechanisms should be put in place.

3.2.4.2 Catchment Topography

It is considered that the objectives of the Environmental Assessment and Itegrated management Plan do not justify the production of new topographical maps for the entire catchment, and the detailed aerial photography and ground truthing that would normally go with this.

However, it is clear that the existing mapping for much of the catchment is not sufficient. The following approach is proposed:

- Scan and vectorise the exisiting 1 : 100 000 or 1:50 000 mapping where this is not already available. The information on these maps should be limited to infrastructure (roads, towns etc) and contours. The colour components representing vegetation changes/types etc should be omitted. This makes scanning an easier and much less expensive process.

- The 1993 TM Landsat imagery (or more recent) should be used as a backdrop for these maps and will allow the up-dating of infrastructure, such as the position of roads, settlements , agricultural developments, land-use changes etc.

- This approach ties in with the philosophy already outlined under 3.2.4.1 b) and GIS requirements.

3.2.4.3 Soils Studies

For both environmental assessment and river basin management purposes, the production of a regional standardized soils database is imperative. The Soil and Terrain Database for Southern Africa (to be released by FAO) contains a preliminary correlation of Angolan soils to the FAO Revised Legend in addition to a full dataset of Botswanan soils. The scale of 1:1,000,000 is, however, of little value for river basin management.

The initial scope of work to be undertaken in the environmental assessment phase should focus on the development of a regional soils database in which information is based upon the FAO Revised Legend and from which thematic maps may be derived at a scale of 1:250,000. This scale is consistent with the general scale to be utilised for the base satellite mapping. It is also a convenient scale for the production of hard copies of complete satellite image scenes.

4. HYDROLOGY, HYDRAULICS AND GEOHYDROLOGY OF THE OKAVANGO RIVER

4.1 Hydrology

4.1.1 General

Section 4.1 and its sub paragraphs are limited to the discussion of surface water. Rainfall has already been discussed under Section 3.1.

It cannot be stressed strongly enough that reliable runoff data over the whole catchment is absolutely fundamental to the understanding of the system. If estimates of runoff are not accurate then the modeling of runoff against determinants, such as climatic and catchment characteristics, and much of the work that goes into their evaluation will be time wasted..

4.1.2 Information Gaps

The lack of any data for the last 23 years in the Angolan section of the catchment is a very serious data gap. At one stage, more than 15 autographic stations were spread around the catchment in Angola. Due to the fact that these stations were usually sited at convenient places (near towns and road crossings), the sites were often inferior from a hydraulic point of view.

Another serious gap in the data collection network is the lack of a cableway for speed gauging in order to check the water level/discharge rating of the Rundu station. The rating of the Rundu station, which is a key station on the river system has not been checked for more than twenty years, and there are strong suspicions that runoff data, especially for the low flow levels are incorrect.

Within the Delta ongoing modeling of the distributary system means that a widespread system of stations is required and that these must be rated. There are a number of new stations in operation, but a major effort is required to rate these stations. According to Sefe (NCR) there is still an enormous gap that exists in the hydrological knowledge of the Okavango Delta, that there is a paucity of data of doubtful quality.

4.1.3 Work required

4.1.3.1 Hydrometric Network

It is strongly recommended that a first step towards re-instatement of the hydrometric network in Angola is taken as soon as possible. This is one of the few actions that should not wait for the elaboration of the Strategic Action Plan. A minimum of 6 stations should be re-instated at their original sites as soon as possible if these sites are found to be suitable. A hydrometric task force should be appointed to investigate as many of the sites as possible and to recommend to the PMU what action should be taken. Where this action simply involves repair and re-instatement of existing stations it should be taken as soon as possible. A minimum hydrometric network should be running before September 1999.

The next step will be to decide exactly which other stations are required for long-term monitoring. This will include the addition of a further +/- 6 stations in Angola, and perhaps 2 in Botswana. In the Delta it is reported that initial .primary data collection is still required and attention should be paid to designing a network that will assure representative spatial coverage It will also be necessary to add a number of cableway sites a for speed gaugings. Allowance will have to be made for 3 permanent cableway installations, one in Namibia downstream of Rundu, and two in Angola at key stations on the Cubango and Cuito Rivers. Sites for cables for temporary speed gauging sites should also be implemented at all stations where discharge measurements are required.

The practice of carrying out joint gaugings as currently carried out by Namibia and Botswana at Divundu and Mohembor should be continued and extended to take in key stations within Angola.

4.1.3.2 River Modelling

A substantial amount of modelling has been carried out in the delta, effectively from Mohembo downwards. This modelling needs to be continued, but it will be necessary to set up a river model that takes the river from source to the Delta. Calibration of this model in Angola will be impossible before river flow data starts to be available, but work will have to begin on setting up the model at an early stage. A number of models can be considered and will be necessary to look at experience gained on the Zambezi and Orange Rivers as well as within the Delta itself. Initially efforts should be concentrated on achieving an accurate picture of flow distribution around the system, but ultimately the model will have to take into account land-use, the various demand centres and their abstractions and become a tool for predictive modelling of the Delta. It will, therefore, become an essential tool for Integrated Management Planning. In the process of elaborating the SAP a specialist group will have to make specific recommendations on this aspect and to consider all possibilities, including for example, the proposal put forward by the National Heritage Institute.

4.2 River Morphology, Hydraulics, Erosion, Sediment Loads and Sedimentation

4.2.1 Data collection and Work Required

Satellite Imagery, both Landsat TM and more detailed SPOT will be required to look at river morphology, especially within Angola, critical areas in Namibia and in the Delta. 1973 imagery (Landsat MSS) and 1993 imagery (Landsat TM) has been acquired for most of the active system and this will provide a useful point of departure. It may be necessary to acquire some aerial photography as well but this can be on a low-cost basis.

There is an urgent need to collect data on suspended and bed load in the catchment uspstream of the Delta. Allowance will have to be made for an investigation into the most effective way of doing this and to implement a data collection programme.

All the above information will be used to obtain an understanding of where and how the erosion and deposition of sediments id happening within the catchment and will ultimately feed into the river model mentioned in 4.1.3.2. The linkages between land-use practices and erosion/sedimentation patterns are clearly fundamental ones.

4.3 Groundwater

4.3.1 General

4.3.2 Information Gaps

The geohydrological data of the Cubango River Basin in Angola is practically non existent.

The lack of hydrogeological information is due to the absence of investigations carried out during the past 20 years, and also due to the loss of a number of documents and reports from the different Centres of Documentation.

With the purpose of having at least a general point of view relating to the geohydrolgical aspects of the Cubango River Basin, and in order to properly prepare and organize future hydrogeological research in this area, it is highly recommended to collect more data and geohydrological information on the Cubango basin. In this respect, it is recommended to programme a "bibliographic/literature search mission" in the different Portuguese institutions which have been working together on the various studies carried out during the colonial period in the south of Angola. These include the "Junta de Investigaciones de Ultramar" and the "Laboratorio Nacional de Ingeniería civil de Portugal ".

It is also recommended to undertake a "geohydrological mission" to the "Hidrominas" in Lubango, with the aim of locating more hydrogeologic information (geological profiles, groundwater chemistry data, aquifer information, etc.) relating to the boreholes constructed over the past decades in the Cubango District.

Within the Namibian Sector of the catchment, a number of studies have been carried out, and it will be necessary to review these in more detail. It has been stated that groundwater levels in the area are not really affected by the level of flow in the river. Water Quality of groundwater is a different matter and analysis of the available and new data will be required.

Up until now, very little is known about hydrogeological processes in the Okavango Delta. This being the case despite the fact that the possible role of shallow groundwater tables in outflow generation was recognised as far back as 1975, when three piezometers were installed in a small experimental area in the seasonal swamps, called Beacon Island (Dincer et al., 1976). In that study, high auto-correlations of the observed water levels were noted leading to the conclusion that "it is nearly impossible to have a year with very low Delta outflow, if preceded by a couple of years with above average hydrological conditions". (Dincer et al., 1976)

That statement is a recognition of the role of groundwater levels in the generation of outflow. Whenever groundwater tables are high as a result of high local rains in the preceding rainy season or as a result of residual groundwater storage from a previous inflow, the following year's outflow is relatively large, and its magnitude bears no relationship to the magnitude of the inflow. There is clearly a need to observe groundwater level fluctuations over large areas of the delta and to incorporate these observations into models of the delta so as to obtain a clearer picture of the outflow generation processes. The existing models do not do this as both evapotranspiration and losses due to groundwater recharge are treated in a compensatory manner; high groundwater losses associated with low evapotranspiration values and vice versa.

5. WATER QUALITY OF THE OKAVANGO RIVER

5.1 Ambient Characteristics, Dissolved Solids, Salinity, Fertilizers and Increased Organic Inputs

5.1.1 General

5.1.2 Information Gaps and Work Required

5.1.2.1 Introduction/general

No recent information exists on the ambient water quality of the Cubango and Cuito Rivers and their tributaries within Angola, and this should be collected as soon as possible. It is important to collect data up and downstream of major settlements such as Menongue and to monitor this regularly

A certain amount is known about the water quality of the Okavango River in Namibia and the groundwater of the region is also documented in terms of its ambient characteristics. The ambient characteristics of the river upstream and downstream of the confluence with the Cuito has not been adequately researched and explained, nor have the variations in quality and chemical content on a seasonal basis been investigated

The detailed work that is required on water quality relates especially to the Delta where the processes are more complicated.

5.1.2.2 Uncertainties in Chemical Processes

The high evapotranspiration rates causing subsequent precipitation of solutes appears to be the Okavango's main chemical process. There is no doubt that this process is very active, but there are still large mass balance deficiencies which cannot be totally explained by precipitation reactions.

Certain islands show salt accumulation at their centers. However, neighbouring islands of similar size, age, vegetation pattern, geology and location can show no salt effect. (Warmeant 1997, unfinished Masters thesis).

The Maun Groundwater Project 1996 has shown that the distal reaches of the deltas groundwater supply are rapidly becoming more saline in places.

Isotopic signatures of some well points indicate that groundwater recharge is primarily from floodwater in origin. Certainly subsurface conduits are active for distribution of TDS, but what remains to be determined is, how much TDS are infiltrating through from the distal portions of the delta, and the longer term effects on Maun's water supply.

Other questions to be considered regarding salinization include:

1) Is the process of salt build-up detrimental, and if so, over what time scale?
2) Is salt accumulation likely to increase or decrease due to further development in the catchment area?
3) Are there any visible effects of adjustment in the water system such as frog, fish or muscle distributions changing?. Fishing species of birds depend on water clarity for survival. Distributions of Pels fishing Owl's could be useful baseline data on general water chemistry changes.
4) Does rainfall add any significant amount of salts to the system given average rainfall and distribution over the delta?

As yet, no one has recorded the chemical changes that should occur when relatively oxygenated and oligiotrophic surface waters of a new flood inundate seasonal floodplaines with underlying deoxygenated, solute rich groundwater. The resulting processes that could occur may provide an insight into the more complex water chemistry that exists in seasonal floodplains. This phenomenon should be monitored both spatially and temporally to assess variation in the composition of both waters.

To assist the understanding of chemical reactions in seasonal swamps, the decomposition reactions and products of plants in the seasonal swamp should also be studied.

5.1.2.3 Methodologies and Analytical Procedures

Cronberg et al 1995, 1996 carried out detailed chemical analysis over a large area of the delta Fig 1. Similar field practices should be adopted for future monitoring with sizes of sample and study grids adjusted accordingly to maintain continuity.

Ideally, analytical procedures used should also be consistent with work previously done. Methods used in Cronberg et al 1996 are shown in Appendix F. However, if possible, methodologies and analytical procedures used for chemical analysis should be available and consistent with corresponding Namibian and Angolan studies.

5.1.2.4 Monitoring Chemical Constituents and Baseline Determinations.

Constituents described in this review should be included in any future study. Some constituents, such as toxics, have received minor attention. However, as development increases in the Okavango catchment the concentration of present natural levels of toxic constituents will be useful in assessing future major impacts.

5.1.2.5 Area Selection Criteria

Suggested areas are given based on the following four criteria:

1) Suitable coverage of varying habitat types.
2) Logistical suitability such as:
i) Proximity to airstrip
ii) Accessibility by vehicle, boat or foot during flood periods
3) Time constraints on study.
4) Availability of previous information.

5.1.2.5 Suggested Study Areas.

In addition to the system in general in Angola and Namibia which should be monitored regularly throughout the year the following detailed monitoring is required in the Delta:

Area 1 (The Jao/Boro River.)

This area should be used to continue monitoring of previous work for comparisons with seasonal variations. This area was initially chosen because of its importance for Maun's water supply.

Area 2 :

The Xudum system is suggested because of its purely seasonal nature. The previous work on the Jao/Boro system has been limited in the lateral extent of study regarding seasonal floodplaines.

Recent work on hydrogeology of islands is being carried our in the Xudum region to determine if similar transpirational processes cause precipitation of solutes in a similar manner to that observed in permanent swamps (Warmeant 1997 unfinished Masters thesis). Correlations can also be made with work being done by Ambrose Gieske in the same region. Significant additional monitoring of chemical constituents will need to be done in the Xudum region to compare it to the results from the Jao/Boro area.

Area 3

The Maunachira River has been studied by McCarthy and the Okavango Research Group as the University of Witwatersrand. Although water chemistry has not been the focus of their studies, valuable information on hydrology and vegetation control have been recorded which will greatly assist in long term monitoring plans.

Area 4

The Mburoka/Santantadibe Fig 1 has received little attention. A comparative study with the Jao/Boro system would give a greater insight into the chemical processes active over larger areas of permanent and seasonal rivers and floodplaines.

5.1.2.6 Work Programme

Immediate Goals

1. Establishment of water chemistry / quality guidelines should be agreed upon and adopted by Botswana, Namibia and Angola to maintain continuity. Such as the guidelines and nomenclature outlined in this review.

2. Establishment of monitoring and analytical techniques that are reproducible by Botswana, Namibia and Angola.

3. Establishment of sample and monitoring sites applicable to water chemistry / quality and other disciplines, time constraints, logistics and budget.

NB The use of satellite imagery available at Tsetse Fly control in Maun would be invaluable in pinpointing exact areas of interest to all scientific disciplines. Local knowledge of the Department of Water Affairs (Jane Nengu, Maun) and independent Pete Smith would enable relatively exact re-sampling of previous studies and an additional insight into other potentially important study areas.

Short term monitoring

General recording of systems variables such as temperature, pH, Dissolved Oxygen, Total Dissolved Solids, toxics, nutrients, salts, dissolved organic carbon and plankton should regularly be monitored. Particular interest should be given to the fluctuations of dissolved oxygen, TDS and nutrient loads in seasonal floodplains.

Historical chemical information on pollen in peat has been previously attempted by McCarthy with little success due to oxidation (Pers comms). Isotope work on microfauna could be an alternative method of determination.

Long term monitoring (3 - 5 years)

Monitoring of approaching floods and the effects on water chemistry, although a relatively quick event, the effect of chemical interaction will need to be monitored throughout the season to assess full chemical interaction. Several such events will need to be monitored to complete a significant data base. Also, the approaching flood water will need to be monitored over the various study areas to asses the effects on similar habitats in different areas and effects on different habitats in all areas. This will be constrained by logistics.

A similar continuation of monitoring will be needed for the process of evapotranspiration chemistry. Rainfall additions of TDS will also need to be monitored to assess the effects.

5.4 Water-borne diseases/health hazards

5.4.1 General

Very little is known about the atatus of water-borne diseases in the Angolan portion of the catchment. With respect to health hazards, it will be necessary to look carefully at current waster disposal practices around all significant settlements, which will require on the ground inspections, interviews and a water sampling programme (see section on water quality earlier)

5.4.2 Information Gaps

Little is known about the seasonality of bilharzia in Namibia and no data are available on where the main contact points are.

Little is known of the situation in Angola. The World Health Organisation (1987) map of the distribution of bilharzia in Africa shows that both urinary and intestinal bilharzia occur in the Cubango and Cuito catchment areas, but there are no statistics as to how serious the situation is.

5.4.3 Work required

5.4.3.1 Investigations, Data Collection and Research

Regular monitoring of the situation is required. A useful way of doing this would be the testing of school children as well as snail counts at the contact points. The effect of molluscicides on non-target organisms should be monitored very closely.

In Botswana, natural water points used by people should be monitored annually to ensure that bilharzia snails have not re-entered the area.

It is recommended that the weir at Andara should be dismantled to reduce the high population of blackflies breeding there. If this is not possible. alternative measures should be considered. Very careful monitoring of the human population needs to be done to detect the presence of river blindness.

It is recommended that a survey be carried out in Angola similar to the one proposed for Namibia by Schutte. The river should be examined for suitable snail sites and children in the vicinity should be tested. The swamp area near Huambo should also be investigated. Rocky areas and any man-made structures in the river such as weirs should be examined for the presence of blackflies which host river blindness.

6. THE OKAVANGO RIVER ECOSYSTEM(s)

6.1 Primary Production

6.1.1 Information Gaps and Work Required

6.1.1.1 General

While some work has been carried out by various international agencies with respect to socio-economics and demographics in Angola, as part of aid programmes, no new work has been done in Angola on flora, habitats and ecosystems. There is therefore a huge amount of work that has to be carried out in Angola to get anywhere near on a par with knowledge in Namibia and Botswana. Fortunately the use of satellite imagery and relatively fast techniques for vegetation mapping it will be possible to make advances fairly quickly in terms of data collection and analysis in Angola.

A number of data requirements mainly within Botswana and Namibia has been identified in the literature during the last decade. Many of these have been included in the discussion below. It should be noted, though, that one of the fundamental issues that needs addressing is the size of the basin in Botswana and the disproportionately important role these waters play in the ecology of northern Botswana (± 95% of all perennial open water in Botswana). During the EIA on the proposed Namibian water abstraction pipeline, the study area was defined as the Okavango Delta fan and Upstream areas. The outflows were not included in the study. The OKACOM study should not make a similar mistake.

6.1.1.2 Taxonomy

The Peter Smith Herbarium, housed in the Okavango research Centre in Maun has been sorted and catalogued and computerisation is now underway. this should be complete by mid 1999. This will offer the opportunity to plot species distributions on a GIS. With certain key species further collection of specimens will be needed to develop useful species maps. Collection activities were not limited to the Okavango River within Botswana. With the envisage expansion of the Okavango Research Centre, including the establishment of proper Herbarium storage, it may be a good idea to expand the collection to include all samples collected during the course of the proposed environmental assessment.

Classification of the dryland plant communities is needed to develop a uniform classification system for Ngamiland. The approach should be based on the Braun-Blanquet technique with soil type being used as one of the main environmental parameters.

Similarly a single definitive classification of wetland communities in the system is needed. This classification should build on the work of the Ecological Zoning report (SMEC, 1989).

Smith (in SMEC, 1989) indicated the need for taxonomic review of certain plant genera which are important to the Okavango. These genera belong the families of Nymphaeaceae, Menyanthaceae and Cyperaceae.

6.1.1.3 Mapping

Satellite imagery, a deal of which has already been obtained and for which preliminary processing has already been carried out is available for all of the hydrologically-active catchment. The approach outlined below for mapping work in Botswana is essentially the approach that should be adopted for the catchment in Angola and Namibia as well. It must be stressed that while satellite imagery will prove to be an extremely useful tool, ground training is absolutely essential, so access into all parts of the catchment will be indispensable.

A recommendation made in the Botswanan Ecozoning report to map the boundary between the seasonal swamp, the flooded grasslands and the intermittently flooded areas has still not been implemented. The approach suggested was for the use of air photos and satellite imagery together with extrapolation from extensive ground truthing to map these boundaries.

During work on the Delta Photographic Area Management Plans (Ecosurv, 1996) it became clear that the rate of change of flooding and hence vegetation was very high as in many areas mapping undertaken during the Ecozoning was out of date. In a system where use of the area relates closely to the distribution of water (tourism and plant resource use), a static vegetation map will always be rapidly outdated. A dynamic vegetation map which will allow us to examine the response of plant communities to changes in annual flooding and fire, is proposed as follows. This would apply to the catchment as a whole, and it should be remembered that vegetation data and land-use data (and other data) can be collected simultaneously on the ground:

i) Develop a single definitive classification of plant communities in the catchment.
ii) Obtain further imagery as necessary. As the work progresses, images should be purchased for the mapping exercise for high and low flood periods in the same year.
iii) The images should be accurately geo-referenced using a large number of locatable points (airstrips, roads and channels)
iv) Collect a large number of locations of plant communities using a GPS. Past work can be included if the classification system can be standardized.
v) Train the computer to recognize different plant communities on the image. Map communities at a suitable scale.

If this single definitive work on vegetation classification is undertaken, then an updated map can be generated at any time in the future and an assessment of vegetation to changes in water supply can be accurately ascertained. This dynamic approach to mapping vegetation in a rapidly changing system will provide us with some idea of the interaction between vegetation and water supply.

6.1.1.4 Ecosystem Functioning and Plant Environmental Water Requirements

With respect to the catchment in Namibia, very little original research (with the exception of fish studies) has been done in recent years and most of the information gathered for this and other recent studies is derived from other work. has been done in the Okavango Region of Namibia and most of the published material is in the form of reviews and/or annotated checklists, or as ancillary information in management and development strategies. The lack of comprehensive baselines, long-term data series and monitoring programmes relevant to developing an understanding of the biology and ecosystem functioning, is a major problem in clarifying the potential impacts of the broadscale changes that have occurred as a result of human interventions over the past 20 years. This is also a major problem in developing recommendations for mitigatory or reconstructive actions to develop the area further in the future. This large gap in original research (most notably in the fields of wildlife management, agriculture and vegetation studies), baselines, data series and monitoring programmes distinguishes the Namibian information base markedly from that pertaining in Botswana which is relatively well covered. As already stated, no studies have been carried out in the Namibian sector of the river which detail the determinants and processes involved in defining the principal riverine and associated vegetation units The importance of plants in the hydrological and biological cycles of the river has not been studied in any detail. This work is clearly fundamental to a good understanding of the functioning of the ecosystem.

The role of fire and frost as determinants of the vegetation units in these seasonally flooded areas is open to question. Fires occur frequently in parts of the system, particularly the *Phragmites* and *Cyperus papyrus* reed beds but whether these fires alter the structure and composition of these units is unclear.
The grazing resources of the floodplain (particularly the *Cynodon dactylon* lawns) are some of the most important natural resources within the Okavango River basin. Fish breeding is to a large extent dependant on the integrity of these resources in that they provide important nutrient inputs into the system as well as provide numerous breeding sites for fish. The commercial (and socio-economic) value of these resources as integral support systems for the maintenance of the regional livestock herds has not been studied in any detail, but should not be underestimated. The seasonal floodplain grasslands and grazing resources warrant considerable investigation relative to the utilisation by livestock owners and the stability of the local economy.

A good deal of time needs to be put aside for the understanding of the ecosystem, which obviously includes the environmental water requirements along the river in both Namibia and Angola.

In the hydrological modeling of the delta, compartments (model cells) are treated as uniform. Yet it is clear that they are made up of a mosaic of plant communities that are dynamically interacting with the water, dissolved solids and sediment supply. Because mapping of vegetation is on a coarse scale ie, the perennial swamp is mapped as a single unit, it is impossible to predict impacts to vegetation with changes in water and sediment supply. When dealing with the outflows of the Delta the situation is even more complex as there are incidences of flood frequency being as low as 1:30 years. It is doubtful whether standard linear modeling will be useful in determining impacts in changes of water supply or in identifying environmental water requirements. It may be necessary to consider other approaches to modeling such as chaos theory.

The Interim Environmental Evaluation specialist consultant reports from the proposed water abstraction by Namibia indicated a large variation in their predicted area of impact from upstream water abstraction. These differences came from different approaches to predicting impacts based on mathematical models. It is therefore important to develop a more empirically based approach to identifying impacts if we are to use resources in the catchment of the Okavango Delta. The vegetation mapping approach suggested above will go a long way to providing empirical results.

Although much of the dynamics of the plant communities of the Okavango are understood, there is little literature concerning environmental water demand. The main problem is the inherent high variability in the system makes definitive requirements impossible to quantify. An alternative approach to developing a mathematical model is to draw on the experience gained during the Lesotho Highlands scheme where environmental water requirements were estimated in a workshop situation. The results of the workshop were useful in identifying "orders of magnitude" water requirements. At such a workshop it is necessary to include the following fields of expertise:

- people with a long term knowledge of the system ,
- hydrological modeller,
- sedimentologist,
- botanist and ecologist,
- an experienced facilitator who is fully aware of the environmental issues.

A workshop of this kind would be a first step in identifying environmental water requirements.

6.1.1.5 Monitoring Issues

There are a number of aspects of vegetation that need monitoring, these are:

- change in plant community boundaries,
- fire and fire frequency,
- spread of *Salvinia molesta,*
- the use of natural resources,
- impact of elephant on vegetation in the Delta.

The satellite based vegetation map will allow for these types of monitoring.

This type of mapping will have additional benefits in terms of monitoring settlement and arable agriculture in the Delta.

6.1.1.6 Resource use and Management

There has been little attention paid to the impact of traditional use of plant resources on the resource base. This is of concern as harvesting changes from traditional subsistence to commercial. The rights of access and use of resources are easy to manipulate for commercial or non sustainable harvesting of natural plants.

Resource use could also be strongly affected by changes in the flood regime, resulting in conflicts occurring due to reduction in wetlands and changes in fire regime.

6.2 Secondary Production

6.2.1 General

The importance of studying and understanding fauna relates to the fact that fauna, as the secondary producers play an important role in the maintenance of habitats and ecosystems in general. With respect to this study, the focus is water and will be important to that the study of secondary production is seen in this light.

Information on secondary production in Angola is minimal, and what there is outdated. According to Alheit (NCR) there is very little visible signs of fauna, either domesticated or wild in much of the catchment. It seems that a search for food during the difficult times of war has had a major impact on the fauna. It will, therefore, be important for work in Angola, to look beyond the current status, but also at the past and possible future status.

6.2.2 Information Gaps

6.2.2.1 Mammals

i) While it appears that increasing elephant populations could be having an impact on biodiversity in the Okavango Delta region, the extent to which this is occurring is not known.

ii) Negative impacts on wildlife (and plant communities) by growing numbers of tourists occupying reduced dry season habitats have been alleged especially in Botswana. No supporting data are available.

iii) While the general distribution of most predators and the smaller mammal species populations has been recorded, little is known of their status, ecology and habitat requirements in the Okavango Delta region. Within Namibia, there is also a need to collect data, although numbers are very low outside of the Muhango Game Reserve.

iv) Aerial census data on large predators are very inaccurate. With the exception of wild dog, systematic species-specific surveys have not been conducted in the Okavango Delta region.

v) The interrelationships between the recent declines in many large mammal species populations and increases in others (elephant, lechwe, wildebeest) in the Okavango Delta region are not well understood.

6.2.2.2 Fish and Fisheries

i) Few data are available on the current status of fish population dynamics and ecology, and their habitat requirements in the Okavango Delta.

ii) Statistical information on fishing activities is imprecise and extremely variable. Harvesting rates and their impacts on key fish populations have received little attention.

iii) Little is known of the limits to productivity of the waters in the Delta and the impact of floods on fish populations.

iv) The long term effects of tsetse fly spraying on the environment, and particularly on fish populations, are not known.

v) There is a shortage of basic hydrobiological and limnological data for the Okavango Delta. Information on hydrobiology is the most significant gap in knowledge of the biota and processes of ecosystem functioning in this area.

6.2.2.3 Birds

i) There is a lack of knowledge of habitat requirements, nesting and feeding habits and sites of several bird species of special concern to conservation.

ii) Negative impacts on vulnerable waterbird populations and nesting and roosting sites by growing numbers of tourists have been alleged. No supporting data are available.

iii) The role of the northern wetlands in the ecology of migrant birds is poorly known.

iv) Limited information is available for raptor species and game birds.

v) There is little information on habitat requirements and ecology of the species of the largest order, Passeriformes.

6.2.2.4 Reptiles

i) Apart from crocodiles, almost nothing is known of the status, macro distribution, ecology and habitat requirements of reptiles of the Okavango Delta region.

ii) Very few data have been collected on the habitat requirements of reptiles in the region (other than the crocodile).

iii) Current population estimates and dynamics information for crocodiles, including hatchling survival rates, are lacking.

iv) Sustainable quotas for crocodile egg collection have not been determined.

v) The role of crocodiles in fish population ecology requires further investigation.

vi) The current effects of human and domestic animal disturbance on crocodile nesting and reproductive success are not well known.

6.2.2.5 Amphibians

i) Almost nothing is known of the status, macro distribution, ecology and habitat requirements of amphibians of the Okavango Delta region.

ii) No information is available on the microhabitat requirements of the different taxa which might explain their apparent uneven distribution (q.v. CSIR/WTC, 1997, Appendix H).

iii) Though some specimens were collected in a limited number of surveys, very little is known of the impacts of large-scale insecticide spraying programmes on amphibians in the Okavango Delta.

6.2.2.6 Terrestrial Invertebrates

i) Apart from the tsetse fly, little is known of the status of terrestrial invertebrate populations of the Okavango Delta region.

ii) Monitoring of tsetse fly control operations has been inadequate.

iii) Little research has been conducted on the ecology and habitat requirements of terrestrial invertebrate fauna in the Okavango Delta, or elsewhere in Botswana.

6.2.2.7 Aquatic Invertebrates

i) No detailed systematic surveys of the aquatic invertebrate fauna of the Okavango Delta region appear to have been undertaken.

ii) Very little research has been done on the ecology and habitat requirements of aquatic invertebrates in the Delta, or elsewhere in Botswana.

6.2.3 Further Studies Required

6.2.3.1 Mammals

i) Systematic aerial monitoring of large mammal distribution and population estimates should continue to be conducted annually (seasonally, if possible). Areas covered and intensity should be based on local conditions, and especially flood regimes and rainfall.

ii) Systematic survey flights covering selected habitats (e.g. perennial and seasonal swamp floodplain ecotones) should be conducted at higher intensity during transitional phases in the annual flood regime.

iii) Stratified random aerial census surveys of important species should be flown annually with distribution linked to habitat type occupation.

iv) Cryptic species (mainly large predators such as lion, leopard, cheetah, wild dog, hyena, etc.) population estimates, habitat preference and ranges, breeding and behaviour information are required.

v) Key indicator, or vulnerable species and their habitats require monitoring. These species include the large predators, tsessebe, sitatunga, impala, giraffe, warthog, roan and sable antelope and waterbuck (ORC/UB have initiated studies on impala and warthog).

vi) Species causing significant changes to vegetation (e.g. elephant impacts on riparian forest, hippopotamus grazing impacts and channel alteration, impala and warthog grazing impacts) should receive high research priority. Baseline data on elephant impacts should be collected immediately.

vii) Floodplain ecotone inter-specific herbivore competition studies are required to better understand population dynamics in relation to limiting dry season floodplain (sedge community) grazing.

viii) Limits of acceptable change (LACs) need to be determined for the habitat types affected by large herbivores, especially elephant in riparian woodlands.

ix) Impacts on wildlife species and populations of visitor (tourist) densities and use of the Moremi Game reserve and the surrounding CHA's should be monitored as described by Ecosurv (1996).

6.2.3.2 Fish and Fisheries

i) Implementation of an integrated fisheries research programme and management strategy is urgently required (MoA Fisheries Unit).

ii) A long-term monitoring programme is required to determine fish population dynamics, primary causes for changes in populations and important habitats.

iii) A detailed survey of current traditional, commercial and recreational fishing activities is required. Harvesting rates, impacts on fish stocks, the interrelationships between different types of use, the degree of subsistence dependence and factors limiting use must be determined for management planning.

iv) Fish farming activities should be assessed as a potential means of reducing pressure on wild fish stocks and increasing revenues and employment opportunities.

v) Further research on fish populations use of habitats, particularly of the Boro floodplain in relation to breeding and nursery habitats, and flow and depth requirements for sensitive species in different habitat types is required (IUCN, 1993).

vi) Further monitoring of the effects of tsetse fly spraying activities on fish species and populations in various habitats is needed.

Hydrobiological and Limnological Studies

i) A complete In-stream Flow Requirement Study should be conducted for the Okavango system (CSIR/WTC, 1997).

ii) A thorough hydrobiological and limnological investigation of the perennial swamp is needed. Attention should be focused on processes such as primary production, nitrogen fixation, decomposition and peat formation, and on the component phytoplankton, periphyton, algal and zooplankton communities, benthic fauna, bacteria and fungi, and the relationships between these. (Research on plankton has recently been initiated as part of a floodplain ecology study being co-ordinated by the Okavango Research Centre).

6.2.3.3 Birds

i) Population status surveys, ecological studies and monitoring of reproductive success are required for the slaty egret, pink-backed pelican, wattled crane, marabou stork, Pel's fishing owl, African skimmer and any other key species (a waterbirds survey is to be initiated under DWNP).

ii) Monitoring the status of heronries and the potential impacts of tourist activities on occupancy and reproductive rates should be a research priority.

iii) Management-orientated studies of the game bird species are required with a view to suggesting hunting seasons and updating quotas and bag limits consonant with species numbers and biology (SMEC/KCS, 1989).

iv) An ecological study of the importance of Panhandle relict forests to bird populations would be of great value.

6.2.3.4 Reptiles

i) Macro distribution of reptile species should be assessed along fixed transects and by sampling populations using pitfall traps and drift fences (CSIR/WTC, 1997).

ii) Monitoring at intervals using these techniques would provide indications of reptile species' status, population trends and habitat changes.

iii) A management-orientated census survey of crocodiles and regular monitoring of active nests is required, with a view to updating quotas for egg collection consonant with population numbers and biology.

iv) A radiotelemetric study of dispersal movements of crocodile hatchlings and juveniles, and of annual movements of females to Panhandle nesting sites should be conducted to gain information on habitat preferences and requirements.

v) Movements of sub-adult crocodiles released from captive populations for restocking should also be monitored.

vi) An assessment of crocodile nesting success elsewhere in the Delta under current conditions should be carried out.

vii) With four species of terrapin occurring in the Delta, it would be useful to know more about distribution, feeding, breeding and habitat requirements of these animals, especially in areas of sympatry (SMEC/KCS, 1989).

6.2.3.5 Amphibians

i) Macro distribution of amphibian species should be assessed along fixed transects and by sampling populations using pitfall traps and drift fences (CSIR/WTC, 1997).

ii) Monitoring at intervals using these techniques would provide indications of amphibian species' status, population trends and habitat changes (particularly for sensitive frog species).

iii) An investigation of the microhabitat requirements of the different taxa would help to explain their apparent uneven distribution within habitat types (q.v. CSIR/WTC, 1997, Appendix H).

iv) A study of the breeding biology of frogs of the Okavango Delta should compare timing of breeding with the progress of flood regimes and with the onset of the rains.

v) Further monitoring of the effects of tsetse fly spraying activities on amphibian species and populations in various habitats should be conducted.

6.2.3.6 Terrestrial Invertebrates

i) A general survey of the status and distribution of terrestrial invertebrate groups of the Okavango Delta region is required.
ii) Monitoring of impacts of tsetse fly control operations and the distribution of tsetse fly using baited traps should be expanded.

iii) Studies on the role of termites in energy cycling and ecosystem functioning should continue under the supervision of the ORC.

6.2.3.7 Aquatic Invertebrates

i) Better knowledge of the distributions of the major groups of aquatic invertebrates throughout the system is required. An extensive baseline survey should be followed up by regular sampling at fixed sites to monitor changes in population structure as an indicator of ecosystem functioning.

ii) A thorough hydrobiological and limnological investigation of the perennial swamp is needed. (Plankton studies have recently been initiated as part of a floodplain ecology study being co-ordinated by the Okavango Research Centre).

6.3 Functioning of the Ecosystem Much has already been said about the need for understanding the linkages between climate, runoff, physical determinants, primary and secondary producers. In this particular study, which must not be seen as merely an inventorising exercise of flora and fauna, it is particularly important to understand how the ecosystems are functioning and how they are affected by natural or man-made changes to flora and fauna. It will also be important to understand how altered ecosystems are likely to affect the focus area of the study, water.**6.4 Influence of Man**The existing and potential influence on man on the environmental status of the Okavango River Basin is clearly central to the study. Much of man's influences relate to land-use and this is dicussed in more detail in Section 7.

7. MAN AND THE OKAVANGO RIVER BASIN

7.1 Introduction

7.2 The People and their socio-economic Structure

7.4.1 General

Information on population totals including the current and expected rates at which resettlement may take place in the Angolan portion of the catchment does exist having been collected by various agencies as part of various support programmes. Nevertheless, it will be an absolute priority to start the collection of useful and relatively accurate demographic data for the basin within Angola. It is likely that data on socio-economic structure will change rapidly from the current aid-dependent situation to one in which empowerment will result in a new structure very rapidly developing. While it may to great a task for the environmental assessment project to conduct a detailed census, a good deal of information will have to be collected looking at demographics, economic activities, social and economic stratification.

A major Rehabilitation Programme for Kuando-Kubango Province will likely consider :

- priority on productive investments and basic infrastructure;
- activities in the social sectors such as education and health, priority on the community base services (primary level education, clinics etc), which serve not only the rural people but also the urban people;
- development of local capacities, either geographic or sectorial based;
- pressure on the education sector, given the lack of qualified human resources in the province;

- assistance to the vulnerable people, as this is a war stricken province; and
- institutional capacity building in management, which will ensure implementation of the programme for the province.

While this work will not be the responsibility of OKACOM and the Environmental Assessment, those involved with implementing the above programmes will have to be involved in the elaboration of the Strategic Action Plan and throughout the duration of the project.

In general for the entire basin area, there are two levels of missing data. Firstly, there are areas in which no data have ever been collected, or where the data are not accessible. Secondly, there is a lot of “unprocessed” data available that has yet to be analysed or used. Often such information is in the form of statistical records kept by various government departments, and can be released under proper authorisation.

7.4.2 Demographic Data

This would have to be collected in Angola, and could perhaps be achieved if co-operation with those agencies responsible for re-settlement provide their co-operation and assistance.

Census data in Namibia and Botswana are recorded and stored at all levels from household upwards. However, only summary information have been published. A particular issue is that much information is only published for settlements of over 500 people. In rural Botswana few villages have reached that size. Data for smaller settlements could be obtained in digital format and analysed.

7.4.3 Economic Activities

Kuando-Kubango Province has a reduced population estimated at 136.000 inhabitants, insignificant town-planning, has been confronted with a 20 year was and 5 years of drought. The consequences of these catastrophes were dramatic for the population and infrastructure: the cities and villages are largely destroyed, the road communication and railways are in a poor state of maintenance (as there is no movement of persons and goods at this level), and as a result the prices of goods are extremely high due to the air transportation costs. As with much of the work in Angola, current data even if they were available are likely to be misleading due to the fact that they do not reflect the likely situation as “normality” returns to the area.

In Botswana information on the extent of involvement in crop production is now being collected, but is not yet available in published form. These data include: number of farmers, number of fields/hectares per farmer and total area under arable crops. Cattle census data are not easily available, but will be released with proper authorisation. There is no way of gaining an accurate picture of cattle ownership. This tends to be a touchy subject, and people lie and under-represent for fear of taxation and appearing much wealthier than neighbours. For the three regions in Ngamiland, quite detailed information has been collected as part of the re-stocking exercise, and this should allow for more accurate ownership data.

7.4.4 Social and Economic Stratification

The current situation in Angola is highly stratified with any wealth that exists in the hand of very few.

This is a natural result of the conflict that the country has gone through.

Very little information exists on changes in the distribution of wealth and assets for either Namibia or Botswana. In the few settlements where socio-economic studies have been repeated, it appears that wealth is being concentrated in the hands of a few. It is also not known to what extent resources are becoming controlled by these few.

No detailed socio-economic report has been found for the Boteti river settlements. Information such as the actual percentage ethnic composition, household structures, degree of participation in various economic activities is not available. A socio-economic baseline and land inventory study was carried out in the early 1990's (van der Maas *et al*, 1995-) by the University of Utrecht, but this has yet to be located.

7.4.5 Natural Resources Use

Within Botswana and Namibia no survey on the extent of subsistence and commercial use of and dependency on key natural resources has been done. No quantitative data exist on rates of extraction for any plant species. This is an issue of major concern because of the large increase in commercial off-takes of reeds and thatching grass for sale in main centres such as Maun.

Within Angola, it will once again be important to look at historical and potential use of natural resources.

7.4.6 Maps and GIS Data

The last aerial photograph survey in Botswana was carried out in 1991. However, this did not cover the whole region. Maps produced by the Department of Surveys and Mapping (DSM) are all based on surveys in the 1970's and early 1980's. This means that their representation of infrastructure is dated. Within Namibia recent work carried out for the entire Okavango Region means that a lot of useful data is available in digital map format and in a GIS. The applicability and usefulness of this data will be looked at in depth during the elaboration of the SAP.

As already discussed, satellite imagery (both TM for rural areas, and Spot for urban areas) will be vital to update mapping in Angola.

Recently DSM and some private sector companies have begun digitising these maps and generating new coverage from GPS data. It is not known whether the Department's digital data is publicly available. Private sector coverage tends to be job-and-study area specific. This means that they are often not complete at national or even district level.

7.3 Asset Ownership and Legislation

It will be necessary to complete the existing picture of asset ownership and to consider carefully how existing ownership within the catchment will fit in with integrated management of the basin, since no management plan can function if it doesn't fit in with existing ownership and management patterns.

7.4 Natural Resources Utilisation, and Natural Resource Economics

7.4.1 Water

7.4.1.1 Unit water demand and projections of water demand

Per capita demands in Angola can only be made once a complete assessment of demographics (especially expected demographics) is made. At present it is likely that per capita demand is extremely low, since almost all water must be manually obtained. Clearly much work has to be done and the PMU will have to develop a good working relationship with all those involved in the resettlement and rehabilitation programme.

The per capita demands in Namibia, as could be derived from available published information, were discussed in section A, where it was shown that the projected per capita demands, when compared to South African and other norms, are relatively low. Care needs to be taken to ensure that they are not too low to support the economic growth that is required to keep up with or exceed the projected population growth. It is therefore important that sufficient care is taken to correlate water demand projections in the economic sectors with that of the domestic sectors.

Future water demands of the human and economic environments in Namibia have been presented in several publications.

For Namibia as a whole, water demands have to be established that reflect the goals in NDP1.

For this purpose it is proposed that a new national water master plan be compiled that renews the framework within which regional water supply plans can be evolved.

A diagnostic assessment of the per capita demands in Botswana was presented in Section A where it was indicated that the projected per capita demands are relatively low and perhaps too low if economic growth is to keep up with or exceed the projected population growth. This observation supports the notion that the water demands should be re-assessed, which, in accordance with DWA policy, should be done every five years. To support the current OKACOM initiatives and the intentention of DWA to re-evaluate every five years, it is recommended that the Botswana water demand projections be updated soon.

Review of the water demand projections will perhaps be best done by using the computerised models that were developed for this purpose by the consultants who compiled the NWMP in Botswana.

7.4.1.2 Water supply balances

For the purpose of integrated catchment management, it is important to link consumers and their water demands with their associated river catchments and aquifers. This will enable the evaluation of the local demands on each of the river and groundwater systems and the need for inter-basin transfers. This in turn will enable improved basin management and provide the information needed for water use agreements and equitable distribution.

- extent of presently developed water sources and surplus potential
- current demands per demand category
- projected demands that reflect regional and national development plans
- allocation of sources to demand categories, based on the social value and full opportunity cost of water

This work should form an integral part of the proposed national water master plan.

The comprehensive work on demand projections on a national basis in Botswana should be supplemented by attaching additional labels to consumer entities and to sources to assess the demand and supply, by category, within the different catchments and major aquifer regions. In particular, this is required for:

- the Okavango Delta area and the adjacent groundwater area that is recharged from the swamps (which will include the requirements of Maun and proposed irrigation land)
- the Okavango Delta – Makgadikgadi Pan axis (which will include requirements of the Orapa diamond mine)
- the Okavango Basin as a whole

Categorisation along river basin and major aquifer boundaries will enable the evaluation of the local demands on each of the river and groundwater systems and the need for inter-basin transfers. This in turn will enable improved basin management and provide the information needed for water use agreements with neighbouring countries.

7.4.1.3 Role of the Okavango River as a source for water supply

The role of the Okavango River as source of water supply in its international context and then in its national context, therefore has to be clearly defined by all involved.

Within Namibia, the current and potential future irrigation demands along the river dominate the water demand figures. Prioritisation of the status of potential irrigation developments at the Okavango River against other competing consumers and interests are therefore of great importance within both Namibia and Botswana.

Along with defining the role of the Okavango River as source for water supply, other relevant issues regarding its utilisation include:

- effective control over the both quantity of water abstraction and quality of discharged effluent
- measures to prevent leaching of nutrients and pesticides from irrigation lands into the river
- extent and significance of groundwater recharge of the area surrounding the swamps
- environmental significance of the delta (which is the focus of reports done by others)

7.4.1.4 Okavango River consumer register

A register of existing users of the Okavango River water that describe their location, methods of water production, methods of wastewater disposal, purpose of use and quantities used, is necessary to:

- put the established claims to Okavango River water in perspective
- evaluate the implications of allowing new consumers access to the source
- exercise pollution control supervision

Certain elements of these have already been surveyed and it is recommended that this information be supplemented where insufficient and incorporated in the Okavango Basin management portfolio.

7.4.1.5 Legislation and regulation

It is understood that the new water act for Namibia is overdue and that completion thereof will go a long way in directing the water sector in Namibia. Apart from the act, it is also proposed that national water supply and wastewater disposal regulations be implemented countrywide to standardise and regulate, amongst others:

(a) efficiency in water use
(b) water metering management
(c) appropriate tariff structures throughout the country
(d) effective revenue collection
(e) wastewater discharge management and pollution control

7.4.1.6 Management information systems

It is essential to understand and quantify the basic nature of the different water consumers in the various demand centres in all three countries and to quantify the water demand patterns of the major consumers. For this purpose, it is proposed that a uniform database and management information system (MIS) be used countrywide to:

- facilitate assessment of water demands that are consistent between different regional water supply investigations
- perform water use audits in relation to pre-defined consumer categories
- link consumers to various geographical and administrative regions for the purposes of regional and basin management
- ensure that water loss control is exercised

7.4.2 Other Natural Resources

Information on natural resource utilisation within Angola is lacking, but it is also clear that were such information to be available it would not be representative of the "normal" situation. It will therefore be important to look at the current and likely re-settled population patterns, the natural resources that exist and to make predictions on how they are likely to be utilized as normality returns.

Regional development within Namibia since independence has also been slow and it has been suggested that there are comparatively fewer development programmes in Okavango than in other northern communal areas. Per capita expenditure (in terms of foreign aid and government funding) is the lowest of the northern communal areas. The result has been a regional economy which has not been able to keep pace with regional developments elsewhere in Namibia.

Critical to the understanding of land use and it's interaction with other basin processes is the development of cross-sectoral extension programmes emphasising the inter-related nature of the defining processes within the river basin. For example, the fact that upslope agricultural practices affects fisheries production through siltation, loss of floodplain habitats and pollution

The Okavango basin and the natural resource base which it constitutes in Botswana can best be characterised by their dynamic nature. Distributions of water, plants and fauna vary on a seasonal and long term basis. In order to make the best use of these resources, and to successfully plan for sustainable development in the basin, it is critical to develop a model of the resource base which reflects its dynamic nature. In order to do this, a wide array of different aspects of the system need to be measured, counted and observed. In this section, an indication is given of those areas which are considered important to measure or monitor to ensure that the resource base gives ample warning when it is being used beyond its sustainable limits. These are merely suggestions and should not be taken as a prescription for basin management.

Data concerning the most recent and planned status of land in the study area are clearly critical for any integrated planning for the basin. These data require collation from various sources, because the study area spans two districts. The District Land Use Planning Units, and the Department of Town and Regional Planning are the correct sources of this information.

The panhandle sector of the study area was identified by the Ecological Zoning study (SMEC, 1989) as "a priority area for a comprehensive investigation relating to land use planning, allocation policy and areas requiring special measures to protect ecological resources." Since then, the socio-economic baseline status of people living in the area has been recorded (van Hoof et al, 1991 & 1993). Little has been done on planning and future resource use aspects. This should be addressed without delay, as the reasons behind the prioritisation of the area by the Ecological Zoning study (high population density, high pressure on the resource base, little effective planning or management of the resource base) all still persist in the area.

It is critical to successful basin management that structured development plans are drafted for those parts of the basin which are currently without plans, or in which the implementation of plans has been delayed or postponed. Such plans are needed as a basis for management planning for the basin, and should be carefully integrated with existing planning.

Paragraphs 7.4.2.1 to discuss the data requirments and work that needs to be carried out in order to better understand the natural resources of the Okavango River basin, their importance to the well-being of the system as a whole, and their economic value.

7.4.2.1 Protected Areas and Tourism

Tourism potentials in Namibia are high and proposals have been made at several levels to allow development of private facilities within the parks (Hines, 1996b; Deloitte & Touche, 1997). The possible positive spin-offs of these facilities have the potential to improve local community attitudes towards wildlife and the parks in general through the provision of jobs and other economic opportunities. The MET has engaged a further round of planning, even though a comprehensive management plan for both areas has already been submitted (Hines, 1996b). This work is essential towards a real understanding of the value of tourism.

In Botswana it is a given that tourism is the major contributor to the study area's economy, and that it is still in the growth phase of development, monitoring of numbers and types of tourists is needed as well as careful monitoring of the resource that the industry is based on. This will allow feedback to the land use and development planning to ensure resource sustainability. It will also help to integrate the environmental changes in the area with the development of the industry. Examples of parameters which need to be monitored are as follows:

1. Total numbers of tourists
2. Lengths of stay
3. Main reason for trip or wanted aspect of tourism resource (wildlife or wilderness or hunting etc)
4. Parts of the area visited

This part of the required monitoring should be carried out by the Hotel and Tourism Advisory Board, or a similar body. Parts of it could be carried out by the operators themselves, and collated by the tourism organisation.

Examples of resource parameters which are required for planning and utilisation are as follows:

1. Changes in landscape resulting from tourism.
2. Upstream and downstream water quality monitoring at camps and lodge sites.
3. Perceptions of tourists of wilderness quality - (how many other people did you see etc).
4. Changes in vegetation balance resulting from tourism related activities eg, decline in recruitment of young trees because of constant clearing around bungalows/chalets etc.
5. Changes in ecology resulting from tourism activities eg, decline in breeding success of birds nesting in heronries due to disturbance by motor boats, excessive take of recreational fish.
6. Changes in hydrology resulting from tourism related developments eg, reductions in flow resulting from pole bridges.

To date, the tourism industry has had a relatively free rein in Namibia and Botswana, primarily due to the limited capacity of the local authorities to implement policies or enforce regulations. This has perhaps had little permanent effect on the resource, because the industry had not yet reached the geographical limits of the system. It seems likely that these limits have been reached (or exceeded) in the last few years, which have coincided with very low flows in the system. If the industry is to sustain the growth of the last few years without detracting from its resource base, not only will the capacity of the local authorities need a major boost, but the industry itself will have to adopt a more responsible attitude to management of the resource ie, some code of ethics is required.

7.4.2.2 WMA’s and associated CHA’s

Since most of the land use that takes place in these areas in tourism related, much of the above discussion applies. However, there are other aspects concerning these land divisions: are they ecologically suitable; what happens when flows no longer reach certain areas, but favour others; are there conflicts over resource use within WMA’s or at CHA level; are there more difficulties administering those CHA’s in which more than one party holds a lease for tourism? A carefully structured system for addressing these and other potential problems needs to be put into place to allow sensitive overall management. These problems have to be addressed at local authority level, and more capacity is required in Land Board, District Administration and Council to ensure equitable and sustainable use of the basin and its resources.

7.4.2.3 Urban Areas

Criteria which require monitoring for urban areas in the study area relate mainly to water use and effluent production. Population and industrial growth both result in increased demand for water supply of a given quality and both result in the production of water of lower quality than that incoming. Parameters which will require monitoring are as follows:

- Population size
- Population distribution
- Portion of the population relying on reticulated water
- Volumes of use and effluent
- Types of treatment for human waste
- Types and size of water-using industries
- Volumes of use and effluent
- Types of treatment for industrial waste

These figures need to be collected regardless of the source of the water (eg, groundwater as opposed to surface) because the groundwater in the peripheries of the delta is very closely related to the surface water.

7.4.2.4 Land Use

Data concerning land use are critical for monitoring extent of dependence on and status of the land resource. Little is known about the extent of arable agriculture from year to year, the changes in emphasis between dryland and molapo farming, and where what is being done. Like the vegetation and fauna of the study area, land use and particularly arable agriculture is extremely dynamic and variable from one season to the next. The present availability of cheap (free) NOAA AVHRR, and other satellite imagery, and the extensive coverage of digital geographic data in the study area provides a cheap and simple system for monitoring this sector. Considerable effort will be required in the initial stages for calibration, but this system of monitoring will be useful across the spectrum of sectors for an index of the health of the resource base in the basin.

Agriculture

The development of a farming systems research programme with its focus on the whole issue of agricultural practices within the river basin and how they could be adapted or improved to safeguard river system functioning are required. It is imperative that agricultural development programmes reinforce and improve systems rather than replace them.

Agricultural statistics are poorly collated and several studies show contrasting results.). If regional production is to be improved there is a need to develop programmes focused on intensification of production per unit under cultivation through soil fertilisation and improved labour allocations

Parameters which are important to monitor for arable agriculture are:

Parameter	Source
Area of dryland ploughed each season	Imagery
Area of molapo ploughed each season	Imagery
Area of cultivated molapo flooded each season	Imagery
Average production per ha dryland	ADD/Regional Agricultural Office
Average production per ha molapo	ADD/Regional Agricultural Office

The development of incentive schemes for the rehabilitation of riverside and upslope agricultural lands. There is a need to improve production levels through fertilisation, reduce runoff through terracing, tree planting and slope stabilisation.

Livestock:
A focus of current land reform in Namibia is to encourage owners of large herds to move their operations onto commercial ranches in order to preserve communal areas for poorer households. Incentives to move remain poorly defined and financially weak. The influence of large scale livestock farmers on land-use practices along the Okavango River warrants considerable further investigation.

Considerable emphasis will have to be placed on active herd management and grazing in the future if this aspect of the regional economy is to be maintained in its current condition or improved in the future.

Future data requirements for sustainable development of the livestock sector are as follows:

Parameter	Source
Total herd size	DAHP
Distribution	DWNP census data, crush figures DAHP
Range quality	Imagery
Annual offtake	BMC figures, district estimates
population trends	DAHP, DWNP census

Fisheries

Little information exists on fish yields and almost no work has been done on the productivity and fish stocks within the system. Estimates of maximum sustainable yields (MSY) vary

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The economic value of the fisheries requires considerable further study and should form the basis of a strategic plan for fisheries management in the Okavango Region.

The development of an understanding of the extent of the fisheries component of the local economy. There is currently a need to understand demands on the system, as well as defining the production capacity of the system to clarify sustainable yields. The non-financial values of fisheries in the economy also need to be better defined. The results could be used to influence decision makers at all levels to be pro-active in conserving the system in such a way that off-takes are sustainable in the long-term.

As pointed out in section **Error! Reference source not found.**, primary data on the use and productivity of the delta fishery are lacking. This is a gap which must be filled if this resource is to be developed and managed sustainably. Research into productivity should be initiated as part of the Okavango Research Centre's programme, while data on real levels of use can only be collected through socio-economic research among the people who live on the peripheries of the Delta. This is considered a major gap.

Hunting

Clearly, safari hunting will continue to be a major form of land use in the marginal CHA's in the study area. Management of the resource is the responsibility of the DWNP. Monitoring of wildlife populations is an expensive and difficult exercise. The DWNP has in the past carried out nation-wide aerial censuses of wildlife populations, and has a commitment to continue this practice. In addition to these censuses, there are some species such as lion and leopard, which are not well counted by aerial census, yet which have very high economic value as trophy animals. These species require concerted ground survey counts for population estimation, and in this regard, the holders of leases in CHA's in the WMA's are required to assist DWNP. This system has not yet been made to work to the satisfaction of all parties, and some further careful thought needs to be given to establishing a mutually acceptable system.

Mining

Feedback from the mineral exploration programme, and from any potential new developments in the mining sphere are needed for planning resource use and allocation in the study area. This will require a specific communication route between planners and the Geological Survey, who is responsible for the administration of prospecting and mining licenses.