MFMP
Makgadikgadi Framework
Management Plan

Chapter 4
Ecology and hydrogeology

October 2010

PULA

Republic of Botswana

CENTRE FOR APPLIED RESEARCH

Report details
This chapter is part of volume 2 of the Makgadikgadi Framework Management Plan prepared for the Botswana government by the Department of Environmental Affairs in partnership with the Centre for Applied Research

The following persons have authored this chapter: Dr Graham McCulloch, with inputs from the following persons: Dr Chris Brooks, Dr Frank Eckardt, Dr Jeremy Perkins, Dr Julius Atlhopheng, Thoralf Meyer, and Dr Jaap Arntzen.

Acknowledgements

A number of people were consulted and gave input into the compiling of this report, for which they deserve many thanks. The geologists, Charles Byron and Martie Sharrock reviewed and provided expert opinion on the geology of the MWS in the site inventory report. Similarly, Martie McFarland gave a comprehensive and much appreciated review of the geomorphology of the system. Birgitta Farrington was extremely helpful in providing background information and red list data for the areas flora. Others who helped in this respect were Tracey Irvine from the Millenium Seed Bank Project, John Dini from SANBI and Tandiwe Nkonki with the PRECIS project. Pete Hancock and Stephanie Tyler were both incredibly helpful with the Birdlife data and inventory. Rob Bryant gave us a unique insight into the hydrological dynamics of Makgadikgadi's surface waters, and a reference to the importance of groundwater input through a study of MODIS satellite imagery. Mike Kock at Debswana was very helpful in providing us with hydro-geological data and general environmental data for the Orapa area and wellfields. Tim Liversedge gave input into some of the species inventories and review of this document. Cornelius van der Post was very helpful with the GIS analysis of some of the species distribution data. Other experts of the area that gave valuable input were Ralph Bousfield, David Dugmore, Roger Dugmore, and Godfrey Nkata.

Citation:
Authors, 2010, Chapter title. In: Centre for Applied Research and Department of Environmental Affairs, 2010. Makgadikgadi Framework Management Plan. Volume 2, Technical reports, Gaborone.

Table of Contents

Acknowledgements 2
1 Introduction 8
  1.1 Component Terms of Reference 8
  1.2 Background to the physical and ecological characteristics of the MFMP area 10
  1.3 The component’s importance and role in the overall project 13
    1.3.1 An updated Site Inventory and core GIS baseline database 14
    1.3.2 Hydro(geo)logy 14
    1.3.3 Biodiversity Hotspots 14
    1.3.4 Ecosystem Functioning 14
    1.3.5 Indicators in Adaptive Management 14
    1.3.6 Rangeland Ecology 15
    1.3.7 Climate Change 15
2 Approach and methodology 17
  2.1 Inception phase activities 17
  2.2 Site Inventory and core GIS baseline database 17
    2.2.1 Methodology 18
  2.3 Hydro(geo)logy 18
    2.3.1 Methodology 18
  2.4. Biodiversity Hotspots 19
    2.4.1 Methodology 20
  2.5 Ecosystem Functioning 25
    2.5.1 Methodology 26
  2.6 Indicators in Adaptive Management 26
    2.6.1 Methodology 27
  2.7 Rangeland Ecology 28
    2.7.1 Methodology 29
  2.8 Climate Change 29
  2.9 Interpretation and synthesis 30
3 Findings 31
  3.1 Hydro(geo)logy 31
    3.1.1 Hydrology Review 31
    3.1.2 Hydrological summary framework 49
    3.1.3 Conclusions 51
    3.1.4 Follow up work 52
  3.2 Biodiversity Hotspots 53
    3.2.1 Major Findings 53
    3.2.2 Minor Findings 70
    3.2.3 Conclusions 73
    3.2.4 Follow up work 74
  3.3 Ecosystem Functioning 75
    3.3.1 Major Findings 75
    3.3.2 Minor Findings 81
    3.3.3 Conclusions 82
    3.3.4 Follow up work 82
  3.4 Indicators in adaptive management 83
    3.4.1 An Ecological Monitoring Framework for the MFMP area 83
    3.4.2 Indicators 90
    3.4.3 Capacity & stakeholder participation 98
    3.4.4 Conclusions 101

3.4.5 Follow on work 102
3.5 Rangeland Ecology 102
3.5.1 Major findings 102
3.5.2 Development Options 115
3.5.4 Follow on work 116
3.5.5 Conclusion 118
3.6 Climate Change 119
3.6.1 Impacts of Climate change 119
3.6.2 MFMP area vulnerabilities to Climate Change 123
3.6.3 Conclusions 125
3.6.4 Follow on work 126
4 Linkages with and findings for other MFMP components 127
4.1 Wildlife 127
4.2 Land use 127
4.3 Economic valuation 128
4.4 Tourism 129
4.5 Scenario issues 130
4.6 Livelihoods 130
4.7 Policy 131
5 References 133

List of Tables

Table 1. Criteria used by global NGOs to prioritise Conservation Targets and/or ecological/biodiversity hotspot identification. 21
Table 2. Biodiversity ‘targets’ used in the Multi-criteria analysis for identifying those most important – ranked the highest in terms of priority conservation. 22
Table 3. Mean monthly and annual rainfall figures for the Makgadikgadi. 33
Table 4. Most persistent and dynamic Makgadikgadi wetspots 36
Table 5. Biodiversity Hotspot MCA, revealing the top ten ranked biodiversity hotspots. 54
Table 6. Management objectives relevant to PA categories 59
Table 7. CHAs ranked according to the combined score of the hotspots occurring within them from the MCA, with CHA land use descriptions. 72
Table 8. Ecosystem services provided by the MFMP area. 80
Table 9. A monitoring programme framework for the MFMP area. 85
Table 10. Some Herbaceous Indicator species in the MFMP area 92
Table 11. Provisional Indicators for Assessing Progress towards the 2010 Biodiversity Target. 97
Table 12. Vegetation classification for the MFMP area. 105

List of Figures

Figure 1: A proposed hydrological model for the Makgadikgadi 19
Figure 2. Shaded SRTM with drainage and major contours. Overview of surface water catchment and topographic setting with special reference to the 945 m (Orange) and 1000 m (Red) contours. 32
Figure 3. Rainfall deviation from the mean (in mm) for selected stations NE of the Makgadikgadi from 1959-2008. 33
Figure 4. Drainage lines, Riparian habitat and groundwater seepage points identified from landsat imagery. 34
Figure 5. A flowing Lower Boteti, a filled Lake Xau and rim full Mopipi Dam in June 1979 as seen in Landsat MSS. 35
Figure 6. 1980-2005 Time series for the Makgadikgadi of NIR Reflectance (%), Lake Area (%), Monthly Precipitation (mm) and Nata River Flow (MCM). 36
Figure 7. Relative Pan wetness and wetspot identification from satellite imagery analysis. 38
Figure 8. Example of MODIS satellite imagery analysis derived flood count map for the flood period in the year 2000. 39
Figure 9. Hysplit model of the relative Aeolian dust deposition for period 2007 to 2009. 40
Figure 10. Groundwater quality data from borehole throughout the MWS 41
Figure 11. Locations of additional wells used to predict the effect of a southern wellfield on BotAsh well pump rates and resulting brine resource levels 42
Figure 12: Orapa Well field 43
Figure 13. Piper plot depicting the chemical composition of the water in the rivers, groundwater leaches and on the surface of Sua Pan. 45
Figure 14. Northern and central Sua conflict area. 48
Figure 15. Areas ranked by MCA analysis as the Top Ten biodiversity hotspots of conservation importance. 54
Figure 16. Hydrological ‘wetspots’ 70
Figure 13. Mammal distribution core ranges and plant species hotspots 71
Figure 17. CHAs ranked by MCA analysis as the Top Ten biodiversity hotspots of conservation important 72
Figure 18. Simple food chain of the main components that make up the biota of the aquatic saline ecosystem on Sua pan. 78
Figure 19. Flow diagram of the important physical and chemical factors controlling net primary production on Sua pan 79
Figure 20. Salinity ranges for the crustacean species on Sua Pan 91
Figure 21. Annual estimated breeding numbers (nesting pairs) and success (chicks fledged) for Lesser and Greater Flamingo between 1999 and 2009 96
Figure 22. A ‘Mind Map’ of the Management Objectives on which the Pans Parks DWNP MOMs programme was based. 100
Figure 23. Broad (6-class) vegetation map of the MFMP area. 103
Figure 24. Vegetation map of the MFMP area overlain with the main habitat land systems to determine grazing sensitivity. 107
Figure 25. Cattle density and distribution within the Makgadikgadi wetland system Kernel density and distribution patterns of cattle 112
Figure 26. Enhanced Vegetation Index (EVI) Map of vegetation recovery trend 2002 – 2010 113
Figure 27. Rangeland carrying capacities 116
Figure 28. 2050 peak flow from Historic 24 hour precipitation ratio of GMC 121
Figure 29. 2090 Peak flow from 24 hour precipitation ratio of GCM. 122
Figure 30. 2090 SPI droughts, change in drought months relative to historic. 123

Abbreviations

AIS	Alien Invasive Species
BD	Biodiversity
BLB	Birdlife Botswana
BRIMP	Botswana Range Inventory Monitoring Programme
BSAP	Biodiversity Strategy and Action Plan
BNWMP	Botswana National Water Master Plan
CBD	Convention on Biological Diversity
CBNRM	Community Based Natural Resources Management
CBO	Community Based Organisation
CHA	Controlled Hunting Area
CITES	Convention on the International Trade of Endangered Species
CMS	Convention of Migratory Species
CSO	Central Statistics Office
DAR	Department of Agricultural Research
DFRR	Department of Forestry and Rangeland Resources
DGS	Department of Geological Surveys
DMS	Department of Meteorological Services
DSS	Decision Support Systems
DWA	Department of Water Affairs
DWNP	Department of Wildlife and National Parks
EC	European Commission
EIA	Environmental Impact Assessment
ENSO	El Nino –Southern Oscillation
FAO	UN Food and Agriculture Organisation
FMP	Framework Management Plan
GIS	Geographic Information Systems
GoB	Government of Botswana
GPS	Global Positioning System
HOORC	Harry Oppenheimer Okavango Research Centre
IBA	Important Bird Areas
IMP	Integrated Management Plan
IPA	Important Plant Area
ITCZ	Inter-Tropical Conversion Zone
IUCN	The World Conservation Union
MFMP	Makgadikgadi Framework Management Plan
MoA	Ministry of Agriculture
MODIS	Moderate Resolution Imaging Spectroradiometer
MSB	Millennium Seed Bank
MFMP	Makgadikgadi Framework Management Plan
MWS	Makgadikgadi Wetlands System
NBI	National Botanical Institute
NCS	National Conservation Strategy
NDP	National Development Plan
ODMP	Okavango Delta Management Plan
OKACOM	Okavango River Basin Permanent Commission
PET	Potential Evapo-traspiration
PRECIS	National Herbarium Pretoria Computerised Information System
RBG	Royal Botanic Gardens

RDL	Red Data List
RWL	Rest Water Levels
SD	Sustainable Development
SABONET	Southern Africa Botanical Diversity Network
SADC	Southern African Development Community
SANBI	South African National Biodiversity Institute
SRTM	Shuttle Radar Topography Mission (1km resolution data)
TDS	Total Dissolved Solids
TFCA	Trans-Frontier Conservation Area
WCU	Water Conservation Unit (Department of Water Affairs)
WMA	Wildlife Management Area
WMC	Water Management Consultants
WWF	World Wide Fund
ZAB	Zambian Air Boundary

1 Introduction

1.1 Component Terms of Reference

The completion of the Ecology and hydrology component, as identified in the Inception Report, was effective through six main groups of activities, which are outlined below.

Biodiversity Hotspots' identification
Concentrating on key biodiversity areas (hotspots of biodiversity) representative of the whole system, the component will assess the sustainability of, and threats to the natural resource base, and how changes in their status as a result of natural and manmade impacts and/or management interventions will be monitored through improved site-specific, local scale management strategies.

Detailed activities undertaken include:
- Initial identification of sites of biodiversity importance by experts using local knowledge and background information. Linked to hydrological review and GIS Map layers/ tourism sites/wildlife distribution and conflict sites;
- Design GIS map of hotspots using Multi Criteria Analysis (MCA), using background data and local knowledge;
- Identify the unique services rendered by these sites, and the relevant level of protection for each site, and the potential threats to their integrity as a result of these recommended uses;
- Design site-specific management plan frameworks for these hotspots, with details of special considerations for each unique site, providing a summary of issues that require focused attention in comprehensive management plans to be written in the IMP, and;
- Establish the key ecological functions that are important to all principal species at these sites and their sensitivities, to be fed into various development scenarios.

Indicator species identification
The Ecosystem Approach recognises that change in resource availability and use is inevitable and this requires effective monitoring that will 'feedback' into an adaptive management approach. A major goal of this component will be to identify biodiversity use potential and its sustainability, and provide the framework for effective monitoring of the MWS biodiversity and ecological integrity that is critical to adaptive management.

Detailed activities undertaken include:
- Species inventory of all taxa, resident and migratory, highlighting locally vulnerable and internationally threatened or endangered species;
- Identify indicator species from different taxa, selected according to defined criteria; habitat type, resident/migrant, type of impact assessment and sensitivity to impact/change;
- Describe population dynamics and develop population models for key indicator species, and threats to populations according to degradation of key hotspot areas using development scenarios (applicable only where population parameters are available for indicator species) / or define information to be collected in next phase to aid the development of these models;
- Using GIS maps and MCA to establish spatial impact on species distribution according to development scenarios;
- Identifying indicator species thresholds to establish monitoring LAC framework, highlighting information gaps and research needs, and;
- Review species-specific management/action plans and design a framework species specific action plan for indicator species on MWS.

Ecosystem functioning and integrity

A guiding principle of the Ecosystem Approach to wetland management identifies the conservation of ecosystem structure and functioning, in order to maintain ecosystem services as a major priority, and that operational focus should be given to functional relationships and processes within the ecosystem (Smith & Maltby, 2003).

This component establishes the ecological interactions that maintain ecosystem integrity, assessing the ecosystems' needs and vulnerabilities, and highlighting the important relationship between changes in biodiversity and changes in ecosystem functioning and services, which ultimately impact resource availability, economic potential and livelihood improvement.

Detailed activities included:

- Desktop review of the basic physical, hydro-geochemical parameters important to ecosystem functioning, building GIS layers to define ecological zones;
- Develop two vegetation maps (a 6 class broad vegetation map and a 20-30 class map) using 30x30m Landsat imagery and field identification data from literature and additional targeted field transects / ground truthing to fill in gaps;
- Establish trophic interactions and a food web, concentrating on the important ecological interactions among indicator species;
- Identify the importance of the MWS to other systems in the region and globally, and establishing the important routes of interplay with these systems through migration corridors and waterbird flyways, highlighting information gaps and research needs;
- Establish the consequences of ecological degradation on MWS on these connections through development impact scenarios, and;
- Conduct a RAMSAR site and Ecosystems Approach appraisal to the land use strategy and management of MWS.

Hydrology review

The hydrological regime and topography are generally the most important determinants of the establishment, type and maintenance of a wetland type and its processes. Hydrological conditions affect numerous abiotic factors, e.g. nutrient availability, soil development and salinity, which in turn determine the biota of a wetland. Water is a primary resource within the MWS and drives the principle determinants of habitat suitability, biological diversity, and ecosystem functioning.

Maintaining the hydrological regime of a wetland and its natural variability is, therefore, necessary for the maintenance of the biodiversity and other ecological characteristics of the wetland. A comprehensive hydrological review of the MWS and consequential improved understanding of the water – environment linkages will highlight the importance of these biodiversity and other ecological determinants. It will also identify opportunities offered by this water resource and the threats to it through resource use conflicts. This will guide water allocation and water quality objectives in the IWMP, as well as future resource use impact assessments through land use and development scenario analysis in their respective components.

Detailed activities undertaken included:

- Desktop review of the hydrology and hydrogeology of the MWS, identifying flood dynamics, watershed boundaries, ground water dynamics etc. Linkages to ecosystem functioning, GIS zoning, and development scenario analysis;
- Define the critical areas of hydrological input and anthropogenic off take and conflict, and management interventions;

Hydrological summary framework

Activities

- Design of a hydrological and climate monitoring programme with special reference to key input / output and conflict areas;
- Define a framework water quality monitoring program.

Interpretation and synthesis of results
Co-ordinate and amalgamate component inputs from all activities and personnel involved, develop report and integrate into MFMP.

1.2 Background to the physical and ecological characteristics of the MFMP area

According to the Ramsar Conventions' classification system, the predominant wetland type within the Makgadikgadi Wetlands System (MWS) and MFMP area is type R - Seasonal/intermittent saline/brackish/alkaline lakes and flats (Ramsar Wise Use Handbook 14). There are, however, four other wetland types, listed in the Ramsar classification, that occur within the Makgadikgadi Basin: Ss - Seasonal/intermittent saline/brackish/alkaline marshes/pools, e.g. Boteti River Pools; N - Seasonal/intermittent/irregular rivers/streams/creeks, e.g. Nata River and others; 5 - Salt Exploitation sites; salt pans, salines, e.g. Botswana Ash Solar Ponds, and; 8 - Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, e.g. Botswana Ash sewage ponds.

When described in more detail, the MWS comprises an ephemeral saline wetland system that forms the hydrological terminus of a large endorheic basin, where climate (rainfall and evaporation) is of major importance to its ephemeral, saline nature. Formerly, the Okavango and other tributary rivers flowed across the site of this large depression, formed within the granitic Zimbabwean Craton, and flowed to the Indian Ocean, via the Limpopo river. An axis of tectonic up warp, the Kalahari-Zimbabwe axis, developed across the path of this drainage system near Francistown and dammed these rivers resulting in the formation of a large palaeolake. Throughout its history, the extent of the lake changed according to climate, techtonics, and river diversions upstream giving rise to a series of palaeolakes of varying depths and geographic extent. The contemporary pans of Ntwetwe and Sua Pan are relics of these immense palaeolakes that once covered much of northern Botswana.

Sua Pan is fed by a series of intermittently flowing rivers; the Nata, Semowane, Mosetse, Lepashe and Mosope Rivers that drain a large catchment (~27,000 km^2), and on the west side, the Boteti River channels water from the Okavango that spills over the Thamalakane Fault line, south eastwards to Ntwetwe Pan. A combination of input from these rivers, direct rainfall, local runoff and groundwater through flow, during the rainy season, contributes annual flooding of the pan surface to form extensive saline lakes. However, a high degree of inter-annual variation and seasonal distribution in precipitation around an estimated average of 450mm, results in extreme variation in the amount of standing water.

Old palaeolake floors, now thought to be pre-Quaternary, have had time to develop numerous karstic depressions; small pans, which flood intermittently during the rainy season. These small karstic pans are loci for rainfall and direct surface runoff recharges to groundwater around the periphery of the larger contemporary pans of Sua and Ntwetwe, e.g. Lake Xau, Rysana, Nkokwane and Ntoskotsa pans. Recharged water then discharges towards the contemporary pan floors as shallow through-flow.

The underlying geology of the Makgadikgadi Wetlands System (MWS) comprises undifferentiated Archaean rocks, Proterozoic rocks of the Damara Supergroup, Jurassic to Carboniferous sediments, and volcanics of the Karoo Supergroup. These rocks are buried by a variable thickness of Tertiary to recent Kalahari Bed sediments. Extensive layers of silcrete and calcrete at various depths also play an important role in soil structure and functioning throughout the system.

Soils in the pans consist of saline lacustrine clays and silts (solonchaks), e.g. in Ntwetwe and Sua Pan. Along the pan fringes, one encounters mostly calcareous soils: calcisols, leptosols and calcaric regosols, that are gradually replaced by deeper sandy soils (arenosols) with as one moves further away from the pans, to the north and west. Fluvisols occur adjacent to the rivers and calcisols, lyeyic luvisols and veritsols overly sedimentary and basalt rocks to the east. Generally, limiting factors in soil composition for vegetation development include drainage (e.g. none on calcite caps and hard pan, or too much in sandy soils) and soil salinity.

The major land systems within the Framework Management Plan area include the Kalahari Sandvelt, the sandridges, the back barrier flats, the paelaeolake bed deposits, the fluvial systems and the Eastern Hardvelt. Within each land system, different discrete sub-units have been identified, which comprise the geophysical bases for the identification of habitats and the ecological processes that are associated with each. Broad vegetation classifications have also been identified on a vegetation map in this study as saline grasslands, shrubbed grassland, mixed mopane, mixed acacia, mixed terminalia and mixed combretum.

Important areas of surface water flooding have been identified throughout the MFMP area as ‘Wetspots’, using ten year MODIS satellite image analysis. Those most prominent wetspots include the deltas and mouths of the main inflowing rivers, the Nata Sanctuary pan sump, Ntwetwe pan sump in the southeast, and some smaller pans like Nkokwane Pan and Dzibui Pan. A highly saline groundwater table also exists 1-2 m below the pan surface and influences the hydrological regime and chemistry of the pans’ surface waters. Most, if not all drainage lines provide and influx of groundwater into the Makgadikgadi. An estimated 1.17 billion m3 of carbonate-rich brine is found under the surface of Sua Pan, which is abstracted by Botswana Ash for the production of soda ash and salt.

The MWS supports a rich and diverse fauna community and has been identified as a biodiversity hotspot in the country’s Biodiversity Strategy Action Plan (BSAP-SR, 2003). Of particular interest is that the MWS wildlife community contains species well adapted to the unique and often extreme conditions of this saline and highly variable wetland ecosystem. In some instances this has led to endemism and, in other cases, has resulted in remarkable feats of physiology and behaviour recorded among some individual species and populations.

One such important behavioural adaptation, which spans many faunal groups and is essential to life in the MWS for many species, is migration. The ability to move in and out of the system to take advantage of a bountiful food source during the wet season and leave during drought, when conditions render survival almost impossible, is a key life history trait that sustains much of the systems faunal biodiversity. Maintaining connectivity to other nearby systems, and in the case of birds, to an extensive network of habitats that span the region and connects global populations from as far away as Europe, is without drought one of the biggest challenges facing the conservation and effective management of the MWS’ fauna.

The aquatic environment of the MWS is a nutrient rich and highly productive system. With the onset of flooding, an abundance of microscopic algae; cyanobacteria and diatoms emerge from their dormant stages, on and just beneath the pan surface. High concentrations and large fluctuations in the salinity of surface water result in relatively low species diversity. However, high nutrient concentrations, high temperatures and lots of light render conditions ideal for rapid productivity making the MWS one of the most productive lakes in Africa. An abundant invertebrate community, made up of mainly crustaceans, e.g. Clam shrimps (Concostracans) Fairy Shrimps (Anostracans), Copopods and Seed shrimp (Ostracods) also occur in the lake waters and provide a bountiful source of food for countless wetland birds.

One hundred and four waterbird species migrate to the pans each rainy season to feed and thirty-two of these breed in the MWS, highlighting its importance to regional populations. The most recent bird count for the area is 385 species, of which eighteen are globally threatened and/or of particular conservation importance, including Wattled Crane, Grey Crowned Crane, Chestnut-banded Plover, Black-winged Pratincole, and Lesser Flamingo. Large numbers of birds are frequently counted at Nata Sanctuary, Mea Pan, the Sua spit area and at Rysana Pan. Extreme variation in annual flooding, among and within seasons, however, makes it very difficult to identify trends in the waterbird populations. Nonetheless, the mean annual total number of birds in the MWS is in excess of 30,000 waterbirds.

Diversity hotspots for birdlife within the MWS occur, predominantly, on and around the major waterbodies, e.g. Nata River Delta and the north basin of Sua Pan, the Boteti River, Lake Xau, the lower Boteti and Mopipi's surrounding pans, Rysana Pan, and Mea pan and its surrounding pans. These areas comprise varying degrees of mixed wetland and terrestrial habitat types, which promotes greater species diversity. The surrounding saline grasslands, for example, provide ideal habitat for endangered raptors that breed here in large numbers, e.g. Lappet-faced and White-backed vultures, and Martial Eagles.

Fish, barbel and bream, also survive and breed in the deep waters of Sua Pan in years of exceptional rainfall and flooding. Reptiles and amphibians are important components of the ecosystem and are of value to the remote-area communities in Botswana. Eighteen species of amphibian and fourteen families with seventy-one species of reptiles have been identified to occur in the MWS, with collections from Khumaga, along the Boteti, Nata Sanctuary and some of the other smaller pan wetland areas showing the greatest species diversity. One species is endemic to the MWS: the Makgadikgadi Spiny Agama (Agama makarikarica), while the Rock Python, Python sebae natalensis and the Nile crocodile, Crocodylus niloticus are listed as protected.

A broad classification GIS anaysis of the predominant terrestrial vegetation types throughout the MWS, carried out during the FMP, identifies six main vegetation types: Saline Grassland, Shrubbed Grassland, Mixed Mopane, Mixed Acacia, Mixed Terminalia, and Mixed Combretum. These vegetation types have been used to develop a broad vegetation map of the MWS area, which highlights their distribution throughout the FMP. This map has been coupled with the geophysical land system units of the system, to identify habitat type.

Soil salinity is a dominant factor in determining these vegetation types around the Pans. At its highest levels, on the salt pans themselves, there is no vegetation. Saline Grasslands begin at pan margins, where windblown sand allows a rooting zone above the saline pan surface. Here salt grasses (*Odyssea paucinervis* and *Sporobolus spp*) dominate, interspersed with other less salt-tolerant, more palatable species, which become dominant further away from the pan surface as salinity decreases. With increasing sand depth and decreasing salinity, the grassland becomes more species rich giving way to shrubs and eventually woodland of varying types, depending on the depth of sand, presence of subsurface calcrete layers, and/or their proximity to fluvial, well drained soils, e.g. along drainage lines.

Rapid development of Botswana has led to increasing loss of habitats. In addition, non-sustainable harvesting, changes to the hydrology of wetlands, fire, alien invasive species, climate change and overgrazing threaten wild plants. The main threat to the flora of Botswana, according to the Red

Data List is, however, livestock grazing. Most of the MWS's rangelands are used for communal grazing and high livestock numbers around watering points and settlements is putting pressure on the indigenous flora. This is the case in areas of high intensity pastoral agriculture around the MWS, particularly, the Rakops-Mopipi area, where rangeland has been considerably denuded, threatening the indigenous floral diversity.

Of the 43 species on Botswana's national Red Data list, seven species can be found in the MWS and include *Hoodia lugardii, an Orbea sp., Blepharis bainesii, a Harpagophytum sp., Panicum colorautm var makarikarienses, Panicum pilgerianum,* and *Sporobululs bechuanicus*. Endemics or near endemics are also considered important as species of conservation concern and include *Neuradopsis bechuanesis and Thamnosma rhodesica*. In addition, some stands of baobabs and marula, are listed as national monuments, and as such are protected by law. Areas in the MFMP area high in RDL species include the Boteti River, near Kumaga and close to Rakops and Mopipi, Thabatsukudu, Ntwetwe pan's northern reaches, Nata Sanctuary, and the Mosu escarpment area of Sua Pan.

The rangeland that surrounds the MWS is a very important habitat for a large and diverse community of mammals. A total of 14 Orders, 32 Families, and 91 species of mammal have been recorded in the MWS. Of these, nine are listed on the IUCN Red Data List; Wild Dog, Lion, Leopard, Cheetah, Elephant, Hippopotamus, White Rhino, Brown Hyaena and the Black-footed Cat. Forty-two, out of a total number of 73 mammal species recorded in the Makgadikgadi Pans and Nxai Pans National Park, were small mammal species.

Large mammals are, in many cases, responsible for the main generators of economic benefits in the region. Due to their size and resource requirements many species walk considerable distances and cover large home ranges in search of preferred resources and mating opportunities. This movement is crucial to the sustainability of these populations and the systems robustness. Some mammal species are important flagship species that are used to rally conservation efforts, e.g. Elephant, and Lion, while also being responsible for most of the human-wildlife conflicts. Single species conservation efforts can, therefore, have significant land use conservation benefits.

1.3 The component role in the MFMP

The Ramsar Convention on Wetlands recognises wetlands as "*ecosystems that are extremely important for biodiversity conservation and for the well-being of human communities*". Wetlands very often contain biodiversity of exceptional conservation significance, comprising unique ecosystems and globally-threatened species (Springate-Baginski, 2009). At the same time, they form essential components of local and national economies, as well as underpinning the livelihoods of adjacent communities. According to the Millennium Ecosystem Assessment (2005), and the Convention on Biological Diversity (CBD) (Secretariat of the Convention on Biological Diversity, 2004) wetlands are the most vulnerable ecosystem to anthropogenic impacts globally and have suffered more biodiversity loss than any other ecosystem. Unsustainable use and degradation of a wetland and its resources impact heavily on the people whose livelihoods depend upon it. There are also significant losses to national and regional economies resulting from the loss of hydrological services, such as flood control and water provision and purification.

Such wetland degradation and/or loss of biodiversity cannot be identified, prevented or even mitigated, if decision makers and managers do not have a comprehensive quantitative and qualitative understanding of the underlying physical and biological components of the system and how they inter-relate. Indeed, a Wetlands' distinctive ecological characteristics are central to their management challenges (Springate-Baginski, 2009).

A conceptual and methodological framework for addressing sustainable use and integrated wetland management issues, especially with regard to effective management planning processes, through integrating biodiversity, economic valuation, policy evaluation and livelihood assessment, requires a comprehensive inventory and detailed assessment of the hydrological and biological aspects of a wetland. Indeed, according to the Ramsar Convention:

"*The delivery of the conservation and wise use of wetlands, in line with the commitments embodied in the Ramsar Convention, entails:*

- *establishing the location and ecological characteristics of wetlands (baseline inventory);*
- *assessing the status, trends and threats to wetlands (assessment);*
- *monitoring the status and trends, including the identification of reductions in existing threats and the appearance of new threats (monitoring); and*
- *taking actions (both in situ and ex situ) to redress any such changes causing or likely to cause damaging change in ecological character (management)*."

(Ramsar Wise Use Handbook, 2007 – vol. 16)

In light of the importance of wetland inventory, assessment and monitoring as tools for the conservation and sustainable use of wetlands, highlighted by the above Ramsar framework, the following sub-components of this report have been guided by, and are an attempt to address aspects of the first three steps of this framework:

1.3.1 An updated Site Inventory and core GIS baseline database

The inventory and data base provide a comprehensive quantitative understanding of the physical and ecological characteristics of the MWS, as well as describing the status of, and trends in the key biological communities of the system. The GIS core element database provides the GIS interface to this inventory for spatial representation. These are provided in a separate Site Inventory report and GIS database (hosted by the Department of Environmental Affairs).

1.3.2 Hydro (geo) logy

Provides a comprehensive hydro(geo)logical review of the MWS and consequential improved understanding of the nature, quantity and quality of the systems' water resource, the water – environment linkages and their importance to ecosystem functioning, biodiversity and other ecological determinants, and the potential threats and use conflicts that are likely to impact both water quantity and quality.

1.3.3 Biodiversity Hotspots

The analysis provides a basis for conservation planning by identifying areas of highest conservation priority and directing limited resources in a strategic manner to help address the conservation of biodiversity. While they represent key biodiversity areas and provide ideal biodiversity conservation and monitoring reference points within the system, their inter-connectivity within the system and their overall role in the functional integrity of the system as a whole should be emphasized.

1.3.4 Ecosystem Functioning

The analysis provides a greater understanding of, and focus on the key processes and functional relationships that maintain the systems ecological integrity, to guide effective management and development decisions, and alignment with the ecosystem approach and sustainable development principles.

1.3.5 Indicators in Adaptive Management

The analysis provides the initial framework for the selection of key indicators of ecosystem change that are important in an effective monitoring programme to ensure adaptive management, while facilitating key strategic management strategies that include rapid impact assessment, designing Limits of Acceptable Change and use of the Precautionary Principle.

1.3.6 Rangeland Ecology

The analysis provides a synthesis of a comprehensive assessment of the rangeland resources of the MWS, in an attempt to highlight its state and capacity for use by various sectors, it's sensitivity and response to overgrazing, the extent of habitat degradation and potential loss of biodiversity, and to identify mechanisms/strategies of sectoral trade-offs to facilitate balanced and improved benefits and to avert and potentially reverse degradation.

1.3.7 Climate Change

The review provides a synthesis of a specialist report, which reviews climate change scenarios and their relevance to the MWS, in an attempt to identify a range of likely plausible future climate scenarios, their likely impacts on the systems functioning and its biodiversity, and the corresponding vulnerability of the wetland to future climate change.

The Ramsar Scientific and Technical Review Panel (STRP) recently proposed updating the definition of "Wise use of wetlands" to "the maintenance of their ecological character within the context of sustainable development, and achieved through the implementation of ecosystem approaches." In order to compliment this wise use concept, the activities of the above sub-components were guided by, and developed under the overarching project assessment framework of the Makgadikgadi Framework Management Plan (MFMP), which is built on a combination of the principles of sustainable development and the ecosystems approach.

Sustainable development (SD) can be interpreted in different ways, but the overriding aspects centre on balancing the substitution of natural capital for human, physical or social capital and identifying critical natural capital to avoid irreversible changes, i.e. ensuring sustainability. Resource use efficiency, linking different spatial levels, e.g. global and river basin levels, and ensuring multi-disciplinary analysis of sustainability are also key principles of SD. Four key aspects of SD can be distinguished: ecological, economic, social and institutional. While appreciating the linkages and inter-relationships between these multi-disciplinary aspects, this component focuses on issues associated with ecological sustainability. The sub-components listed above, and their activities, therefore, are directed at addressing the following issues:

- The conservation of biodiversity in all its forms;
- Maintaining the integrity of the pan's ecosystem;
- Recognition and maintenance of spatial and temporal variability within the ecosystem;
- Maintaining migratory links between pans and other major ecosystems;
- Ensuring that use of renewable resources does not exceed their regeneration, and;
- Ensuring that pollution remains within the natural absorption capacity or pollution abatement measures.

The Ecosystem Approach is defined by the CBD secretariat as "a strategy for management of land, water and living resources that promotes conservation and sustainable use in an equitable way". In many respects, it provides momentum to efforts to integrate biodiversity management into sustainable development practice and decision-making (Smith & Maltby, 2003; Shepherd, 2004). Key distinguishing features of the Ecosystems Approach are. It:

- Is designed to balance the three CBD objectives (conservation, sustainable use and equitable benefit sharing of genetic resources);
- Puts people at the centre of biodiversity management;
- Extends biodiversity management beyond protected areas while recognising that they are also vital for delivering CBD objectives; and

- Engages the widest range of sectoral interests.

When applying the twelve Principles of the ecosystem approach, the following five points are proposed as operational guidance:

- Focus on the functional relationships and processes within ecosystems;
- Enhance benefit sharing;
- Use adaptive management practices;
- Carry out management actions at the scale appropriate for the issue being addressed, with decentralisation to lowest level, as appropriate, and;
- Ensure intersectoral cooperation.

2 Approach and methodology

2.1 Inception phase activities - baseline data

As part of the initial planning and development of the Ecology and Hydro(geo)logy Component and the overall MFMP, the following activities were carried out during the inception:

- A Site Inventory review and update for the wetland began, with data collection from relevant departments, researchers, and literature reviews. Data accessed included;
  - GIS Data from all the relevant government departments to produce a baseline core critical element GIS map for the MFMP area;
  - Physical, ecological, and infrastructure / settlement / development data from various government departments, NGO's, independent researchers and in the literature;
  - Hydrological and basin data from database, literature, maps and from remote sensing analysis;
  - Physical and soil GIS data for vegetation map;
  - Data on indicator species and their use in monitoring and LACs from the literature, NGO's (e.g. Birdlife Botswana) and local experts/researchers, and;
  - Ecosystem functioning data from the literature, NGO's (e.g. Birdlife Botswana) and researchers;
- Core critical element analysis and design of GIS map detailing current bio-physical status and character of the system as well as the infrastructure and land uses for use in the activities of this and other components;
- Formulation of the FMP project boundary and its justification, following the Ramsar Convention 'Wise Use' Handbook 14 guidelines on defining site boundaries;
- Selection of short-term specialists for Hydrology, Rangeland Ecology, and Climate Change was carried out, and;
- The identification of other projects, with which to collaborate was conducted.

2.2 Site Inventory and core GIS baseline database

The Ramsar Convention has paid considerable attention to the importance of wetland inventory, as a tool for the conservation and wise use of wetlands, as well as to their use in effective management planning processes to maintain and enhance the ecological character of wetlands (Ramsar Wise Use Handbook 11 and 12). Indeed, the first step in the delivery of the conservation and wise use of wetlands, in line with the Ramsar Convention guidelines, entails "*establishing the location and ecological characteristics of wetlands (baseline inventory)*". A comprehensive quantitative understanding of the bio-physical characteristics of the MFMP area its available natural resources; physical and biological, is also essential to the adoption of a sustainable development and ecosystems approach analytical framework.

A site inventory provides an information base tool that guides the development of appropriate assessment and monitoring activities and that can be used by decision makers and managers, and updated following further assessments and monitoring during the FMP and IMP implementation, thereby facilitating adaptive management and addressing one of the key operational guidelines of the ecosystems approach. A GIS mapping interface to the site inventory provides a vital interactive spatial representation of the bio-physical character of wetlands, essential in effective management and development planning, e.g. land use planning (Ramsar Technical Report 2; Guidance for GIS applications for wetland inventory, assessment and monitoring).

2.2.1 Methodology

Alexander et al. (2002) first conducted a site inventory of the physical and biological components of the MWS in 2002. This component has updated that document with substantial additions of data and information from subsequent research, literature reviews and additional in-depth studies carried out during the process of this Framework Management Plan. A large amount of the information used for this inventory was that compiled during the inception phase, listed in 2.1 above. The resulting document is a stand-alone document, separate from this report. It should be viewed as a continual work in progress, in order to keep it current and ensure its value as a useful management tool that will facilitate future effective decision making and ensure adaptive management.

2.3 Hydro (geo) logy

The hydrological regime, geomorphology and topography are generally the most important determinants/drivers of the establishment, type and maintenance of a wetland type and its processes. Wetland hydrology is, however, the primary driver of wetland character and function. It affects numerous abiotic factors, e.g. nutrient availability, soil development and salinity, which in turn determine the biota of a wetland. Indeed, water is one of the primary resources of the MWS and is critical to the maintenance of livelihoods in the area and the development and wise resource use potential of the system.

Quantifying this resource and understanding the hydrological regime of the MWS, its natural variability, and its linkages and interactions to the physical, chemical and biological components of the MWS is, therefore, essential for the maintenance of both ecological integrity and establishing the potential for improving resource availability, development potential and livelihood improvement. A comprehensive hydro(geo)logical review was, therefore, conducted as a stand alone specialist report and integrated into this component report.

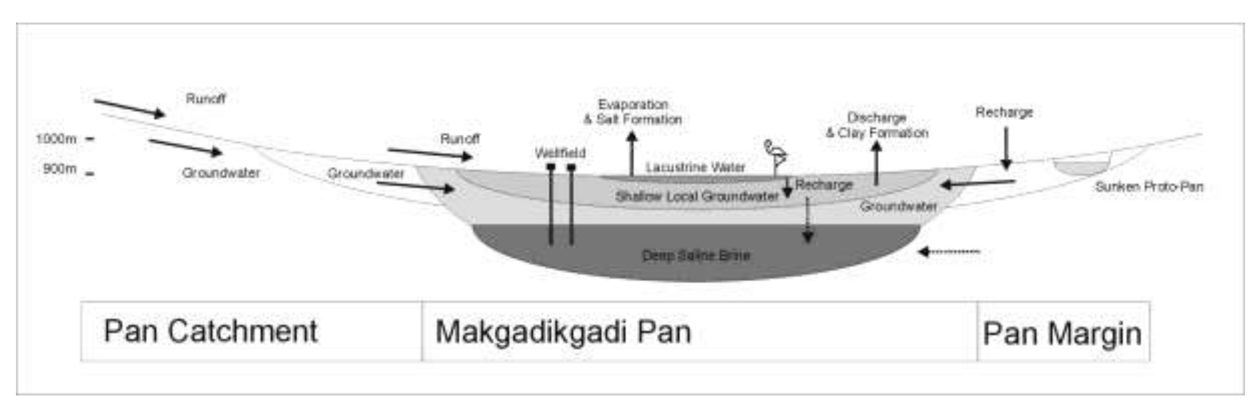
The study also identifies the threats to this water resource from resource overuse and resulting conflicts. This guides water allocation and water quality objectives in the FMP and recommendations for safeguarding the resource quantity and quality within the system. In doing so, the sub-component addresses some of the sustainable development issues, outlined above, and facilitates adoption of the ecosystems approach by focusing on the systems hydrological functions and processes.

2.3.1 Methodology

The overall hydrological regime of a pan is determined by both external drainage controls such as catchment configuration and climate, and by internal controls such as the surface and groundwater relationships, which were addressed in this report. In particular, the present-day hydrology and processes that govern the Makgadikgadi was examined, with focus on the quantity, temporal availability and primary controls of its ephemeral surface waters. To help in this regard, a comprehensive study of MODIS sensor images (from the Terra and Aqua platforms) over a ten-year period (2000-2009), conducted by Rob Bryant at Sheffield University, was updated and used to detect the extent and variability in seasonal flooding on the pans. MODIS provides twice daily coverage across a range of wavebands, enabling the production of detailed temporal analysis of the entire Makgadikgadi basin on a daily basis for that time period. Most notably, it was used for the identification of areas indicative of pronounced surface water presence, worthy of further examination and consideration, which for the purposes of the MFMP have been called “wetspots”.

This report will, in particular, examine the present-day hydrology and processes, which govern the Makgadikgadi with focus on controls of its ephemeral surface water. Figure 1 depicts a hydrological schematic of the pan system. It needs to be stressed that surface water in pans is not merely the result of standing rainwater but is in fact the net result between various inputs and outputs. In particular the status of the pan crusts and sediments as well as the shallow groundwater determines the amount of water present at the surface.

Figure 1: A proposed hydrological model for the Makgadikgadi.



Source: Author and McFarlane unpublished.

The hydrological specialist report attempts to review, present, analyse and examine existing data and in particular highlight knowledge gaps. In addition, a future improved and comprehensive monitoring programme is proposed in order to further our understanding of this system and manage the Makgadikgadi and its sub-systems effectively, which has been incorporated into an overall monitoring programme framework. The study represents a systematic breakdown of the Makgadikgadi system into its hydrological sub-components, the methodology of which can be found in chapter 8, this volume. These sub-components include:

- Topography and catchment/watershed delineation
- Meteorology
- Drainage hydrology
- Riparian system
- Lacustrine water
- Pan surface morphology
- Pan chemistry
- Groundwater
- Mass water balance
- Water Use and Conflicts
- Hydrological Monitoring

2.4. Biodiversity Hotspots

There is a growing emphasis on the importance of conservation planning, a process aimed at identifying areas of highest conservation priority in order to direct limited management and conservation resources in a strategic manner. The overall aim is to facilitate immediate and most needed protection of biodiversity and ecosystem functioning from unsustainable development, its associated threats and other challenges to biological diversity like loss of habitat. This section, therefore, addresses, specifically, the first two sustainable development issues and follows a key aspect of the ecosystem approach, outlined in 1.2 above.

The ultimate goal of many global conservation planning approaches is biodiversity protection. Biodiversity, however, includes richness at all levels from landscapes to genes (Gaston & Spicer, 2004). Within that range of attributes, species richness and variety of habitats are the most practical and common measures of biodiversity importance. When implemented at a regional or local level, conservation planning targets include areas that contain, for example, threatened or protected species (IUCN Red List of Threatened species), rare or endemic species, populations of restricted range species, or any species, collection of species or habitats of particular rarity or importance to biodiversity and/or ecosystem functioning. However, all approaches, unilaterally, assume that implementation of biodiversity conservation is best accomplished by protecting habitat, even for those that ultimately target species for conservation (Groves *et al*., 2003).

Biodiversity Hotspots

Identifies areas of highest conservation priority and directs limited management and conservation resources in a strategic manner to help address the protection of biodiversity and ecosystem functioning from unsustainable development, its associated threats and other challenges to biological diversity. As well as providing direct protection to species, site conservation also reduces the loss of natural habitats, the main cause of extinctions. BD hotspots also provide ideal reference sites for monitoring the state of biodiversity within the system, facilitating effective monitoring programs.

The primary or immediate objective of conservation planning is to set internal priorities for conservation action. Vulnerability and irreplaceability of the species/habitat/site are important criteria to include in the identification of key areas. Areas that rank high in both of these are the areas most likely to be lost and with the least likelihood of replacement, which then require immediate protection through improved site-specific, local scale management strategies that will safe guard the systems biodiversity in a cost effective way.

2.4.1 Methodology

For this study, a review of eleven Global and sixteen regional and local conservation planning approaches was conducted to clearly identify the salient priorities and criteria used in conservation area planning by various conservation NGOs:

- Alliance for Zero Extinction (“AZE Sites”)
- BirdLife International (“Endemic Bird Areas” & “Important Bird Areas”)
- Conservation International (“Biodiversity Hotspots”, “High Biodiversity Wilderness Areas" & “Conservation Corridors”)
- Wildlife Conservation Society (“Range-wide Priority Setting" & “Last of the Wild")
- World Wildlife Fund (“Global 200")
- RAMSAR Convention (“Wetlands of Global Importance”)
- Convention on Biological Diversity (“Biodiversity Hotspots”)
- Plantlife International & SABONET (“Important Plant Areas”)
- The Nature Conservancy (Ecoregional conservation planning)
- Ducks Unlimited Canada (Canada's Boreal Forest Programme)
- Important Freshwater Sites from 13 different schemes, reviewed in Darwall & Vie (2003)

From the conservation planning approaches reviewed, a set of criteria (Table 1), and their associated thresholds most suitable for the identification of ecological hotspots in the MWS was identified. Species endemism (& restricted-range species) (used in 22 approaches), threatened species (used in 16), species richness (used in 13) and representation (used in 13) were the most frequently used criteria.

Table 1: Criteria used by global NGOs to prioritise Conservation Targets and/or ecological/ biodiversity hotspot identification.

	Criteria	Description
Biological Value	**Representation**	A portfolio of conservation sites should include sites representing all of the different ecosystems in the area of concern and representing as much biodiversity as possible as efficiently as possible (for example, within a limited area)
	Species Richness	The number of species within a given area; sometimes used as a simple measure of biodiversity
	Species Endemism	The number of species found exclusively in that location, relative to a particular geographic unit
	Rarity	Species and/or ecosystems that are naturally rare
	Significant Ecological or evolutionary Processes	Ordinary and extraordinary ecological processes. Examples: key breeding areas, migration routes, globally outstanding centers of evolutionary radiation, unique species assemblages
	Biome Restricted Assemblages	Site is known/thought to hold a significant component of the group of species whose distributions are largely or wholly confined to a biome.
	Congregatory Species	Species that are vulnerable at the population level to the destruction or degradation of sites, by virtue of their congregatory behaviour at any stage in their life-cycles. These may comprise breeding colonies or other sites used during the non-breeding season, e.g. stop-over sites.
	Presence of special Species or Taxa	Presence of an umbrella, keystone, indicator, or flagship species; or a Habitat for a particular species or taxa; for example, wide ranging species or waterfowl
Conservation Value	**Threatened Species**	Species (or the presence of species) that have been nationally or globally listed as threatened or endangered
	Species Decline	Species whose populations have undergone significant decline in recent years
	Habitat Loss	Areas that have lost a significant percentage of their primary vegetation or habitat
	Fragmentation	Areas that have been fragmented into smaller parcels and have low connectivity
	Large Intact Areas	Areas with a certain minimum size with no or minimal human impact

Targets were then selected comprising:

a) “Wetspots”; areas of pronounced and prolonged surface water, identified in the specialist hydrological report, and which were also deemed the most important wetland habitat for aquatic biodiversity, including wetland birds;

b) Core mammal distribution ‘hotspots’, identified in the wildlife component report, as areas with the most concentrated large mammal numbers year round;

c) Important Plant areas, identified in Botswana’s Biodiversity Strategy Action Plan (2003), as areas containing Red Data List species on and around the MWS, and;

d) Sites/areas of important hydrological input and, therefore, ecosystem functioning, i.e. the main rivers and discharge points.

Sixty-one biodiversity 'targets' were identified in total and are listed in Table 2 below.

Table 2: Biodiversity 'targets' used in the multi-criteria analysis for identifying those most important – ranked the highest in terms of priority conservation.

W - Boteti Delta - west	W - Mosope Delta	M – Lebu area
W - Boteti Delta	W – Kudiakam Pan	M – Manxotai area – CT7
W + V- Boteti Delta Lagoon	W – Nkokwane Pan	M - CT5
W – MakPans NP – Pan area 1	W – Maditsinyane Pan	M - CT3
W – MakPans NP – Pan area 2	W - Xhorodomo Pan	M - CT4
W – Mak Pans NP - Pan area 3	W - Tsitsane Pan	M - North CT7
W – Mak Pans NP - Pan area 4	W - Ntsokotsa Pan	M - Central CT1
W – Mak Pans NP – Pan area 5	W - Sokarokatsha Pan	M - Southern CT1
W – Mak Pans NP - Pan area 6	W - Dzibui Pan	M - NG 42
W - Tabatshakudu	W - Guquago Pan	M - North NG43
W + V - Tabatshakudu 2	W + V - Rysana Pan	M - South NG 43
W + V - Ntwtwe Spit	W - Mompswe Pan	M - NG45
W + V - Nata Sanct 1 - combined with NS 2 below	H + V Lake Xau	M - NG 47
V – Mosu escarpment area	H + V Boteti River	M - Nxai Pan
W – Mosetse Delta and lagoon	H Nata River	NG - 41
W + V - Sua Pan South basin	H Semowane River	M – East MPNP
W – Mea Pan 1	H Mostese River	M – Central MPNP
W - Mea Pans 2	H Lepashe River	M – Western MPNP
W - Mea Pans 3	H Mosope River	M - CT8
W - Lepashe Delta	M – CKGR – western CT8 area	M-NG51

Note: W indicates wetspots, V indicates Important Plant Areas, H indicates rivers of hydrological importance, and M indicates population 'core' areas for mammals. Refer to wetspot and mammal core maps in the E&H report for locations.

These target sites were then systematically assessed against each criterion (13 in all). Each criterion was weighted (5, 4, 3, 2 or 1) according to its popularity score (in the Conservation approaches reviewed) before use in scoring target sites. This study adopted, where possible, the thresholds used by the various approaches reviewed, e.g. the RAMSAR Guidelines for identifying Important Wetlands identifies a number of thresholds under different criteria, e.g. if the site regularly supports 20 0000 wetland birds, or at least 1% of the population of one or more species (Ramsar Wise Use Handbook, 2007; Vol 14), and guided by international criteria, e.g. IUCN list of threatened species.

Scoring followed the following background logic and thinking per criteria:

- **Endemic species** – Criteria weight of 5 and scored per species on an existence or absence (0 or 1) bases per target site, according to SABONET/Botswana Herbarium distribution of endemics, and other endemic species the literature and from expert opinion.
- **Threatened, Protected or Conservation concern species** – Criteria weight of 5. Threatened species identified in IUCN Red Data List, BLB Birds of Concern, DWNP protected species, SABONET & KEW Gardens Plant Red Data list, literature & expert opinion; scored 0 to 3 based on abundance distribution per target, based on the Bird Atlas spatial distribution data and/or large mammal distribution kernel analysis, BSAP Report and expert opinion. In addition, weighting was given to separate the importance of certain species of importance, e.g. a threatened species distribution score (0 – 3) per site, was weighted by a factor of 4 if the species is listed as Vulnerable on the IUCN list of threatened species, by 3 if listed as

Near threatened, and by 2 if it is a species of Least Concern, and/or of conservation concern or protected nationally;

- **Representation** - Criteria weight of 4. Each hotspots gained a score of 1 for each habitat represented in its area, according to the habitat map and the table in the ecosystems functioning section of this report, and additional scores for the species richness, i.e. the combined score of plant, bird and mammal species richness for each site calculated in d), below;
- **Species Richness** – Criteria weight of 4. The species richness was the combined species richness identified in the Bird Atlas (Score; >300 = 25, >250spp = 20, >180 = 15, >120 = 10, >60 = 5), overlaying large mammal species distribution (score of 1 per species range overlap at site) and number of vegetation species per km, per eco-region, from the BSAP stocktaking report multiplied by the size of each target site. Habitat and biome diversity from the land systems table, in the ecosystem functions section of this report, was also used as a rough surrogate of vegetation diversity, in combination with the broad vegetation map and associated species lists;
- **Significant or Outstanding Ecological or evolutionary Processes** – Criteria weight of 3. Each hotspot was scored 1 for each significant ecological or evolutionary process, identified from the literature, Birdlife Botswana reports, and expert opinion, e.g. migration routes/stops, breeding sites, unique species assemblages, refuge sites, and evolutionary radiation;
- **Rarity** – Criteria weight of 3. Scored 1-5, based on the presence of species or habitat deemed to be rare; unique to the MWS, e.g. large open saline ephemeral lake habitat, and Sesame bush;
- **Presence of special Species or Taxa** – Criteria weight of 3. Each target site scored 1 per umbrella/flagship and/or keystone species identified to occur in it. Species determined special by review of literature and largely expert opinion;
- **Habitat Loss** – Criteria Weight of 5. Scored according to the amount of impact from human encroachment, which was estimated from GIS "footprint" analysis; a combination of the percentage area of human footprint (conducted for land-use component) in each hotspot, the extent of cattle overlap estimated in Arc View from cattle home range kernels percentages (scored 1-4 according to overlap with 5%, 25%, 50% and 95% cattle range, 4 equals high overlap and 1 equals low overlap), and; the amount of rangeland degradation, estimated from the NDVI analysis in the vegetation mapping component (scored 0-3 depending on the percentage area of degraded rangeland at the site);
- **Habitat Functioning** – Criteria weight of 2. Each hotspot was scored 1 for each habitat function, under the provisioning services, supporting services, regulating services and socio-economic services of the respective habitat ecosystem functions, identified for each site from the table in the ecosystem functioning component of this report, and expert opinion.
- **Biome Restricted Assemblages** – Criteria Weight of 2. Each site scored 1 per endemic and/or biome restricted species, e.g. Greater and Lesser flamingos, Chestnut-banded Plovers, and Zebra and Wilderbeeste, with a significant proportion of their total population regularly occurring there, plus one per Zambezian halophytic ecoregion species that occurs, i.e. MWS specific saline grass species, algae species and crustacean species (score 0-3), plus endemic species score in a), above;
- **Congregatory species** – Criteria weight of 2. Six Congregatory species (Flamingos, pelicans, chestnut banded plovers, zebra, wildebeest, springbok) were assigned a score of 1 each and their respective combined occurrence in each hotspot gave a score of (0-6);
- **Species Decline** – Criteria weight of 1. A score of the combined bird species of national Conservation Concern (from the BLB list) and threatened mammal species in b), above was estimated for each hotspot, based on the occurrence or absence of each species in each hotspot;

- **Fragmentation** - Criteria weight of 1. A score of 0-3 was assigned to each hotspot according to the degree of habitat fragmentation/separation and connectivity, assessed by GIS analysis of the human footprint of roads, fences and power lines etc. in Arc view, whereby a high degree of fragmentation scored 3 based on its high vulnerability;
- **Hotspot Vulnerability** - Criteria weight of 1. A visual GIS assessment by experts determined the minimum size of each hotspot relative to the size of the populations it supports: 3 scored high owing to its high potential viability, based on three indicators: size (e.g., the population size, or size of the ecosystem patch); condition or quality of the species habitat; and the condition of land and water surrounding the habitat patch).

We used a wide variety of data to inform the development of our hotspots. National and local place-based knowledge was developed through comprehensive species lists (in the site inventory), a vegetation map (developed during the MPFMP process), range atlases (e.g. Bird Atlas of Botswana (Penry, 1994), BSAP stocktaking report (2003) and RED Data List species of vegetation from SABONET/KEW Royal Botanical Gardens; Birgitta Farrington, (pers. comm.), literature studies, field studies, and expert knowledge. Species status data came largely from the IUCN Red Data List of Threatened Species (www.iucn.org), the Centres of Plant Diversity data (KEW RB Gardens and IUCN), and regional data sets such as Birdlife Botswana (Birds of Concern list) and DWNP (protected animal species) (see Appendix 1 in site inventory report for some of these lists). Much needed information, particularly about species, local conditions, habitat requirements, and ecosystems was not always available and, like in all planning approaches reviewed, the analysis relied heavily on expert opinion, which included field experts, scientists, and local knowledge. GIS mapping was heavily relied upon as an analytical tool, e.g. habitat and species distribution, habitat impact/degradation analysis and as a hotspot area planning tool.

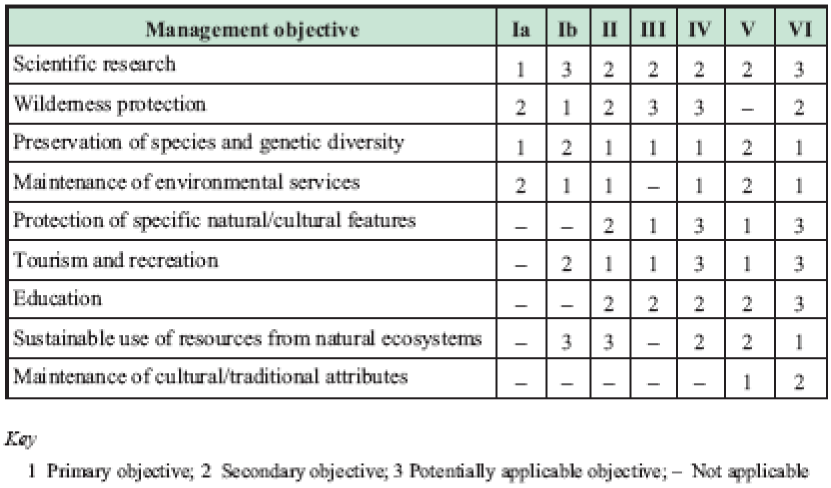
Once the Biodiversity Hotspots were identified, brief descriptions of the top ten were made, highlighting their associated salient characteristics, and key functional relationships and processes. These descriptions guided the development of a site-specific framework management plan for each site, outlining the important components & issues requiring consideration for each site. The RAMSAR guidelines for the development of management plans were then used to build the framework management plans. Small pan hotspots; e.g. Rysana Pan or Mea Pan, for example, comprised important pan edge habitat and species diversity and in order to accommodate this important component of these sites, a 2km ‘pan edge’ area surrounding these pans was included in both the hotspot analysis and description. As per the human footprint analysis in the Land Use component, this is the minimum distance away from roads required to avoid direct physical impact.

Protected Areas are increasingly being viewed as a ‘range’ of management practices rather than isolated, no-go restricted areas for conservation. A diversity of protected area categories identified by the IUCN can be used to tackle an ecological necessity of a, or a collection of species or an ecosystem, in a balanced way to meet society’s needs (Dudley, 2008). This approach attempts to implement biodiversity conservation planning in a balanced approach through sustainable use and effective management planning (Thomas & Middleton, 2003), and as such, compliments the principles and operational objectives of the MFMP’s overarching analytical framework of sustainable development and the ecosystems approach. The following IUCN protected area (PA) categories were, therefore, reviewed and used to help assign the appropriate level of management objectives for each site, particularly those outside existing protected areas:

I. Strict protection (a. Strict Nature Reserve & b. Wilderness Area)
II. Ecosystem conservation and recreation (National Park)
III. Conservation of natural features (Natural Monument)
IV. Conservation through active management (Habitat/Species Management Area)

V. Landscape/seascape conservation and recreation (Protected Landscape/seascape)
VI. Sustainable use of natural ecosystems (Managed Resource Protected Area)

The mix of management objectives relevant to each of the categories is summarised in the following table (IUCN 1994, p.8). Each category has its own set of selection criteria and appropriate management objectives, which guide the appropriate management processes for respective categories:



Management objective	Ia	Ib	II	III	IV	V	VI
Scientific research	1	3	2	2	2	2	3
Wilderness protection	2	1	2	3	3	–	2
Preservation of species and genetic diversity	1	2	1	1	1	2	1
Maintenance of environmental services	2	1	1	–	1	2	1
Protection of specific natural/cultural features	–	–	2	1	3	1	3
Tourism and recreation	–	2	1	1	3	1	3
Education	–	–	2	2	2	2	3
Sustainable use of resources from natural ecosystems	–	3	3	–	2	2	1
Maintenance of cultural/traditional attributes	–	–	–	–	–	1	2

Key

1 Primary objective; 2 Secondary objective; 3 Potentially applicable objective; – Not applicable

2.5 Ecosystem Functioning

A central premise of the ‘ecosystem approach’ to sustainable development and sound ecosystem management is maintaining the structure and functional integrity of an ecosystem, while at the same time allowing for the use of the goods and services provided by the system (Smith & Maltby, 2003). Indeed, among the twelve guiding principles of the ecosystem approach, three relate directly to ecosystem function and processes. In addition, the first operational guideline to adoption of the ecosystem approach calls for “Focus on the functional relationships and processes within ecosystems”. According to the CBD, “*a much better knowledge of ecosystem functions and structure, and the roles of the components of biological diversity in ecosystems, is required, especially to understand: (i) ecosystem resilience and the effects of biodiversity loss (species and genetic levels) and habitat fragmentation; (ii) underlying causes of biodiversity loss; and (iii) determinants of local biological diversity in management decisions*.”

Awareness is, however, lacking of the significance of ecosystem functioning, along with inadequate recognition that ecosystem services are vital for human social and economic welfare, as well as wildlife (Smith & Maltby, 2003). Effective ecosystem management benefits considerably from planning processes and mechanisms that allow the economic and wider value of ecosystem functions to be realised. This requires a comprehensive understanding of, and consideration for the key ecological processes and functions.

To this end, this sub component attempts to highlight the main ecological processes and functions within the MWS in order to consider their importance and inclusion in guiding an effective framework management plan for the system. This sub-component is in line with the principles and operational guidelines of the ecosystems approach and also directly addresses the first two sustainable development issues outlined in 1.3 above.

2.5.1 Methodology

A number of key 'drivers' determine the ecological functions and processes of an ecosystem; for wetlands these are predominantly climate and geomorphology (Semeniuk and Semeniuk 1995, Mitsch and Gosselink 2000). Climate has an overriding influence on the distribution and abundance of rainfall which directly controls wetland hydrology, flood duration, seasonality and frequency, both annually and in long-term patterns or cycles. The geomorphic setting is a key factor that determines the water source of wetlands, the size and shape of wetlands, their location, their hydrology, and the physico-chemical properties of the water and soils.

Each habitat comprises unique 'hydrological and geomorphologic conditions' that determine the ecosystem process and functions within, and maintains its biodiversity and other resources and services. Some functions connect habitats and sustain the biological component of the entire system, and that of other systems. By focusing on a description and evaluation of the various habitats within the system and the biological connectivity between them, one can, therefore identify the key functions and process that control wetland integrity.

An assessment of the land systems of the Makgadikgadi Pans and Nxai Pan National Parks, and its surrounding area was conducted for the "Pans Parks" Management Plan (Appendix 5; DWNP, 2006). The major land or terrain systems in the region were divided further into land units and sub-units of uniform physical, chemical and biological character. From this classification an assessment of their respective ecological character and processes was possible, in order to establish their individual land use potentials and constraints.

For this study, we updated the Land System classification analysis of the 'Pans Parks', by expanding the analysis to the entire MFMP area. In order to do this, details of the underlying geomorphology, soils and hydrological processes that formed the different physical terrain units was used. The dominant vegetation types in each land unit were then identified according to the broad (six class) vegetation map developed for the FMP, and the associated wildlife/birdlife composition were determined. From this analysis, we then identified the main ecological processes important for the functioning of the habitat and the overall ecosystem as a whole.

In addition, the goods and services provided by the systems processes and functioning were listed according to four main service categories (identified by Ramsar; Handbook 16, and the CBD); provisioning, regulating, cultural and supporting.

2.6 Indicators in Adaptive Management

Understanding how wetlands respond to anthropogenic use and pressures is essential in order to implement sustainable development. Indeed, the reliable detection of impacts and changes to ecosystem integrity and resource use potential is identified as one of the main issues under the sustainable development framework (1.3 above). By using variables considered important in conservation and/or development terms - called indicators, changes in the health of a wetland, its attributes, functions, and the goods and services that it generates can be identified (Springate-Baginski, 2009).

Adaptive management, whereby management and conservation actions are refined and adjusted according to research and lessons learned in the field can only be achieved through monitoring (Ramsar Wise Use Handbook 16). Monitoring provides a feedback mechanism of information that feeds into decision support systems (DSSs), e.g. data bases and models, and appropriate indicators are a vital link in this monitoring-feedback-response mechanism. Adaptive management is one of the five main operational guidelines when adopting the 'ecosystem approach' to wetland management (ASCE, 1998; Smith & Maltby, 2003). In addition,

With widespread limited resources and personnel to allow for adequate monitoring of multiple indicators, selecting widely accepted key indicators of ecosystem functioning and sustainable use is crucial if effective monitoring is to be cost-effective and stand a greater chance of being implemented, both on a wider spatial scale and by more participants, including local 'users'.

The selection and use of key indicators is also crucial to the implementation of the Precautionary Principle approach to conservation and/or impact mitigation, i.e. management action/intervention before real evidence of deleterious impacts and important ecosystem-level changes can be scientifically proven (Anonymous, 2005). Indicators can also provide rapid assessment tools that can facilitate monitoring and lead to the design and monitoring of impact thresholds, e.g. Limits of Acceptable Change (LACs), or critical loads, whereby unacceptable change beyond a chosen indicator threshold calls for management intervention to mitigate or abate such and regulate the activity/development. Indicator thresholds can be altered according to sensitivity, conservation value and/or land use, and according to the management objective.

A good indicator will actually indicate or track something – it will respond clearly to changes and should be linked clearly to the conservation and/or management goals – and placed accordingly in an monitoring framework. It must be possible to collect information for the indicator within the likely constraints of capacity and resources, and should also be scientifically credible, simple to monitor and easily understood, in order to quantify information so that its significance is clear (Ramsar Handbook 16, SBSTTA 1999).

2.6.1 Methodology

This sub-component provides a comprehensive review of indicators in adaptive wetland management, to identify key monitoring indicators and a framework monitoring programme that will facilitate the long term effective management of the MWS.

The most powerful impact monitoring programs will generally be those that include two types of indicator, namely those associated with early warning of acute impacts and those closely associated with (usually longer-term and harder to identify) ecosystem-level effects (Anonymous, 1999). 'Ecosystem-level' indicators might include ecologically important populations (for example, 'keystone' species) or habitat, or communities of organisms that serve as suitable ecosystem 'surrogates', i.e. indicators closely linked to ecosystem-level effects. With both types of indicators measured in a monitoring program, information provided by 'ecosystem-level' indicators may then be used to assess the ecological importance of any change observed in an early detection indicator.

Early warning indicators, used in rapid assessment methods can be defined as a measurable biological, physical or chemical response to a particular stress, that precedes the occurrence of potentially significant adverse effects on the ecosystem as a whole (Anonymous, 1999). A framework for wetland monitoring has been developed by Finlayson, C.M. (2003) and adopted by the Ramsar Wetlands Convention, which includes rapid risk assessments of an array of early warning, easily sampled and identified hydro-chemical and biotic indicators (Anonymous, 1999).

This framework has been used in this study to guide the identification and appropriate use of rapid assessment indicators for the MFMP area. Potentially useful biotic indices include macrophytes, fish, amphibians, invertebrates and birds. Monitoring of wetland systems around the world has, however, tended to focus on the use of invertebrate communities to fill this role. For the MFMP area, focus was given to those species, for which more is known about their diversity, habitat requirements, and population status and trends and so change in their characteristics can be somewhat more accurately quantified and understood.

Both ecosystem level indicators and rapid assessment indicators can be regarded as performance indicators, i.e. indicators of change in a ‘feature’ or part of the ecological character/integrity of the system, that are used to monitor progress in achieving the management objectives for that feature (Ramsar Wise Use Handbook 16). The CBD and Birdlife International’s IBA monitoring framework programme (SBSTTA 1999; Birdlife International, 2005), for example, identifies performance indicators according to a 'Pressure–State–Response' framework that are appropriate to particular management objectives;

- Pressure indicators identify and track the major threats to key species, populations or communities/species assemblages. Examples might be rates of agricultural encroachment, timber extraction or water abstraction;
- State indicators refer to the condition of the system, with respect to its biodiversity. State indicators might be population counts or measures of the extent and quality of the habitat required by a keystone or ‘trigger’ species, and;
- Response indicators identify and track conservation actions: for example, changes in legal status, management actions or funding of conservation projects.

The monitoring framework designed in this sub-component, therefore, identifies specific performance indicators, whether of ecosystem state or rapid assessors, according to key management objectives. Identifying who monitors these indicators is also crucial before an appropriate and effective monitoring programme can be designed. Recommendations on the monitoring focal persons/institutions were, therefore, included in the monitoring framework table.

In addition, the importance of follow-up action in effective adaptive management, advocated by the ecosystem approach, is examined, outlining some of the important considerations and actions required to achieve successful management using information gathered by key indicator monitoring, as outlined in by Ramsar (Ramsar Wise Use Handbook 16). If monitoring is to be successful, participation by local stakeholders, including community representative, is advisable and different approaches of doing this are also presented in this framework to help guide a participatory approach when executing an effective monitoring programme for the MWS.

2.7 Rangeland Ecology

The importance of rangeland to sustainable livelihoods in Botswana is beyond question. The MWS comprises a very important extensive area of rangeland around the pans complex, which provides important grazing and browsing for large numbers of both wildlife and livestock.

A good understanding of the status of, and trends in such a resource must, however, be gained in order to highlight its use potential, its vulnerability to degradation and overuse, and in order to stabilise, and potentially reduce human-wildlife and other rangeland use conflicts. This is particularly true of a marginal semi-arid and predominantly saline habitat that is sensitive to impact and degradation, such as the MWS rangeland.

This report, therefore, identifies the optimal stocking rates and carrying capacities for the different vegetation types, defines the current threats to biodiversity and ecosystem functioning, and defines existing opportunities and challenges to the conservation and sustainable use of rangeland resources in the MWS. In addition, the identification of key monitoring techniques to assess the impact of overgrazing and the effectiveness of land use and rangeland management decisions is also addressed and the results were incorporated into the monitoring framework, in the Indicators sub component. Development options are also proposed to offset the current constraints to the wise use of rangelands in the MWS, including their degradation.

2.7.1 Methodology

To achieve these objectives it was important to gather and analyse the following data:

1) Past reports and research undertaken within and around the Project area;
2) Historical census data on wildlife populations in the region;
3) Historical and anecdotal evidence of ecological conditions in the study area;
4) Undertake targeted research within the Project area;
5) GIS analysis of Landsat Imagery to define a borad 6-class vegetation map, and;
6) Enhanced Vegetation Index analysis was used to identify vegetation recovery from the drought period of 2002, till 2009.

2.8 Climate Change

Significant uncertainties surround the science of the future climate. Most scenarios predict a decline in precipitation and increase in temperatures by some varying percentiles, resulting in a pronounced downturn in flow regimes and the replenishment of groundwater. Almost all specialists and scenarios predict exacerbated extreme climate events. However, it is important to point out that these climate change (CC) scenarios do not consist of definite predictions, but rather present plausible future climates and that what matters is the ability to manage uncertainties portrayed in these scenarios. This includes reducing current vulnerability to climate variability and extreme events, as well as keeping management options flexible and open enough to deal with the worst-case scenarios.

Botswana is vulnerable to climate change and variability. One of these physical characteristics that predispose the country to its vulnerability to CC is the visible contrast between wetlands and the surrounding arid zones. Some of the country’s major watercourses originate in the high rainfall areas of neighbouring countries, with their water resources shared among several different countries. This results in considerable interdependence in water resource use and management and calls for considerable efforts in trans-boundary water resource management. In addition, a considerable proportion of Botswana’s population live in poor rural communities and depend heavily on subsistence rain-red agriculture. Meanwhile, water harnessing for agriculture, domestic, industrial uses and power generation is relatively under-utilized and holds little potential in this topographically flat country.

This report, therefore, also synthesises a specialist report, which reviews CC scenarios and their relevance to the MWS, in an attempt to identify a range of likely plausible future climate scenarios, and the likely impacts they will have on the systems functioning and its biodiversity. The vulnerability of the MWS is also briefly assessed using examples of the physical processes, ecological functioning and the biological components, in order to predict future vulnerability to change and highlight the importance of designing appropriate management interventions. Indicators are also proposed that will guide future CC monitoring, contribute to an early warning system and monitor the impacts of extreme climate variability on the system and its biodiversity.

2.9 Interpretation and synthesis

Interpretation and synthesis of the above components consists of placing them into context in the overall framework management plan and focusing on their relationship to an effective analytical framework adopted in this management planning process. This entails constant guidance by, and compliance with the methodology and framework provided by a sustainable development or 'wise use' approach, as provided for by the Ramsar Convention and the ecosystem approach.

In addition, the successful integration of this report into the main report (volume 1) requires appropriate referral of each sub-component to other relevant components, and identification of the relationship and interplay between and among them. This enables all aspects of the ecology and hydro(geo)logy component to be incorporated into a single integrated FMP for the MWS.

3 Findings

3.1 Hydro(geo)logy

3.1.1 Hydrology Review

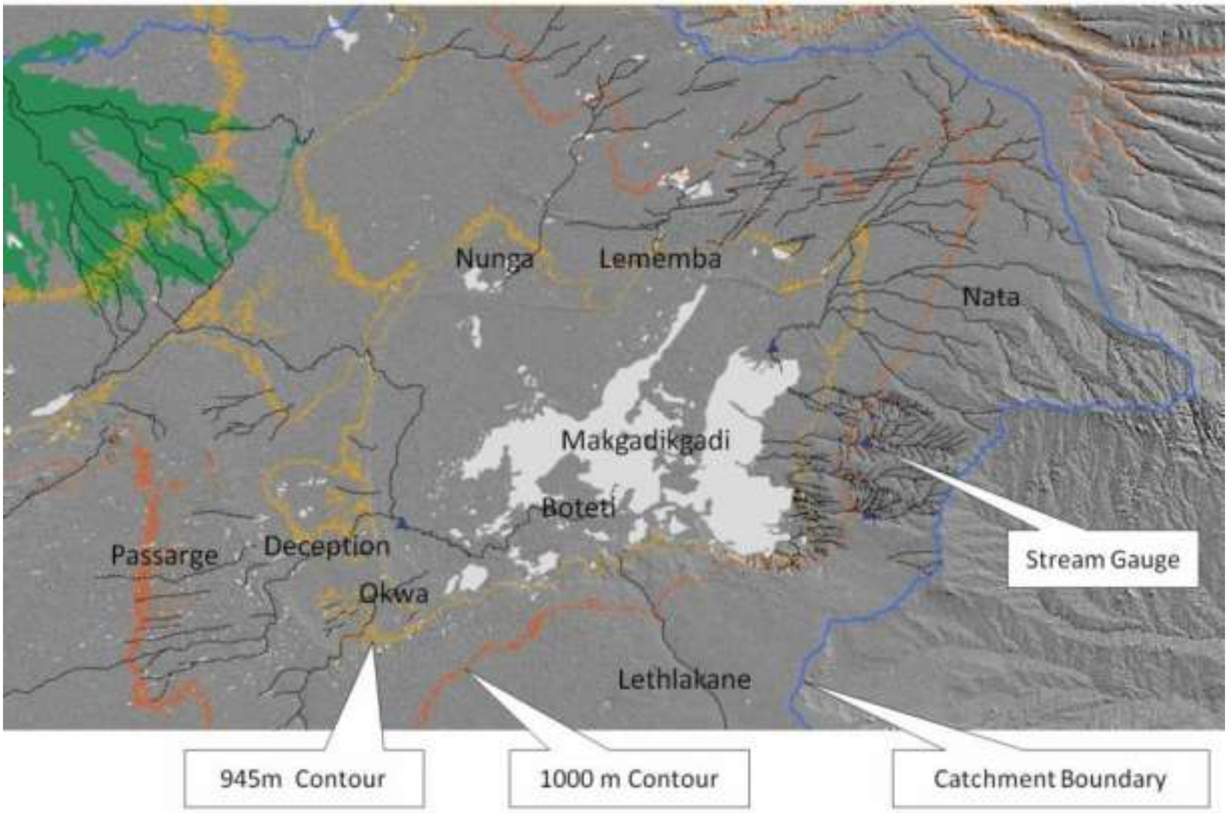
3.1.1.1 Catchment and Drainage lines

Drainage features in general are very subdued with the exception to the east of the Pans, where watershed boundaries are well defined and rivers appear most active (Figure 2). A range of surface features such as the former palaeolake shores to the north and west act as topographic watershed boundaries but may not have an impact on the movement of groundwater.

In the eastern catchment, two distinct drainage patterns or zones appear from analysis of the SRTM image below: Above the 1000 m contour most of the rivers are well incised and portray a dendritic surface pattern; Below the 1000 m contour the rivers (Semowane, Mosetse, Lepashe, Mosope) enter the terrain of the former lake floor, which has a higher infiltration potential due to its calcareous and silica karst morphology. The watersheds between these rivers below the 1000 m contour are wide and flat and may act as direct recharge zones to the Pan basin. The channel flood plains widen towards the Pan and shallow discharge supports a host of riparian wetlands and delta systems. In addition recent tectonic activity to the north of the Pan has resulted in fault controlled topography, and produced the potential for “channelled” groundwater flow in a number of ill-defined channels such as the Nunga, Lememba and Letlhakane, which may contribute to groundwater movement towards the main pans.

This suggests that the pan receives significant groundwater recharge and explains why Sua Pan, in particular, holds water for much longer periods than otherwise expected, owing to significant and delayed groundwater recharge. Smaller ‘proto–pans’ surrounding Ntwetwe and Sua pans are elevated yet sunk into the margin of the raised perimeter of the pan. These smaller pans nested in the karstic terrain of the older lake floor below the 1000 m and 945 m contours may act as important elevated recharge points to the main pans.

Figure 2. Shaded SRTM with drainage and major contours. Overview of surface water catchment and topographic setting with special reference to the 945 m (Orange) and 1000 m (Red) contours.



Note: not all rivers reach the pan and note pronounced incision of eastern catchments. Contours are indicative old lake floor, which may now facilitate infiltration and pan groundwater recharge.

Source: Chapter 8, this volume.

3.1.1.2 Climate and Rainfall

Average annual rainfall is 450mm, ranges from 359mm in Rakops to 545mm in Maitengwe, along a southwest – northeast rainfall gradient (Table 3 and Figure 3). Highest mean monthly rainfall is in January and July and August are the driest months. Inter-annual variability is highly pronounced, with significant deviation around the mean. Rainfall in the Makgadikgadi basin is strongly linked to ENSO (El Ninõ Southern Oscillation) cycles in the Pacific and SST (Sea Surface Temperature) anomalies in the Indian Ocean. Records for the 1980-2000 time series showed a strong correlation between wet season rain (December, January, February) in the Nata River Catchment and the Subtropical Indian Ocean dipole (SIOD) values for (January, February, March) of the same year (Bryant *et al*., 2007).

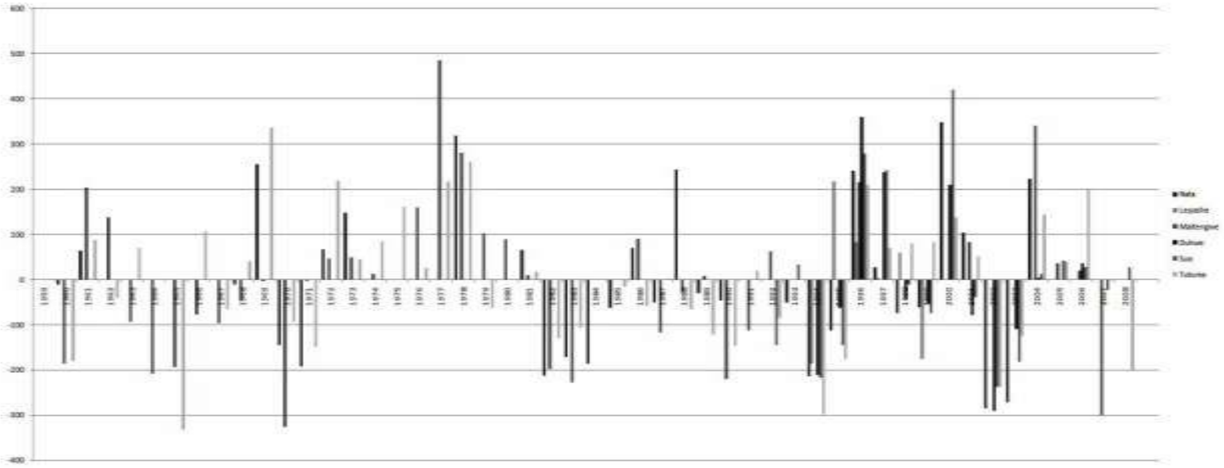
In addition, extreme rainfall events are linked to the landfall of tropical cyclones during periods of La Nina conditions and associated anomalous low level moisture flux into eastern southern Africa. Overall rainfall records for this area as well as most areas in Botswana have a slightly negative trend, suggesting that Bostwana is becoming drier (Botswana National Atlas 2001), which may not necessarily be due to global warming.

Table 3: Mean monthly and annual rainfall figures for the Makgadikgadi

Months	Motopi	Rakops	Letlhakane	Sua	Nata	Dukwe	Lepashe	Tutume	Maitengwe	Sebina
August	0	1	0	0	0	0	0	0	0	1
September	3	3	3	4	3	2	2	5	5	7
October	21	16	12	14	20	12	16	20	23	20
November	62	44	56	56	53	69	67	69	78	75
December	60	61	77	79	83	84	89	95	131	87
January	121	93	93	123	112	133	111	116	120	109
February	87	66	87	87	96	73	72	84	93	83
March	48	49	58	53	55	58	39	68	62	44
April	12	21	11	6	25	6	11	25	26	21
May	4	3	5	5	4	7	10	4	5	3
June	0	3	3	5	1	3	12	2	3	1
July	1	0	0	2	1	0	4	0	0	0
Total	**419**	**359**	**405**	**435**	**453**	**448**	**433**	**488**	**545**	**452**

Sources: based on data from Botswana Meteorological Office.

Figure 3: Rainfall deviation from the mean (in mm) for selected stations NE of the Makgadikgadi from 1959-2008.



3.1.1.3 Drainage Hydrology

During the period 1971-1999 the Nata River discharged most water in total (4 471 MCM), the Boteti slightly less (3 274 MCM), with Mosetse (688 MCM) and Mospue (208 MCM) rivers discharging much less. Flow is highly variable and all months recorded zero flow records over the years. Eastern river floods are typically short and sharply peaked floods, and synchronized with rains and therefore peak flow is usually attained in January. The Boteti River peaks much later during September as its floodwaters originate from the Okavango Delta, via the Thamalakane. Flood periods may extend over many months with noted variations being gradual.

Work by Bryant *et al*. (2007) has pointed to a strong ENSO control in the Nata River stream flow and a good link to surface water conditions in the Makgadikgadi. Other gauges only capture runoff at some distance from the pan.

3.1.1.4 Landsat Imagery analysis: Riparian systems and groundwater seepage points

Landsat imagery lends itself to map small seepage points and water pools as well as riparian distributions and historical status (Figure 4). Landsat data is from the historic archives of the GLCF (Global Land Cover Facility). This record extends back to 1973 and hosts imagery for the 1970's in the form of MSS (Multi Spectral Scanner) data (80 m resolution), TM (Thematic Mapper) data for the 1990's (30 m resolution) and ETM (Enhanced Thematic Mapper) data for the 2000 period (30 m resolution). Surprising amounts of water was observed in the lower Boteti River despite historic floodwater recession, suggesting significant groundwater input;

- Numerous small proto-pans host water as part of recharge or discharge events;
- No noticeable proliferation of dams or micro-dams in Pan catchments;
- Arable land expands mostly to the east of the Makgadikadi watershed;
- Dynamic land surface response to rain and drought cycles as well as fires;
- Some of the proto-pan riparian is relatively persistent suggesting healthy groundwater status; and
- Lake Xau in full flood and the surrounding riparian extent (Figure 5)

Figure 4. Drainage lines, Riparian habitat and groundwater seepage points identified from landsat imagery.

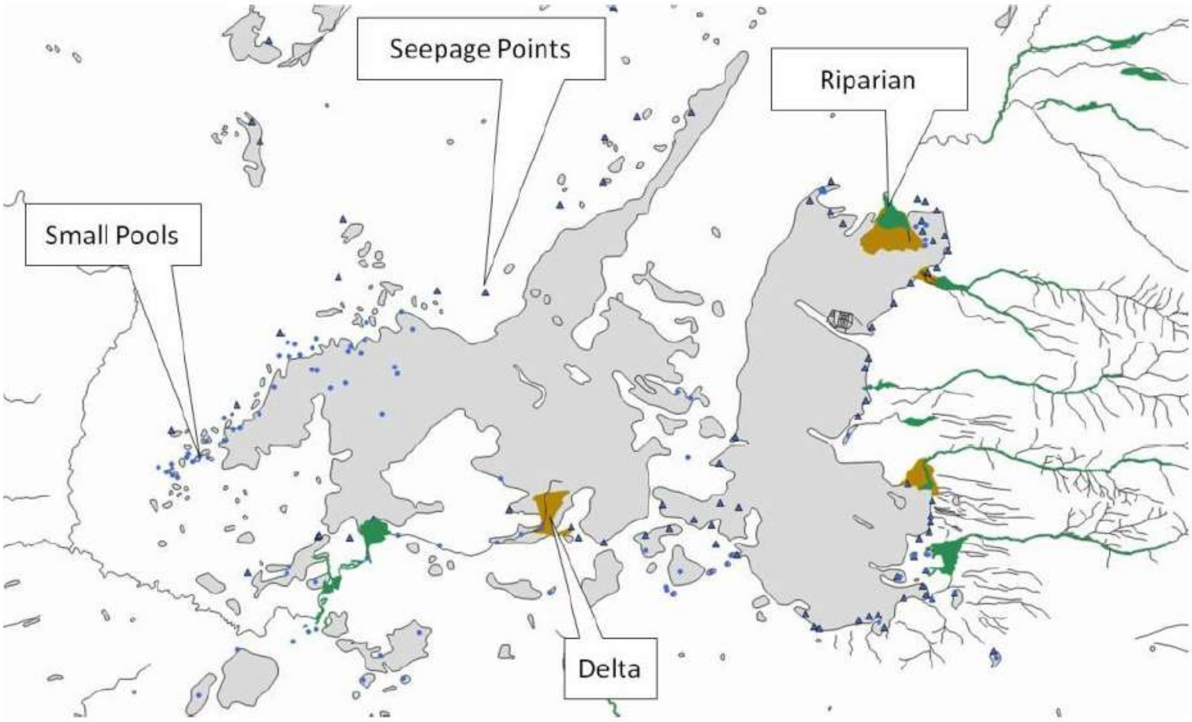
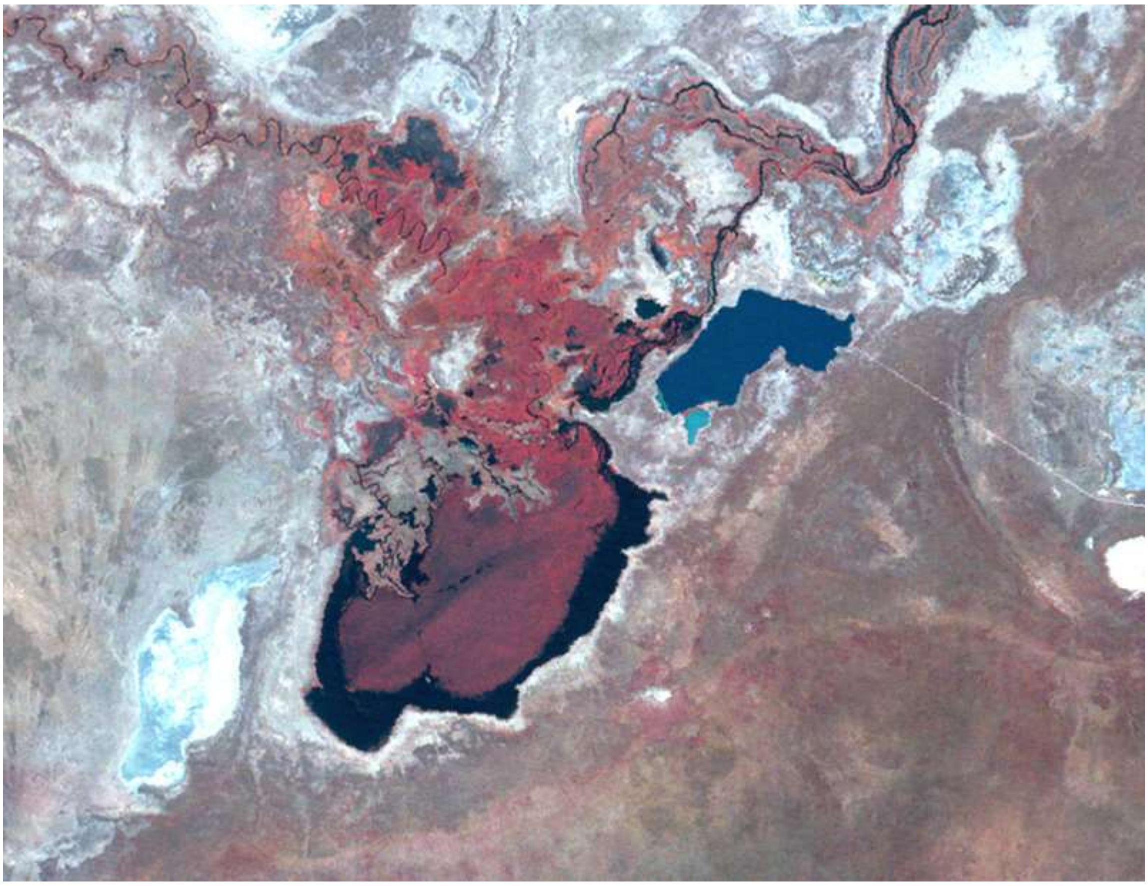


Figure 5. A flowing Lower Boteti, a filled Lake Xau and rim full Mopipi Dam in June 1979 as seen in Landsat MSS.



Source: GLCF.

A rapid appraisal of 14 images was used to identify the features above, and their various degrees of surface change and dynamics between the 1970's and 2000. A full analysis into these and other related Landsat imagery especially in the context of climatic variability would provide a more systematic and quantifiable appraisal of change within the Makgadikgadi Basin.

The observations made so far can, however, be sumarised as identying the following:

- Total desiccation of Lake Xau in the 80's
- Decommissioning of Mopipi Dam in the 80's
- Relatively persistent riparian ecology to the eastern margin of the Pan
- Seemingly persistent lake margins and grass islands at the depicted scale up to 2001
- Small fresh water lake below Mosu escarpment prevails (lat -21.1761° lon 25.9842)
- Numerous small proto-pans host water as part of recharge or discharge events
- No noticeable proliferation of dams or micro-dams in Pan catchments
- No massive changes in land use land cover noted
- Arable land expands mostly to the east of the Makgadikadi watershed
- Establishment and growth of mines and associated towns including Sua Town
- Dynamic land surface response to rain and drought cycles as well as fires

3.1.1.5 Lacustrine surface water and flood dynamics

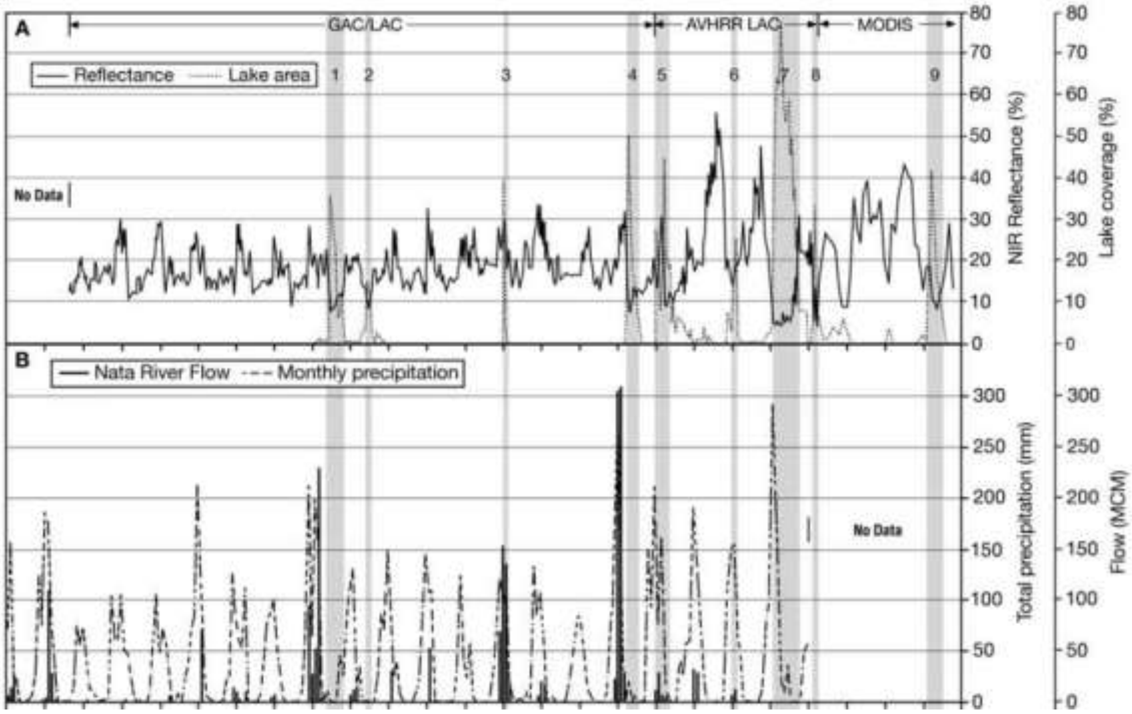
Analysis of daily NOAA AVHRR data (during the period between 1980-2000) at 5 km and 1 km resolution was used to produce the lacustrine history of the entire Makgadikgadi basin (Bryant et al., 2007) (Figure 6). Superior pan moisture detection can, however, be derived from the MODIS sensor (Terra and Aqua platform), and analysis of the flooding on these MODIS images from 2000 to 2009 has identifies areas indicative of pronounced surface water presence and highlight areas worthy of further examination and consideration, called “wetspots” (Table 4 & Figure 7).

“Wetspots”:

Are areas indicative of pronounced surface water presence and highlight areas worthy of further examination and consideration, called “wetspots”.

Wetspots are pan surface areas, which have the potential to support an ephemeral wetland. These areas gradually grade into wet mud, hydrated salts and during dry cycles may be reduced entirely to a bare, moisture free, pan surface. Wetspots are produced by direct rain contributions to the pan surface, water runoff from adjacent river catchments and the discharge of shallow groundwater.

Figure 6: Time series for the Makgadikgadi, Including NIR Reflectance (%), Lake Area (%), Monthly Precipitation (mm), Nata River Flow (MCM).



Source Figure 13: Bryant *et al.* 2007.

Table 4. Most persistent and dynamic Makgadikgadi wetspots.

Location	Most Likely Water Input	MSS 1970’s	TM 1990’s	ETM 2000	Lat	Lon	Map ID
Northern Sua	Nata & Semowane River	142	118	0	-20.3	26.2	1
Central Sua	Mosetse River	0	40	0	-20.6	26.1	2
Southern Sua	Lepashe River	0	0	0	-20.8	26.2	8

Southern Sua	Mosope River	0	0	0	-21.1	26.2	11
Southern Sua	Groundwater	0	0	933	-20.8	26.0	3
Northern Ntwetwe	Groundwater	0	18	8	-20.4	25.5	5
Central Ntwetwe	Groundwater	0	0	0	-20.5	25.6	6
Southern Ntwetwe	Boteti Groundwater	0	0	0	-20.8	25.4	4
Western Ntwetwe	Groundwater	0	0	11	-20.7	25.0	9
Western Ntwetwe	Groundwater / Boteti	0	0	13	-20.9	25.0	10
No Name Pan	Groundwater	0	0	7	-20.9	24.7	12
Nkokwane Pan	Groundwater	0	23	0	-21.1	25.5	7
	Sum	142	199	968			

Note: Summary of pan surface regions with detectable moisture fluxes as identified from MODIS time series. Size observations in km^2 are estimated from actual observations in Landsat data.

While some of these “wetspots” are directly linked to surface water inputs most of them may well show a response to short-lived groundwater pulses or even rainwater ponding depending on pan topography. Southern and central Sua Pan appear to host larger water bodies than the northern section, and occurs mostly in the pan center and is not closely associated with the pan margin inputs. This is surprising when taking into account the relative size of eastern catchments and observed discharge in particular from the Mosetse, Lepashe and Mosope streams. This might suggest that lacustrine water in the northern portion is largely dependent on direct river runoff while water in the southern section is perhaps more dependent on groundwater discharge.

In addition, no direct surface water input is associated with the southern portion of the Pan as is also the case in the central (6) and southern portion covering about 300 km^2 (4), which certainly gives credence to the importance of groundwater discharge sustaining some of the lacustrine water bodies. There are numerous pans on the southern margin of the Makgadikgadi, some of which often appear to host surface water, in particular, Dzibui Pan (12) and Nkokwane Pan (7). In general total surface water accumulation may be less than 100 km^2, 2000 saw up to 1000 km^2 (Figure 8) and there might be the potential to host up to 2000 km^2 of water.

Figure 7. Relative Pan wetness and wetspot identification from satellite imagery analysis.

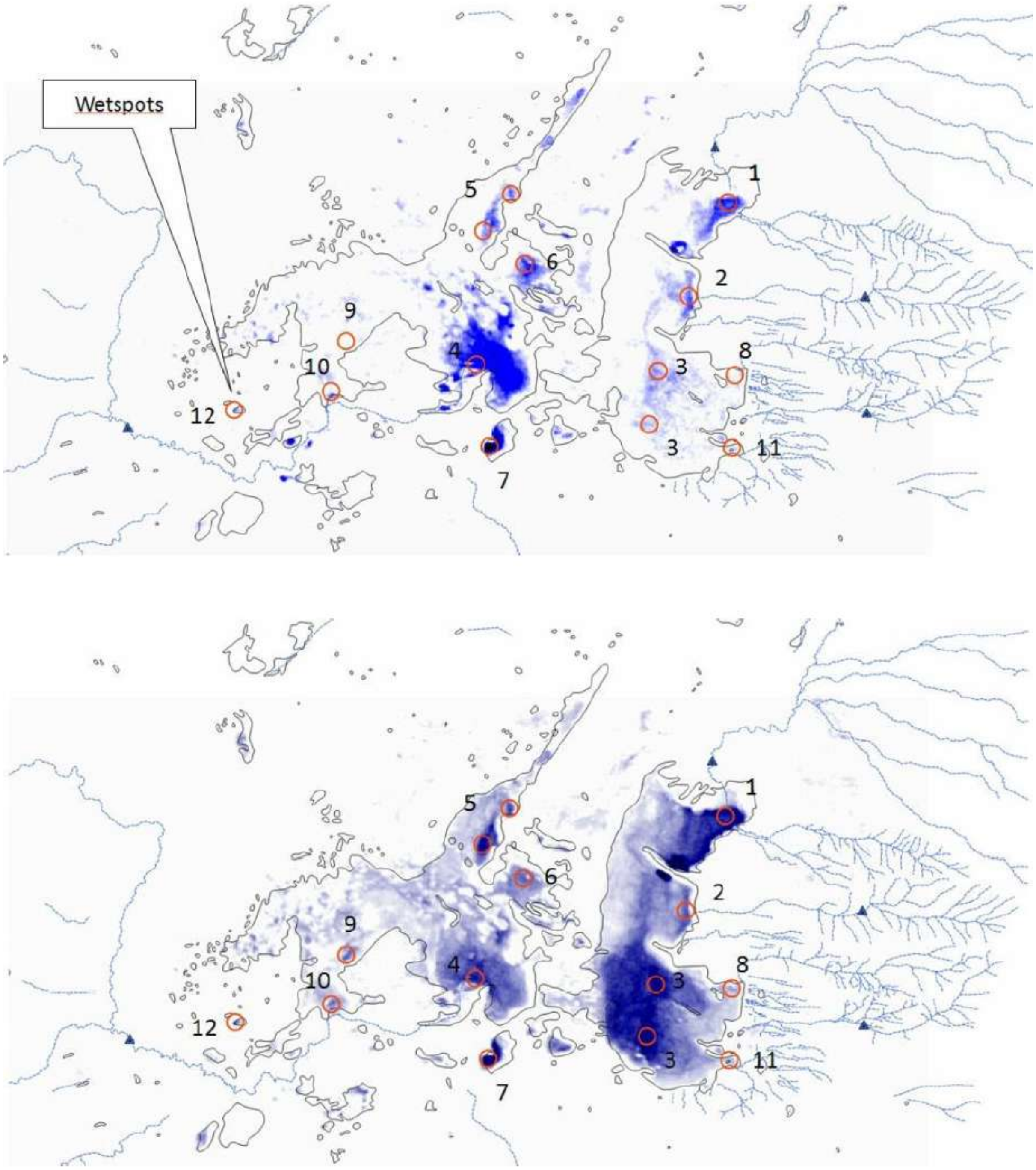
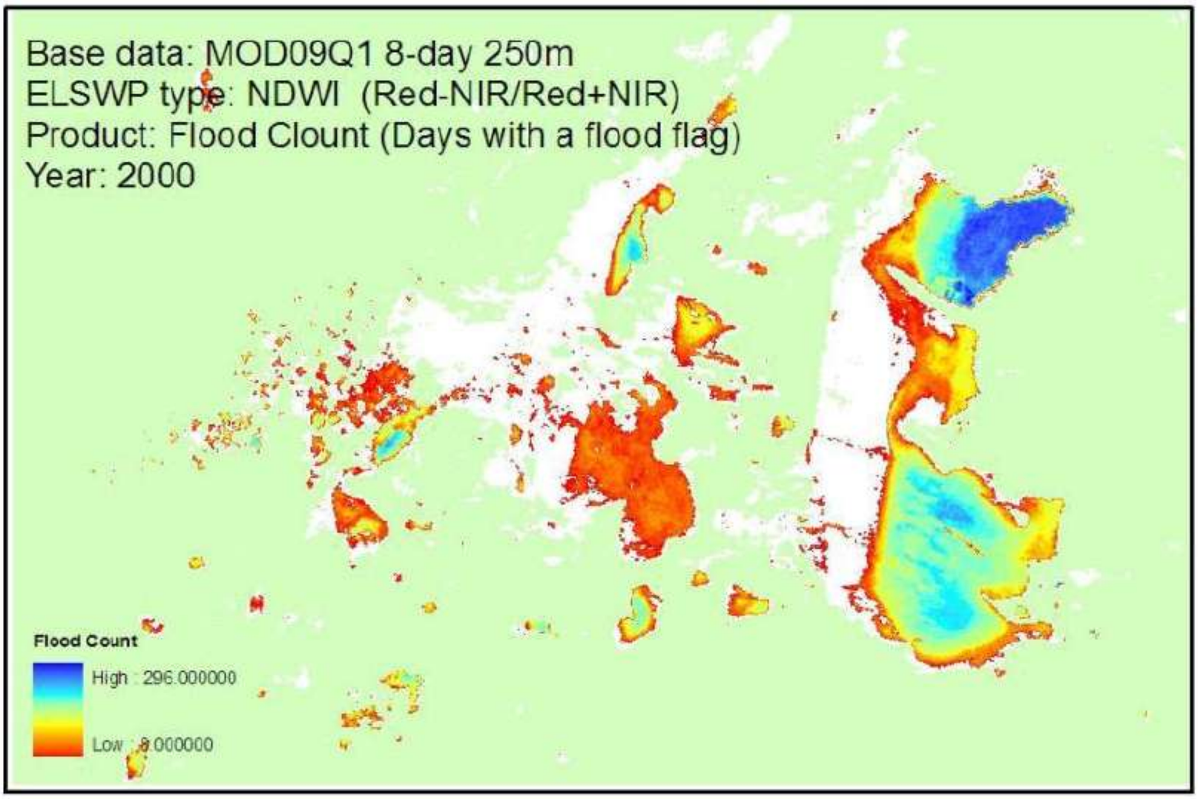


Figure 8. Example of MODIS satellite imagery analysis derived flood count map for the flood period in the year 2000.



Source: Chapter 8, this volume

3.1.1.6 Pan surface morphology

One can use the pan surface and composition as an indicator of hydrological processes and trends. Current pan surface conditions are governed by shallow groundwater dynamics.

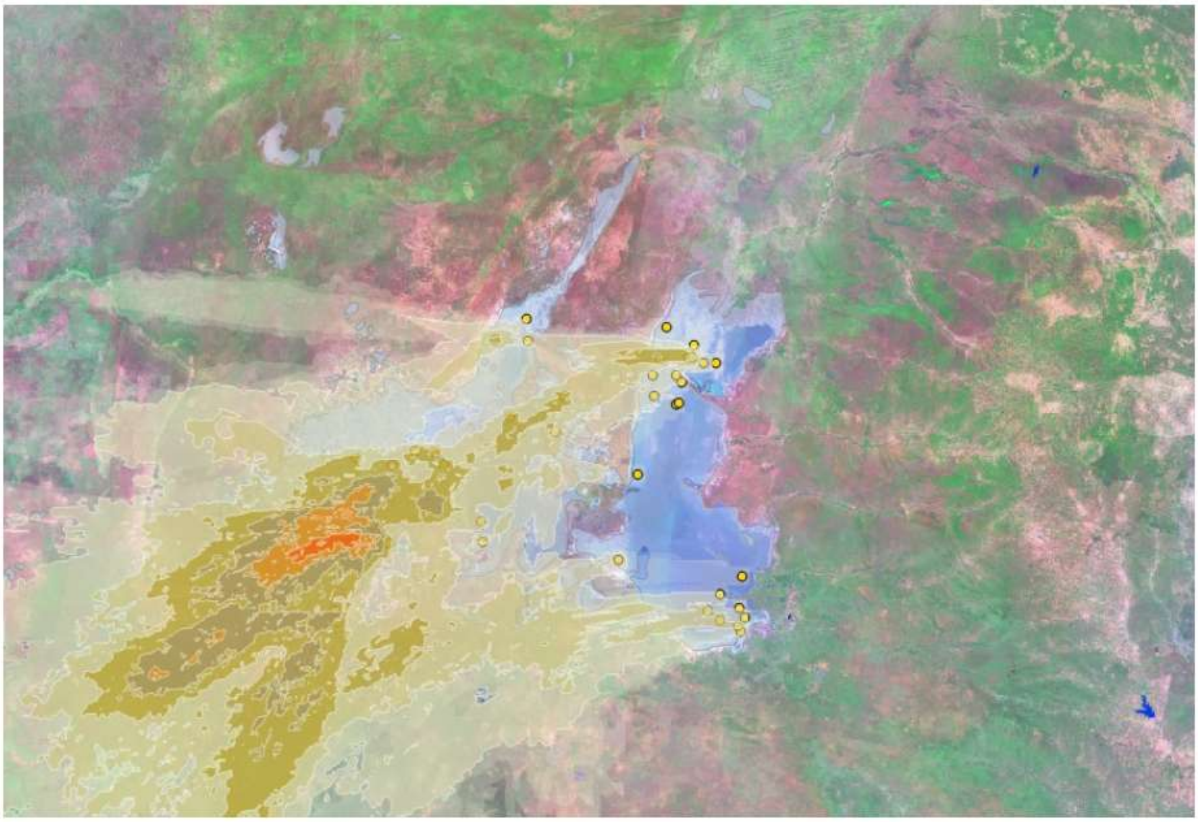
The main pans are clay-rich with shallow groundwater and few, sporadic salt crust accumulations when compared to discharge pans elsewhere. The salts that occur at the surface are often mixed into the muds are may be the product of lacustrine water evaporation and some shallow groundwater evaporation.

A clay rich pan will be able to support a relatively shallow ground water table and capillary fringe and during rain or runoff will quickly cause flooding on the pan surface due reduced infiltration capacity. The fluvial, hydrological and aeolian environments at the Makgadikgadi are tightly interwoven (Bryant *et al*., 2007). Dust production is directly linked to fluvial inputs into the pans. In particular flood events provide sediments and salts for deflation and the Makgadikgadi has been considered a “supply limited” system.

Groundwater levels along the southern margin of Sua must have dropped in the past which produced distinct lag gravel on the pan surface and, currently, a lowering of the capillary fringe in the Botswana Ash wellfield may have triggered surface activation and deflation, giving rise to debkha dunes behind newly established salt bushes.

Dust sources points have been mapped for the 2007-2009 period and are located in hydrologically dynamic areas while associated dust depositions zones have been modelled for the basin with the main impact in SW sector towards Rakops (Figure 9). The annual average chemical dust footprint is approximately 150 km long and contains three million metric tons of chloride, sodium, and bicarbonate (Wood et al. 2010).

Figure 9. Hysplit model of the relative Aeolian dust deposition for period 2007 to 2009.



Source: Chapter 8, this volume.

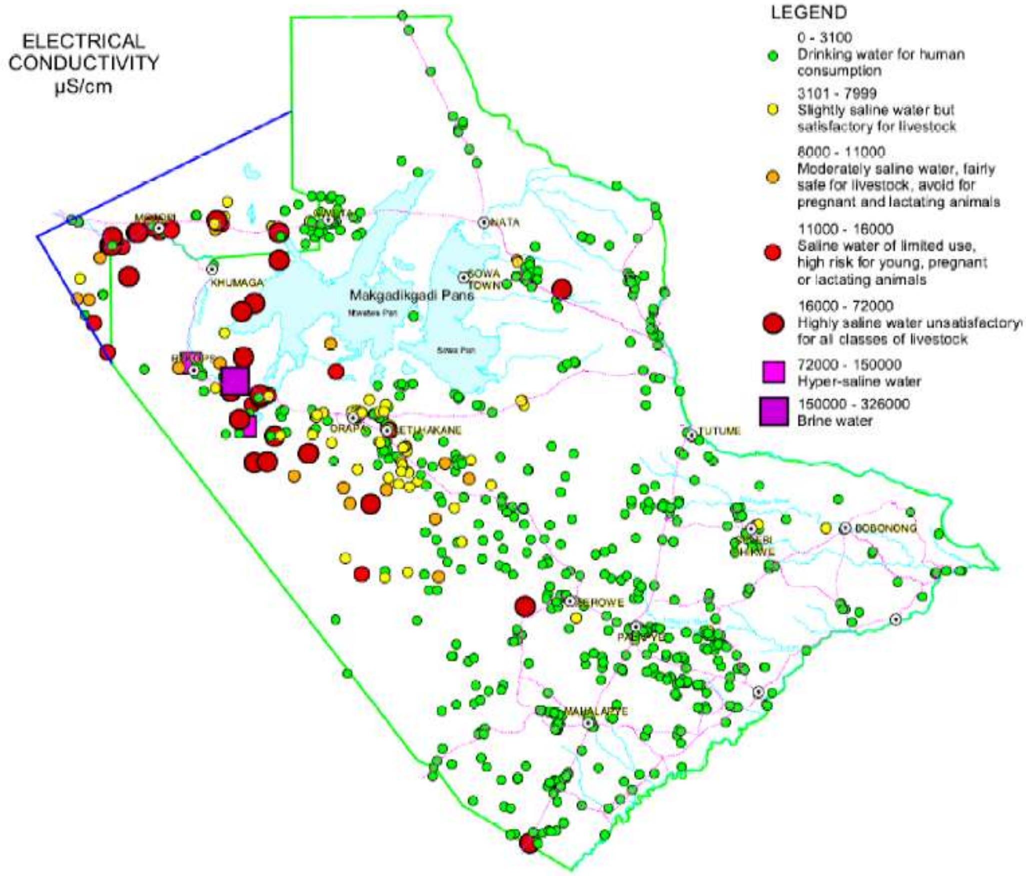
3.1.1.8. Groundwater

Groundwater quality in Makgadigkadi catchment is variable (Vogel 2004). In general the most saline water occurs around Rakops and other sections of the Boteti as well as Letlhakane (Figure 10). It is assumed that such shallow groundwater is subject to prolonged evaporation. Water at Gweta and Dukwe are pumped from some of the karstic terrain, which is fresher in nature and more suitable for human consumption.

The Pan itself hosts 2 types of groundwater. The shallow near surface water, as well as the deeper saline brine; Gould (1986) stated that the pan holds 8013 MCM of brine containing 1026 million tons of NaCl and 233 million tons of Na_2CO_3. It was concluded that current river water has little to do with the development of the brine and that recharge from the surface was unlikely, which was supported in part by isotope analysis carried out by Eckardt *et al*. (2008).

BotAsh pump from over 90 well points in the north basin of Sua Pan and aim to expand to an area that covers much of the middle basin of Sua Pan, for which they already have a prospecting licence for and are drilling some test boreholes (Figure 11). Pump rate is at about 2 400m^3 per hour and pump rate is inversely related to TDS, suggesting little brine recharge and decoupling of surface and subsurface waters. Pump rates of 3 500 m^3 are considered feasible with the expansion (WMC, 2008).

Figure 10: Groundwater quality data from borehole throughout the MFMP area

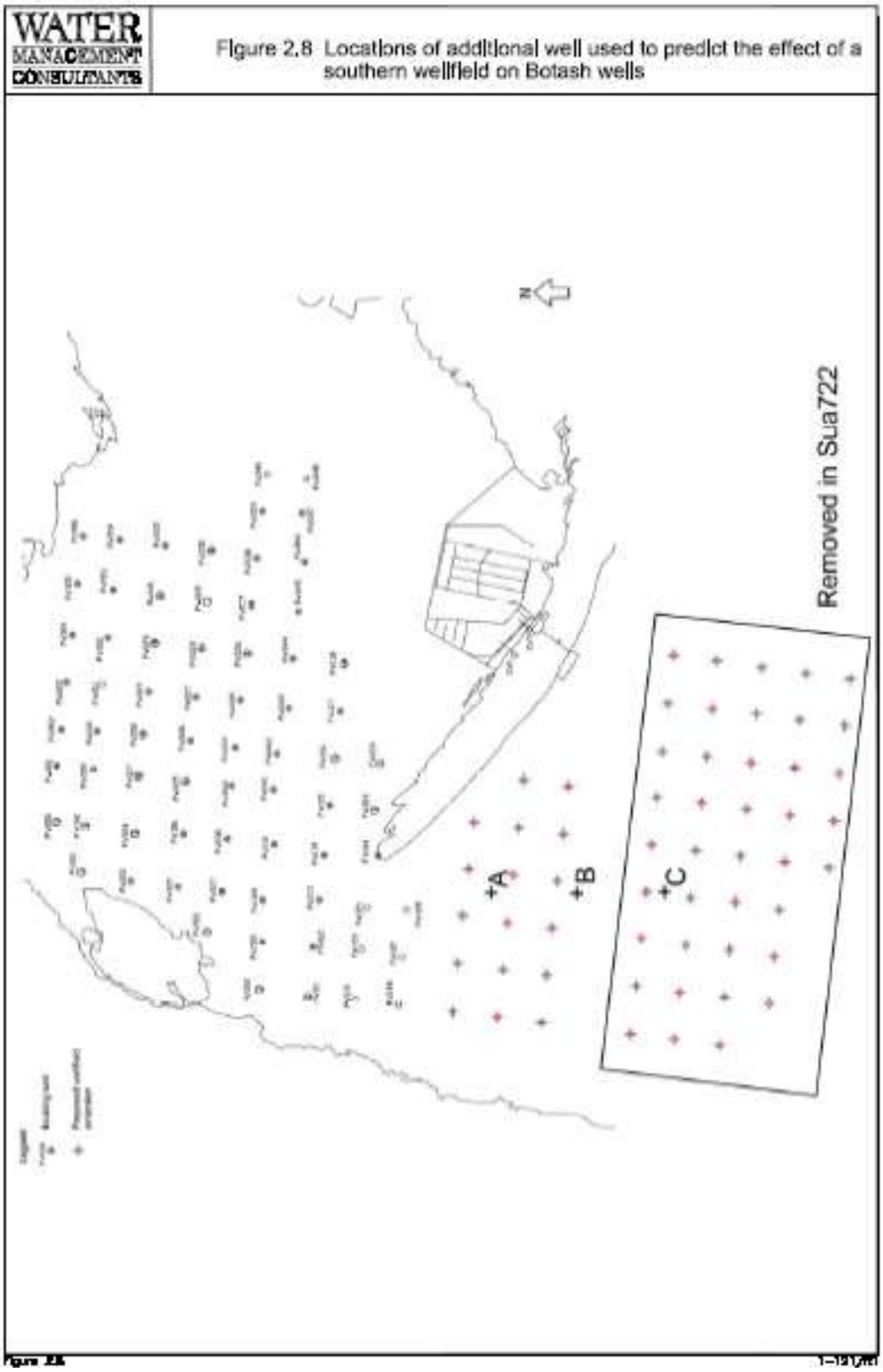


Source: Vogel, 2004.

WMC (2008) modelled that a drop in the brine water level of up to 7m is to be expected with an increase in brine extraction in a southern extension wellfield. This is to be accompanied by a drawdown of the shallow groundwater of up to 5m in the south of the current wellfield, and diminishing evapotranspiration at the surface of the Pan. This trend has indeed been manifested in all monitoring wells with modeled and observed drawdown currently centered to the north west of the spit at (lat -20.38° lon +25.99°). This draw down will gradually shift southward as production also shifts south of the spit. Despite the pumping in the BotAsh wellfield, we have no handle on how the system and in particular the lacustrine environment will respond to drawdown.

Groundwater is also pumped from many wellpoints and boreholes beyond the pan margins, particularly at Dukwe, Letlhakane, Orapa and Gweta. How much of this constitutes a loss from the pan and effects groundwater, and even surface water levels on the pan is very hard to say. Groundwater flow rates and directions around the pan are not known, but one can expect most, if not all drainage lines provide and influx of groundwater.

Figure 11. Locations of additional wells used to predict the effect of a southern wellfield on BotAsh well pump rates and resulting brine resource levels



Note: Locations of simulated observation wells at points A, B and C taken from WMC 2008.

Source: WMC, 2008.

Since 1984 Orapa mine has become wholly dependent on groundwater and the greater Orapa area has seen the development of new wellfields and extensions to existing wellfields to meet Orapa’s continuing increase in water demand. At present 6 wellfields in Ntane/Mosolotsane aquifer are in operation (Figure 12).

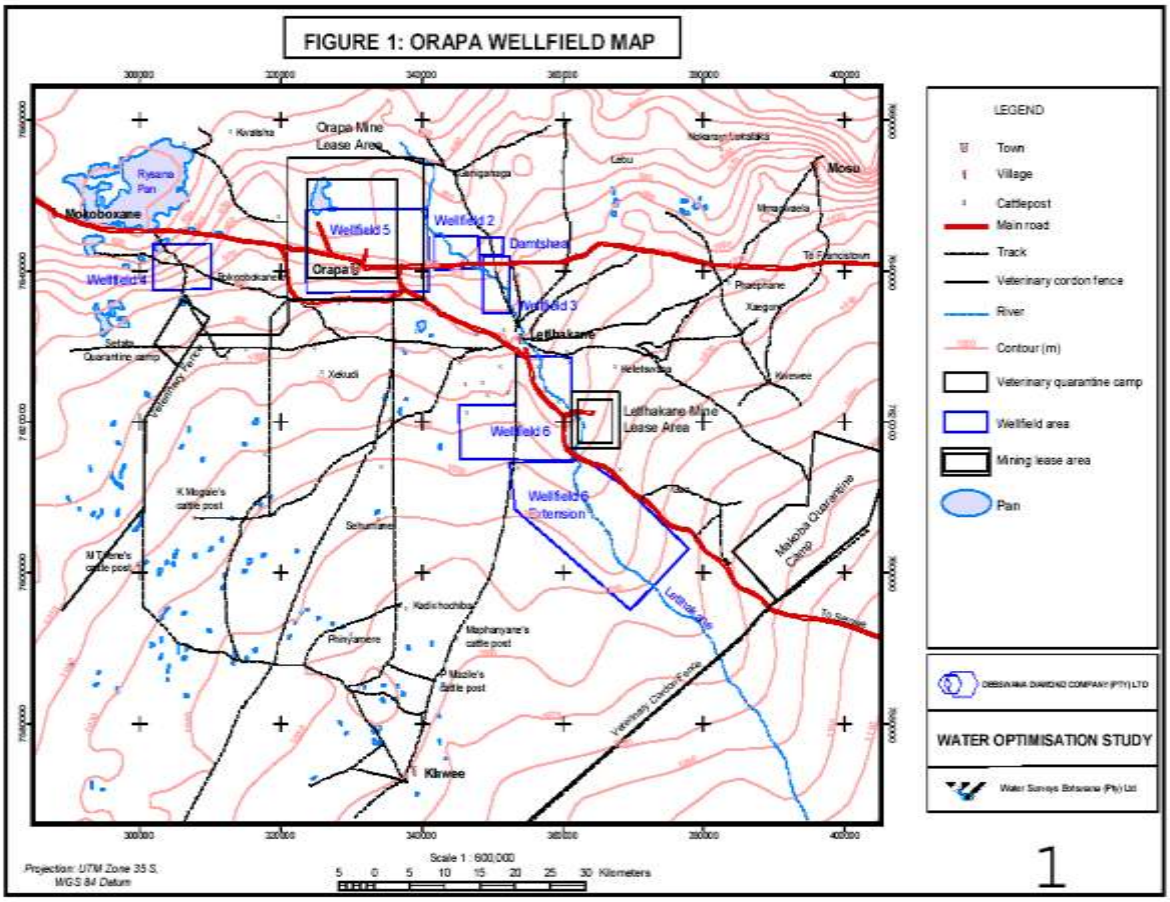
Continued mining of this groundwater at current rates may not only reduce the long-term water supply to the mine but also for the supply of domestic water to Letlhakane, may affect the numerous cattle posts in and around the mine well fields, and may eventually lead to ingress of saline water especially from the north as regional groundwater flow gradients are changed.

Groundwater modelling (SHEC/ESH, 2006) showed that continued and increased abstraction resulted in many of the boreholes in wellfields 2, 3 and 5 breaching a 50% drawdown constraint (50% of Ntane /Mosolotsane aquifer dewatered). Simulated impacts on the DWA wellfield at Letlhakane showed a 25m drawdown over the 20-year period (2024).

The total annual abstraction from the six operating wellfields, and the three pit dewatering systems for the 2008 monitoring period was 11 790 694 m^3 with a monthly average of 982 558m^3, with water levels data indicate the continued decline in water levels around the Orapa and Letlhakane mines wellfields (Debswana, 2009). Wellfield 6, which provides potable drinking water, has fallen to Class II (BOS 32: 2000) in terms of its drinking water quality.

This Debswana groundwater report concludes that water quality around several boreholes is also seen to be degrading especially from boreholes around pit dewatering centres, and that continued pumping in the current system could result in unsustainable abstraction and supply and hence long term detrimental effects to the aquifers.

Figure 12: Orapa Wellfield



The following are the actions recommended for the improvement of the Orapa water resource (SMEC/EHS, 2006):

1. A pipeline from Gweta to Orapa along the fringe of Makgadikgadi Game Reserve carrying potable water and serving villages along the way;
2. Artificial recharge of Orapa-Letlhakane aquifer with Nata River water;
3. Transfers from the Zambezi (Chobe-Zambezi);
4. Use of Nata River in conjunctive scheme;
5. Use of effluent (from Francistown, Gaborone and other urban centres);
6. Use of saline water for processing;
7. Duplication of NSC; and
8. Stormwater harvesting –This is an option that is linked to all the other recommended options and steps must be taken to realise its full potential as soon as possible, independent of any other scheme adopted.

According to the most recent Botswana Water Statistics (CSO, 2009), available developed resource in Dukwi Wellfield is estimated at 5 700 m^3 per day. Currently, estimated abstraction is around 6 600 m^3 per day; a combination of 1 200 m^3, 1700 m^3 and 3700 m^3 per day from, respectively, Chidumela, BotAsh and the Dukwi boreholes. Current abstraction is way above sustainable limits, estimated to be 600m^3/day. While predictions indicate that pumping at these high rates can be supported up to at least 2020, no indication have been given to the implications of continued unsustainable extraction of this wellfield on it, the surrounding water table, or the pan groundwater and recharge.

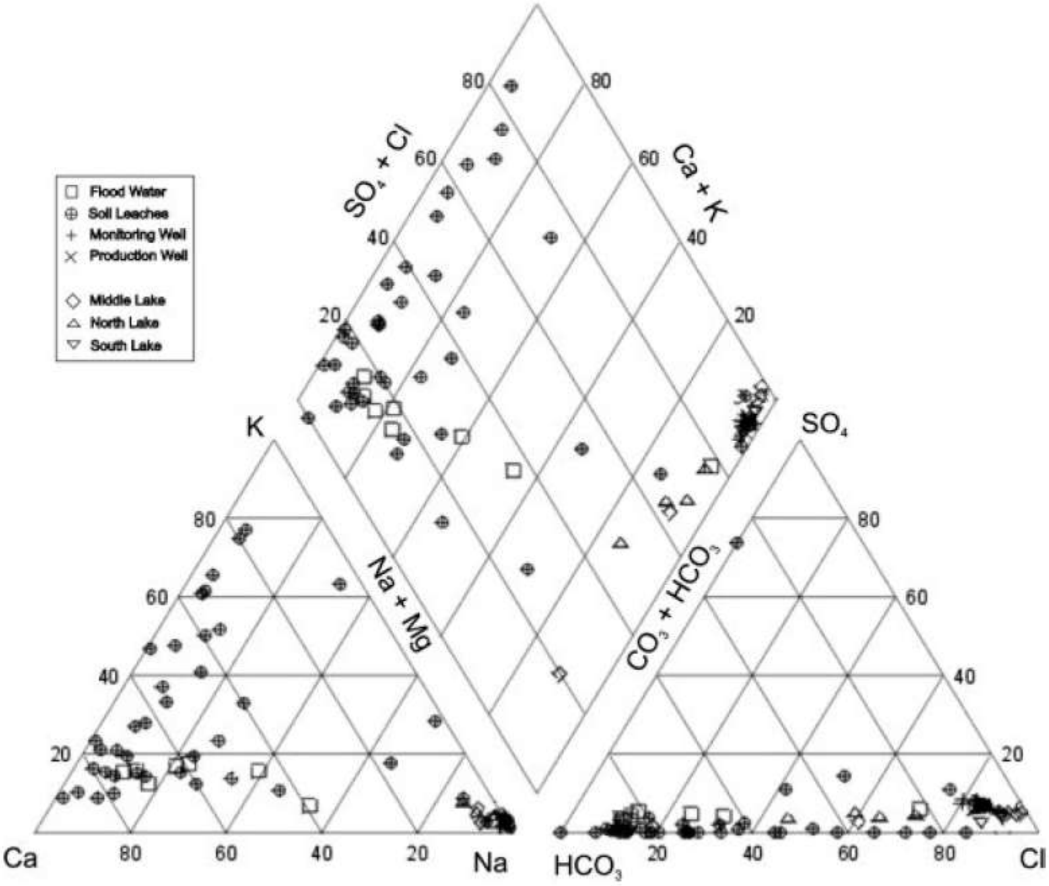
3.1.1.9 Pan Chemistry

River water is generally high in Ca-HCO_3 supporting the calcareous paleomargins as important recharge zones. Na-Cl is added with the leaching of salty river sediments close to the pan margin and on the pan floor itself. Catchment soils add much of the Ca, bicarbonate, Mg and K (Figure 13).

Once lacustrine conditions are generated, both calcium and magnesium go out of solution first, which promotes the formation of calcite and dolomite in the pan environment (Figure 13), followed by sodium and nitrate evaporates which produces salt. The bulk chemistry of the surface lake and deep brine appears comparable at first glance, with the degrees of concentration being the only difference.

However, both strontium and sulphur isotope analysis suggest that the subsurface brine pumped at a depth of 38 m by BotAsh, has been in prolonged contact with some of the underlying geology and, therefore, further suggesting little contemporary recharge from the surface lake or possibly even the shallow groundwater (Eckardt et al. 2008). Molwalefhe (2004) considered geothermal contributions to the deepest brine in the basin.

Figure 13. Piper plot depicting the chemical composition of the water in the rivers, groundwater leaches and on the surface of Sua Pan.



3.1.1.9 Water balance and water use/conflict

Average rainfall in the area is around 500 mm. This would add approximately a total of 3 600 MCM directly to the main pan surface each year, assuming the pan surface area measures approximately 7200 km^2 of which Sua occupies a smaller portion (3 200 km^2) than Ntwetwe (400 km^2).

One should add stream input to this. The Nata River alone may receive a total of 10 081 MCM of rain per annum (assuming 500 mm rainfall per annum and catchment size of 20 161 km^2). Lesser contributions can be expected from the Semowane (483 MCM/966 km^2), Mosetse (775 MCM /1549 km^2), Lepashe (518 MCM/ 1035 km^2), and Mosupe (584 MCM/ 1 168 km^2). The eastern catchment in total would receive approximately 12000 MCM and assuming that theis occupy roughly a third of the wider pan basin, the total rainfall directly received on the pan (3 600 MCM) and the wider basin may be as much as 40 000 MCM (total area of 80 000 km^2).

This is in stark contrast to the amount of water detected from remote sensing which estimates that on average 94 km^2 of the pan surface is witness to lacustrine conditions. The total amount of water may cover close to 1000 km^2 (14% of the pan floor). Since the bathymetry of wetspots is unknown, we have no handle on the volume of water present at the surface, but it is unlikely to be more than a few hundred MCM at most. This is not a lot compared to the overall inputs described above.

The lake at Nata may cover an area of up to 300 km^2 and assuming an average depth of 50 cm, may hold as much as 150 MCM. The Makgadikgadi surface as a whole probably never holds more than 200 MCM of surface water at the most. There is clearly a stark discrepancy between the annual amount of water inferred from remote sensing on the pan surface (200 MCM at most) and the amount of water received by the pan surface (3 600 MCM) and the wider catchment (40 000 MCM).

This can partly be attributed to potential evaporation rates (2 500 mm per annum) which are obviously high. From the pan floor alone (7 200 km^2) those may be in the order of 18 000 MCM per annum. However, water does not spend much time at the surface, since the Kalahari arenosols and the pan surface have a high infiltration potential. Much of rainwater received, will recharge shallow and deep groundwater. This is certainly evident when looking at the stream gauge data.

For example the Nata River may receive up to 10 000 MCM of direct rain input per annum, however mean annual flow rate at Nata is only 136 MCM with a maximum of 622 MCM. It is likely that a significant portion of the 10 000 MCM of rain is turned into groundwater. This may indeed be typical for most of the eastern catchments, karst areas, recharge areas and proto pans. Rain water is recharging the shallow and deeper groundwater of the wider basin. Some of this groundwater will follow the gentle topographic gradient and terminate in the Makgadikgadi pan.

At this point it is important to remember that pans are groundwater features and that surface water is only a temporary by-product. If groundwater is shallow it will evaporate and promote the production of surface salts and crusts. Shallow groundwater may even experience surface seepage and form pools of water driven by local discharge. If the groundwater is deeper, on the other hand, any surface water will contribute swiftly to groundwater recharge.

Pan surfaces are in general an indicator of the prevailing pan state. A salty crust would suggest shallow groundwater and dry sediments would suggest preferential recharge. The presence of surface clasts, such as silcrete, would suggest that the pan floor has dropped to accompany the falling groundwater level, which exposed duricusts nodules, once formed at depth under the pan floor. In short the pan floor will, through time, follow the net groundwater table. A moist surface will produce crusts and retain sediments and a lake may even accumulate sediments, whereas a dry pan is prone to sediment deflation and surface loss.

Hence the important distinction is made between recharge pans and discharge pans. A pan the size of the Makgadikgadi is both, recharging and discharging with pronounced variation in both space and time. It might in fact be recharging in some areas and discharging in others. The shallow groundwater level in the pan is likely to be dynamic. It determines the amount of crust that can form at the surface and the amount of infiltration that can take place. It represents the “pulse” of the pan and a driving parameter which is currently not measured at all. This represents one of the biggest knowledge gaps regarding the pan system and is by no means trivial.

Shallow groundwater may for example determine where and when wetspots form on the pan floor. Wetspots are not merely areas of pounded rainwater but areas where rainwater and surface runoff is prevented from rapid infiltration. Such low lying areas may act as topographic sumps but are also closer to the groundwater table, hence areas of potential discharge. The existence of wetspots may even be prolonged by active discharge.

Furthermore, shallow groundwater is able to sustain some of the wetspots. For example, some of the Nata groundwater will feed the northern Sua Pan. Water may even reach a point of surface discharge and small wetspots may form as a result of this. However it takes floods from the river itself which produce the most extensive wetspot in the Makgadikgadi. The Nata wetspot may hold as much as 150 MCM assuming a depth of 50 cm and area coverage of 300 km^2. This number compares favourably with the average annual flow volume for the Nata River which is 136 MCM at Nata, not far from the pan margin. The vertical movement of water near the surface is one of the key controls governing the lacustrine environment and as yet not properly quantified.

Any water present at the surface will infiltrate and evaporate at the same time. Potential evaporation rates (2 500 mm per annum) from the pan floor (7 200 km^2) are in the order of 18 000 MCM per annum. Evaporation rates are largely subject to known diurnal and seasonal dynamics and are relatively uniform over much of the basin.

This is in contrast to the deep brine resources, which are assumed to be less dynamic. The northern Sua Pan hosts an estimated 8 013 MCM of deep saline brine and 5 502 MCM for the shallow less saline brine (Gould 1996). The current pump rate of 26.28 MCM/annum (3 000 m^3/hour) at BotAsh wellfield, translates into a low and gradual net loss from the deep brine. As the deeper brine is lost, the shallow brine adjusts; hence drawdown has been noted in monitoring wells which might cause changes to the pan surface.

This drawdown has resulted in lowering of saline yields for some of the wells with highest pump rates, suggesting that shallow brines are compensating for a loss from the deep brines (Eckardt *et al.* 2008). This compensation is largely of a vertical nature but with time and deepening of the drawdown could also result in a lateral adjustment. The centre of the drawdown and the western most margin of the Nata wetspot are separated by more than 10 km, hence contributions to the area of drawdown and losses from the wetspot are possibly minimal at this moment in time. Still this interface deserves to be monitored more closely. Baseline data needs to be collected in order to identify future trends. The pumping of deep brines may change pan surface properties, including recharge potential, surface composition and topography which also needs to be monitored along with accelerated losses of surface water.

A dam is being considered for the Mosetse catchment, which is upstream of central Sua and its wetspots. One has to draw particular attention to the presence of a major wetspot centered on the Mosetse River mouth which will be directly influenced by any upstream development. The dam, once in place, will be able to store 50 MCM, which is a third of the annual discharge measured for all the eastern catchments and is twice the mean annual surface flow of the Mosetse (23 MCM). Stream gauges at the Mosetse and Mosope (7 MCM/ average per annum) are positioned only halfway down the streams, which is not a good measure of how much runoff is contributed to the pan surface. However, significant infiltration losses can be expected in the karstic margin of the pan slope, below most of the stream gauges. In any case, a dam will most certainly prevent significant surface and groundwater from reaching the pan. Surface water which sustains the riparian and delivers water to the pan surface and groundwater which recharges the aquifer and pan subsurface will be reduced.

Our current lack of understanding wetspot hydrology prevents us from truly quantifying the potential impact. The absence of any baseline data collected in and around wetspots such as the Mosetse mouth, underlines the need to specifically monitor such sites in the near future.

To conclude, the proportion of surface water on the pan is small (average 94 km^2, assuming 0.5 m depth, 47 MCM/annum) and a tiny fraction of rain contributed to the pan (5%) and the wider catchment (less than 1%). It is also not surprising that it is subject to such temporal and spatial variation. Estimation of surface water from remote sensing is in need of improvement and validation. Water depth, pan bathymetry and lateral movement rates of surface water are totally absent. The water body is so shallow and bathymetry so subtle that the lacustrine extent can even be subject to movement by wind (Nkala pers. comm..). The actual volume of surface water is one of the most important parameters to quantify wetland quality but is bound to be small and highly variable but is still a very rough estimate at best.

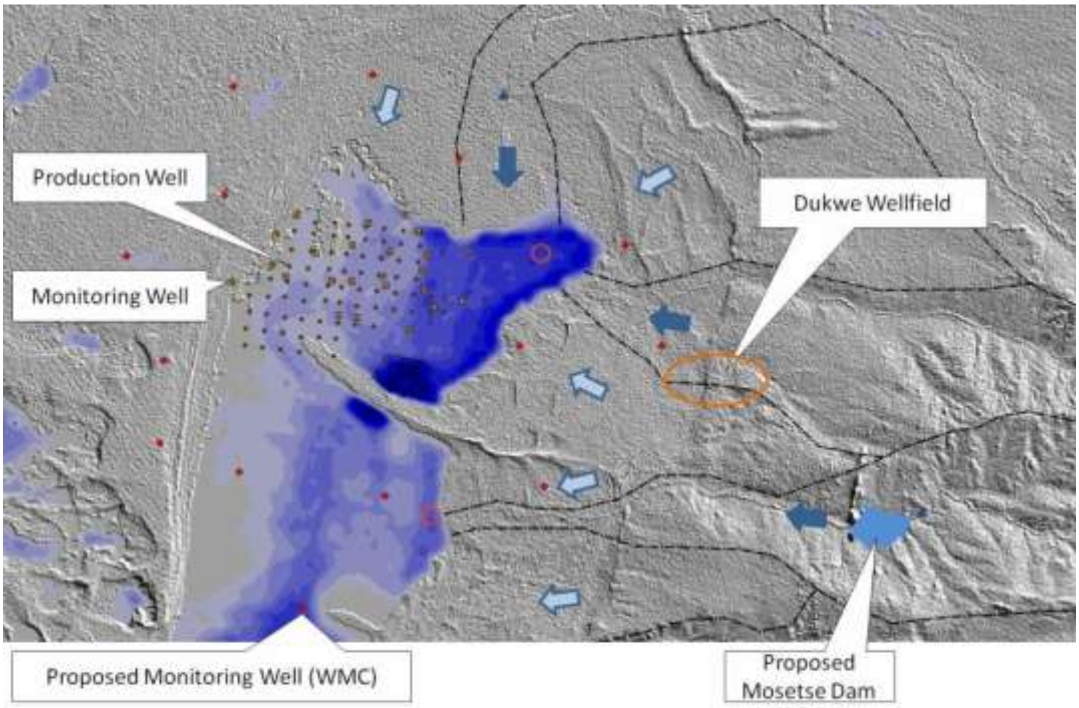
The pan surface represents a complex interface between the pan sediments, groundwater dynamics (recharge and discharge) and the atmosphere (runoff, evaporation and rainfall losses and contributions). The net state of the surface is a result of these variables which are not well constrained at this moment in time.

3.1.1.10 Water off-take & conflicts

Conflict areas can be identified by juxtaposing pan surface wetlands (“wetspots”) with various take-off scenarios as stated above. One has to take into account that there are uncertainties concerning both wetland detection and take-off scenarios. Impacts from take-offs are not always direct and remote sensing of surface water is still subject to some degree of validation. Still it is possible to identify and rank areas where conflict has the potential to arise.

There is no doubt that northern Sua and to some extent central Sua are the areas which deserve most of our attention. Extraction from the BotAsh wellfield, alongside significant surface water inputs by the Nata River play out north of Sua spit (Figure 14). In addition this area has the potential for surface dam construction in the Mosetse catchment and is subject to ongoing groundwater extraction in the Dukwe wellfield within the Semowane catchment. It is also the most visited area by tourists due to the proximity to the tar road the Nata Camp and Nata Bird Sanctuary. Brine extraction is set to continue and expand until 2050, providing scope for environmental change.

Figure 14. Northern and central Sua conflict area.



Note: note location of proposed Mostse Dam and location of Dukwe wellfield on Semowane/Karst watershed (dashed line).

Source: WMC, 2008.

The Mosetse Dam is expected to store 50 MCM, with significant losses to the middle pan runoff regime and recharge of groundwater through the karstic margins of the pan slope. The EIA shows no clear impact on the resulting ecology of the pan as a result of this surface discharge loss. Groundwater extraction at current levels in Dukwe Well field is unsustainable and likely to decrease groundwater input into Sua Pan, while the Letlhakane, Orapa and Gweta well fields have the potential to impact upon Ntwetwe Pan. Groundwater quality for potable water supply is also likely to be impacted and further degraded, as is already the case at Orapa.

The pan holds an estimated 8 013 MCM of deep fossil brine. Botswana Ash pumps from over 90 well points in the north basin of Sua Pan and aim to expand south of their current well field. The current pump rate is at about 2 400 m^3 per hour and rates of 3 500m^3 are considered feasible with the expansion. A drop in the brine water level of up to 7 m is to be expected with an increase in brine extraction. This is to be accompanied by a drawdown of the shallow groundwater of up to 5 m in the south of the current well field, and diminishing evapotranspiration at the surface of the Pan. This trend has indeed been manifested in all monitoring wells with modeled and observed drawdown currently centered to the north west of the spit at (lat -20.38° lon +25.99°). Although pumping has taken place for two decades now, it is largely unknown how the system, in particular the lacustrine environment, will respond to drawdown. There is an urgent need for more monitoring.

Since 1984, Orapa mine has become wholly dependent on groundwater and the greater Orapa area has seen the development of new well fields and extensions to existing well fields to meet Orapa’s increase in water demand. Continued mining of this groundwater at current rates may not only reduce the long-term water supply to the mine but also affect supply of other uses (e.g. domestic water in Letlhakane and surrounding villages and the numerous cattle posts in and around the mine well fields); moreover it may eventually lead to ingress of saline water especially from the north as regional groundwater flow gradients are changed.

The total annual abstraction from the six operating well fields, and the three pit dewatering systems for the 2008 monitoring period was 11.8 MCM, with a monthly average of 982 558 m^3. Water levels data indicate a continued decline in water levels around the Orapa and Letlhakane well fields. Well field 6, which provides potable drinking water, has fallen to Class II (BOS 32: 2000) in terms of its drinking water quality. In addition, recent groundwater modeling suggests that continued and increased abstraction from boreholes in well fields 2, 3 and 5 will result in the breaching of a 50% drawdown constraint (50% of Ntane /Mosolotsane aquifer dewatered).

Simulated impacts on the DWA well field at Letlhakane showed a 25m drawdown over the 20-year period (2024). Currently, estimated water abstraction rates at Dukwi Well field are estimated at around 6 600 m^3 per day; a combination of 1 200 m^3, 1 700 m^3 and 3 700 m^3 per day from, respectively, Chidumela, Botswana Ash and the Dukwi boreholes. Current abstraction exceeds recharge, estimated to be 600 m^3/day. While predictions indicate that pumping at these high rates can be supported up to at least 2020, no indication is given to the implications of continued unsustainable extraction of this well field on the aquifers’ future detriment, that of the surrounding water table, or the pan groundwater and recharge.

3.1.2 Hydrological summary framework

The Makgadikgadi is vast, complex, dynamic and subtle. Rather than trying to determine inputs into the pan as whole it is recommended that monitoring should be focused on selected areas in particular with emphasis on the dynamic and persistent ‘wetspots’ as identified from MODIS. These sites need to be evaluated on the basis of their ecological merit upon which a shortlist should be subjected to on-site observations which fully capture the pan processes including atmospheric, pan surface and subsurface conditions. It should be the aim to fully quantify site specific water and solute dynamics as set out for sabkhas in the Emirates (Yechieli and Wood 2002). These observation points need to produce climatic data which includes rainfall, temperature, evaporation, windspeed and direction as well a surface state of the pan, water depth and conductivity, movement of water and sediment as well as groundwater dynamics and conductivity. Data needs to be collected at least at an hourly resolution.

This should not be considered a short term research endeavour but a systematic long term monitoring program which produces baseline data and captures environmental change and dynamics.

An integrated network of several such stations which measure synchronously in and around the wellfield as well as pan margin at northern Sua for example and would place the subsurface brine as well as the record from the hinterland (rain and stream gauges) into the appropriately nested context and allow for satellite data validation.

Such monitoring efforts should in the first instance be focused on northern Sua as well as the Nata, Semowane and Mosetse Rivers. The range of natural variability and the oscillations in lake cover against the backdrop of significant brine extraction renders this area worthy of such attention. It also features a host of infrastructure, such as existing well points, power grid, telemetry networks and monitoring wells and is part of the mining concession given to BotAsh which would make the operation and supervision of such infrastructure feasible.

The exact locations for such stations requires consideration and refinement and this decision process should be executed in conjunction with the BotAsh mine, the wellfield consultants as well as the MMP and other stake holders such as the Nata bird sanctuary.

Specific water quantity and quality monitoring has been included in the comprehensive environmental monitoring framework in the Indicators section below (Table 9), using the following indicators:

3.1.2.1 Hydrology and Climate indicators

- Hydrological flows monitored at flow stations are critical to any wetland monitoring programme. Estimates of hydrological input from historical daily meteorological data (supplemented where necessary with rain stations) and current and new gauging stations can also be used.
- Hydrological storage/volume and off-take can be monitored quickly and simply using Remote sensing data, of which MODIS daily imagery from the Terra and Aqua instruments are the cheapest (free) and easily accessible, by estimating the extend of flooding on the pan. Depth measurements for the lake when in flood and at various levels of flooding are, however, still not available for this calculation.
- Combined with rainfall, river discharge and Surface and annual groundwater reports, this will allow an estimate of overall net through flow of water in the wetland basins and provides a good gauge of overall wetland integrity and the amount of water needed by the system to maintain its integrity.
- Alterations to natural features of the hydro-morphology and hydrogeology should also be identified and ranked according to the nature and extent of impact. This includes the development of dams, channelisation, groundwater abstraction and irrigation schemes.

- Impacts can be monitored using remote sensing to look at changes to current and historical extent of wetland exploitation (physical impact indicators), and wetland current and past boundaries, which should be added to a baseline GIS map of the ecosystem. Baseline data, historic records and local knowledge can be supplemented with modelling to make sense of the changes and flag any deleterious impacts needing intervention.

3.1.2.2. Hydro-chemical indicators

- Although the majority of early warning indicators are of a biological nature, physicochemical indicators do exist and often form the initial phase of assessing water quality.
- Physico-chemical monitoring has also been recognised as being a vital component of an integrated assessment program that utilises biological measures and indicators for assessing the condition of wetlands.
- Most standard physico-chemical water quality meters are simple, inexpensive and quick to measure, and should be used to complement any ecotoxicological or biological monitoring study.
- Hydrological and hydrogeological, pollutant loads (sediment, nutrients and pesticides), and water chemistry data in river catchments and on the pan can then be estimated using existing baseline information and supplemented by targeted monitoring and relevant mathematical models.
- Pollutant loads can be linked with land use categories and estimated through use of simple coefficient and semi-distributed models. Invertebrates and algae are important indicators of pollutant loads, although much work is required here to develop these indicators through, for example, rapid response toxicity tests to facilitate in situ rapid risk assessments. Sample site selection depends on the scale of the catchment and wetland and the areas of potential pollution, i.e. near mining areas, but should include both a temporal and spatial network.
- Seasonal water chemistry variables sampling in river inflows should be targeted to the first rains, base flows and, where possible, peak flows. Samples should also be taken from main inflows and at sites “up-stream” and from surface and groundwaters that account for catchment soil characteristics, management and topography factors.

3.1.3 Conclusions

Overall, current records and observations are fragmented, with variable resolution, overlap and quality and were not gathered for the purpose of wetland characterization. Observations on climate, catchment and pan surface dynamics can only be tentatively linked, which hampers efforts to model the system or characterize its current state, trend and thresholds. Existing records focus on the distant flood volume and rainfall, which determine the state of the pan surface but only represent muffled linkages which are subject to lagging and unknown groundwater dynamics. Even less indicative is “end of pipe” volume and chemistry from the BotAsh wellfield. Deep monitoring wells need to be augmented with shallow groundwater and surface measurement equipment in the wellfield, pan margin and grassland perimeter and in particular around selected “wetspots” of the Makgadikgadi. Groundwater level, movement rate and direction can be considered, but due to the size of the entire basin it is suggested that an observational emphasis on the pan wetlands and their immediate surroundings be implemented.

It is unrealistic to accurately model the pan as whole and it is instead encouraged to monitor selected pan sub-systems or wetlands (wetspots), which are considered ecologically important. Such site specific monitoring will reveal natural on-site controls and dynamics essential for future management of this system.

3.1.4 Follow up work

Rainfall

Monthly rainfall data is available for the wider catchment of the Makgadikgadi Pans. While such data can give you a sense of seasonality, variability and trends it does not allow for climate change prediction. Climate change scenarios are played out using various shifts in southern Africa's synoptic states. Such analysis requires daily rainfall data against which synoptic information can be attached. In the absence of daily rainfall data, covering several decades, no reliable change analyses can be conducted. Such work could be carried out by attaching a Motswana student to the Climate Systems Analyses Group (CSAG) at UCT.

Furthermore rain records for the pan surface are nonexistent. The weather station near BotAsh mine, which was the only station in proximity to the pan, has just been moved to Sua Town. Long term monitoring should consider rainfall observations dedicated to the pan environment in particular its wetspots.

Wetlands

Pan surface wetness maps have identified areas of persistent moisture, termed wetspots. Identification of wetspots is based on the 10 year observation record from the MODIS sensor, which provides daily, as well as 16 and 8 day averaged products. Future follow up instruments are to be deployed on the Joint Polar Satellite System (JPSS). As detection techniques develop, confidence in surface area estimation is improving. Satellite data validation should include on site observations on parameters such as water edge determination, pan spectra analyses and sediment and algae content of water bodies. The Makgadikgadi wetspot map is subject to ongoing improvement.

Precise determination of water volumes is hampered by lack of data regarding pan topography and wetland bathymetry. Future wetland monitoring should also include a measure on water depth. In addition maps on pan surface topography should be generated. Clearly global elevation data (SRTM and ASTER GDEM) are not of sufficient quality. Icesat data has an adequate vertical accuracy but only provides spot heights. Digital contour and elevation data generated by the Botswana Government (Department of Survey and Mapping) has as yet not been evaluated for this project. This should be considered a priority.

In the absence of any sufficient height data, deploying differential (precision) GPS on the pan surface should be considered. A UCT PhD student will be tasked with this objective as part of a wider pan surface characterization required to improve global dust modelling. Initial focus in 2011 will be on the area to the north of Sua spit and include the Nata Lake and BotAsh wellfield. However a wider survey of the entire Makgadikgadi Pan with focus on the wetspots would be desirable.

Wetspots identified in the MODIS 10-year time series, should be subject to a dedicated limnological and ecological characterisation. This would help determine the most important wetlands on the pan surface.

Shallow Groundwater

Pan surface water is being maintained by the presence of shallow groundwater. Such water is of a low quality and yield and has as such not been explored, extracted or monitored. It is however crucial in sustaining wetspots in the pan environment. Such shallow groundwater is partly derived by direct rain input, regional groundwater contributions and surface flood waters. Instead of monitoring all of these, it is recommended that piezometers are deployed at selected wetspots. Particular emphasis should be placed on the BotAsh wellfield – Nata Delta interface as this area arguably hosts the most important wetland and the largest off-take from the system. A piezometer transect could ascertain if there are linkages between brine extraction, drawdown, and surface recharge in the form of shallow groundwater movement.

A second shallow groundwater monitoring site should be considered at the outlet of the Mosetse River to determine the role of surface and groundwater inputs towards maintaining one of Sua Pans wetspots. Such baseline data would ascertain the impact of any future dam development.

Pan surface

The pan surface is the product of surface and subsurface processes including water, drying and wind. In particular the state of the crust and its relationship to groundwater is of interest. Efforts are currently underway to characterize the pan surface and shallow subsurface as well as vegetation cover such as grass invasion, in support NERC funded project to study dust transport at the Makgadikgadi. Current focus is on the area around Sua spit. A wider survey of the system would be desirable and is feasible in 2011. An attempt will be made to widen the scope of satellite data used to study the pan surface. Current focus has been on Landsat data but Spot and ASTER data is now also being considered. Recent high resolution georeferenced orthophotos, generated by the Botswana Government have not been made available to this project. Their acquisition and evaluation should be made a priority.

Deep Brine

The BotAsh wellfield is subject to significant brine extraction as well as drawdown. While chemical and physical parameters are generated by BotAsh and its consultants, focus so far has been on brine production. Monitoring efforts should give additional consideration towards pan surface alterations and relationship with surface waters and wetlands at north eastern Sua.

3.2 Biodiversity Hotspots

3.2.1 Major findings for FMP

3.2.1.1 Priority Biodiversity Hotspots

On completion of the Multi criteria Analysis (MCA) analysis, all 61 targets were ranked in terms of their biodiversity importance (their combined criteria scores). For the purposes of the MFMP, this study has focused on the overall top ten priority targets, or Biodiversity (BD) Hotspots for the MFMP area, identified as the highest ranked of all the targets and these are listed in Table 5, below. For management planning purposes, some of the targets were combined to form hotspots, where they were of the same management unit/area, e.g. MPNP East, West, and Central, and Nxai Pan and Kudiakam Pan. The top ten BD hotspots are, in order of rank/priority, the Boteti River, The Makgadikgadi Pans National Park, Nata Sanctuary, Nxai & Kudiakam Pan, Nata River, the Boteti Delta, NG47, Lake Xau, Mosu and Rysana Pan (Figure 15). A brief description of each hotspot is given in table 5, but more detailed descriptions of the salient features/characteristics of each site, the important biodiversity it contains, and the processes and functions that provide the system and are required to sustain their integrity are provided in the site specific management plans, below.

Figure 15. Areas ranked by MCA analysis as the Top Ten biodiversity hotspots of conservation importance

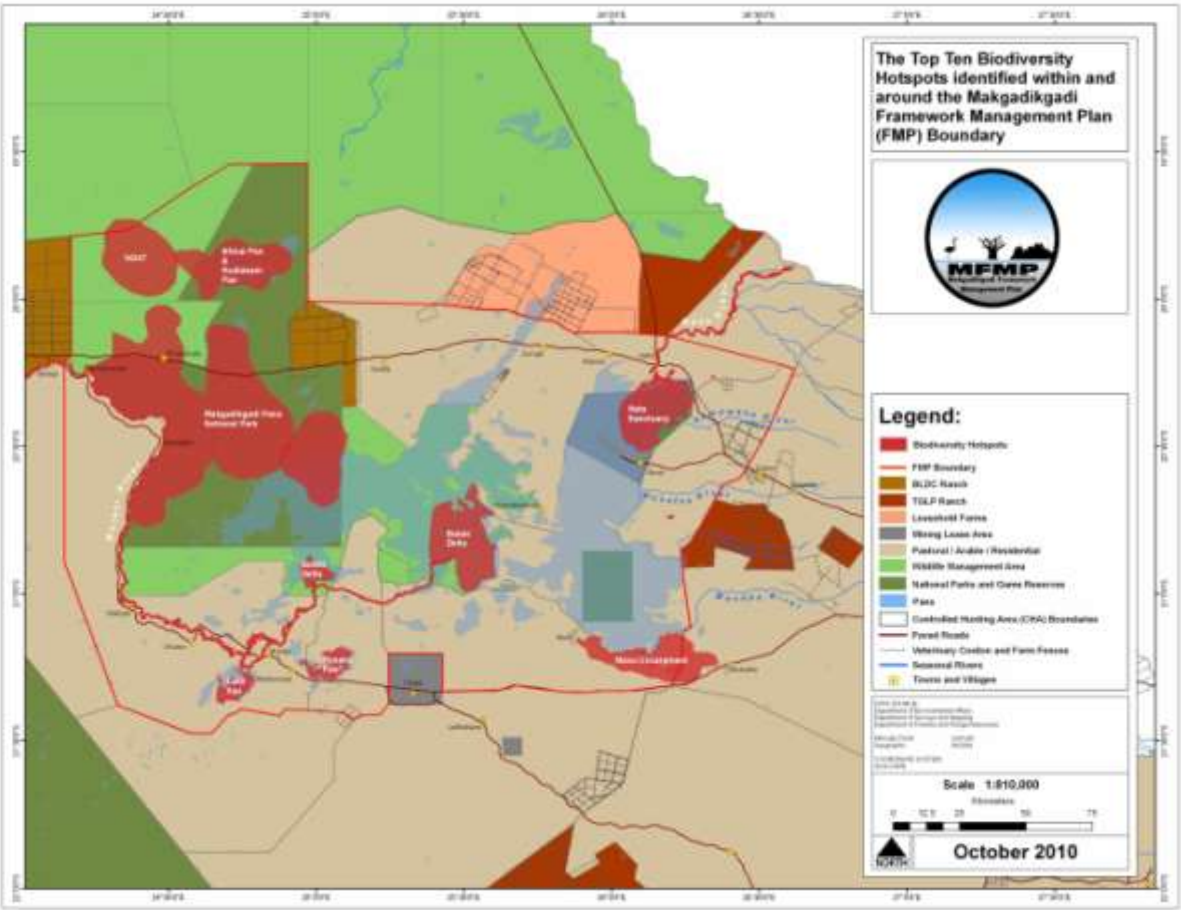


Table 5: Biodiversity Hotspot MCA, revealing the top ten ranked biodiversity hotspots.

Rank	Top Ten Hotspots	Characteristics	Protection Status
1	**Boteti River**	Episodic surface river, of great hydrological importance and crucial to wildlife in MNPNP, and elsewhere	Partially protected (MNPNP), western side unprotected - CT8
2	**MPNP**	Open sand veld and saline grassland savannah of great importance to large herbivore migrations – Zebra and Wildebeest	Protected - National Park
3	**Nata Sanctuary**	Nata River delta and north basin wetspot, of great importance to birdlife and other fauna	Protected - Bird Sanctuary
4	**Nxai & Kudiakam Pan**	Grassed and open pans on the palaeolake floor, of great importance to wildlife and birdlife	Protected – (MNPNP)
5	**Nata River**	Largest River on Sua Pan, of crucial hydrological importance to the Nata Sanctuary and Sua Pan wet spot, and birdlife and other fauna along its length	Unprotected – CT7
6	**Boteti Delta**	A pan wet spot associated with the Boteti River, important to birdlife and surrounding wildlife	Unprotected – CT10 (un-gazetted state land WMA – pastoral)
7	**NG 47**	Kalahari sand veld bush savannah of crucial importance to migration and connectivity of the system to the Okavango and Linyanti wetlands	Protected - WMA
8	**Lake Xau**	Episodically filled freshwater lake, of great importance to wildlife in the area and birdlife on the lake	Unprotected – CT8
9	**Mosu**	An Important Plant Area, with high value to vegetation, as well as wildlife in the area. Also important hydrological input – freshwater springs	Unprotected – CT21
10	**Rysana Pan**	'Protopan' on the palaeolake floor that fills seasonally and is important for birdlife.	Unprotected – CT8

3.2.1.2 BD Hotspot site-specific Management Plan Framework

In order to sustain the biodiversity of the MWS, an appropriate level of management and protection should begin with site-specific management plans for these top ten BD hotspots. A framework for the designed and development of these management plans is guided by and complies with the Ramsar guidelines to effective management planning (Ramsar Wise Use Handbook No. 16). These guideline focus on a site-based scale of management planning; the application of these guidelines are flexible depending on the particular size, characteristics and circumstances of the site.

This section attempts to:

a) Outline the overall management planning process and management plan framework required to develop appropriate site-specific management plans, and;

b) On a per site basis, outline the ecological characteristics and salient features, their trends and potential threats, and a list of appropriate management objectives for each of the top ten BD hotspots.

In general, the management planning process should ensure a common agreement between managers, owners, occupiers and other stakeholders in order to maintain ecological character. A management authority that is clearly identifiable to all relevant stakeholders should be appointed to implement the management planning process and the plan. The plan itself should also be as a large or complex as the site requires, i.e. proportional to the size of the site and the number of issues and objectives to be addressed in the management plan. It is also important that the planning process not be restricted to the defined boundary of the site, but rather should also take into account the wider area, in which the site is located, e.g. aspects of external influences (functions and processes) and incorporating internal multi-use zones and external buffer zones.

The Ramsar management planning guidelines state that "*When considering the carrying capacity of a site for any human use, activity or exploitation (i.e., its sustainability), the best available evidence should indicate that the activity will not be a threat to the features of the ecological character of the site (the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time).*" In doing so managers are encouraged to adopt the precautionary approach; - where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason to postpone cost-effective measures to prevent environmental degradation.

According to the Ramsar, "*adaptive management is key to enabling wetland managers to learn through experience, take account of, and respond to changing factors that affect the sites features, continually develop or refine management processes, and demonstrate that management is appropriate and effective*". The adaptable management process is as follows:

i) A decision is made about what should be achieved (i.e., quantified management objectives are prepared for the important features);
ii) Appropriate management, based on the best available information, is implemented to achieve the objectives;
iii) The features are monitored in order to determine the extent to which they meet the objectives;
iv) If objectives are not being met, management is modified;
v) Monitoring is continued to determine if the modified management is meeting the objectives, and step iv) is repeated for any further adjustments, as necessary;
vi) In exceptional circumstances, it may be necessary to modify the objectives;
vii) The adaptable management cycle is usually repeated at predetermined intervals, taking into account the nature and in particular the fragility and rate of change of the site features.

In many cases, outstanding or representative features of the state or health of the sites can be identified as appropriate 'indicators' of site integrity, or be used as rapid assessors of specific pressures/impacts. These indicators facilitate cost-effective and effective monitoring programmes that are essential to adaptive management (this is developed in detail in the 'Indicators' sub-component, below).

The format of the management plan, as recommended in the Ramsar guidelines, should comprise five main sections, reflecting the main steps in the management planning process:

a) **Preamble/policy**; a concise policy statement that should reflect, in broad terms, the policies and/or practices of international, national, and/or local authorities, and other organizations and traditional management systems;

b) **Description**; a collation and synthesis of existing data and information on the site, including biological, socio-economic, cultural etc. The identification of any shortfall of relevant data and information is also a key function of this part of the process. The description (site inventory) should be regularly reviewed and updated, so as to incorporate new sources of data and information, including updates from a well structures time-series monitoring programme;

c) **Evaluation**; the process of identifying or confirming the important features or foci for management planning. Evaluating ecological character (providing a list of the features and confirming their status) should be done using criteria such as the size, habitats, species richness and processes of the site. This has already been conducted in great detail in the BD Hotspot MCA analysis for this report and the salient features will be included per site in the site descriptions below to guide effective planning for each site. This ecological character evaluation should, however, be coupled with an indicative list for socio-economic and cultural criteria, which should be further developed for each site to take into account its specific socio-economic and cultural characteristics. Similarly, other important features like the geology, archaeology and paleontology, and scientific research value of the site should be evaluated. The evaluation should also focus on the values and functions, goods and services provided by the site and its biodiversity;

d) **Objectives**; through undertaking the evaluation, a list of the important site features will have been identified. The next step is to prepare management objectives for each of these features. An objective is an expression of something that should be achieved through management of the site. Objectives should have the following characteristics;
   - Objectives must be **quantifiable and measurable**. If they are not measurable, it will be impossible to assess through monitoring whether they are being achieved;
   - Objectives should be achievable, at least in the long term. This is a very obvious, but often forgotten, characteristic;
   - Objectives must not be prescriptive - they **define the condition required of a feature** and not the actions or processes necessary to obtain or maintain that condition;
   - Objectives are an **expression of purpose**. A differentiation should be made between the purpose of management and the management process, because the management undertaken to safeguard a feature will vary according to the condition of that feature;

   The process of preparing measurable objectives requires: a description of the condition that is required for a outstanding feature in an attempt to regain or maintain this condition; Identification of factors (human and natural, e.g. pollution and climate change) that influence the feature, and consider how the ecological character of that feature may change (both positively and negatively) as a consequence; and identify operational quantifiable limits (considered acceptable or tolerable), and monitor them.

e) **Monitoring of indicators**; identify and quantify a number of performance indicators for monitoring progress in achieving the objectives for that feature. Indicators are characteristics, qualities or properties of a feature that are inherent and inseparable from a feature and should provide a cost-effective way of monitoring the health/condition of that feature. These indicators and their monitoring should be part of an effective monitoring programme for the site (as identified and outlined in sub-component 3.4 on 'Indicators in adaptive management');

f) **Rationale outline**, the management considered necessary to maintain the site features in (or restore them to) favourable status. Control can mean the removal, maintenance or application of factors. For example, grazing is an obvious factor influencing rangeland habitat. Options that may be considered in the management rationale here could include removing, reducing, maintaining current levels, or introducing grazing. Operational objectives need to be prepared to ensure compliance with legal and other national obligations (for example, suitable pastoral areas and required cattle post densities in land use plans, district and national development plans).

An example of the management planning process for identifying features, factors, objectives and operational limits to be included in the Management Plan of the MFMP Biodiversity Hotspots.

Feature: an important population of breeding wetland birds

Factor: disturbance to the birds by tourism activities that threatens their viability

Objective: the maintenance of a viable population through establishing controls on the tourism activities in, and public access to the area

Operational limits (adopted following consultation and agreement with local stakeholders):
- A limit to the number of activities and guests in the area – carrying capacity set
- A limit to access to the area during the breeding season
- A to access to the areas airspace by aircraft
- A limit to the distance from the breeding site, a fence or powerline can be erected

g) **Action Plan**; Management processes considered most appropriate to safeguard each feature are outlined. The function of the management project is then to describe in detail all the management work that will be associated with each feature. For each management project, it is important that the following issues be given attention:
- When the work will be carried out and for how long;
- Where on the site activities will take place;
- Who will do the work and how much time will be required;
- What priority is given to the project;
- And how much the work will cost.

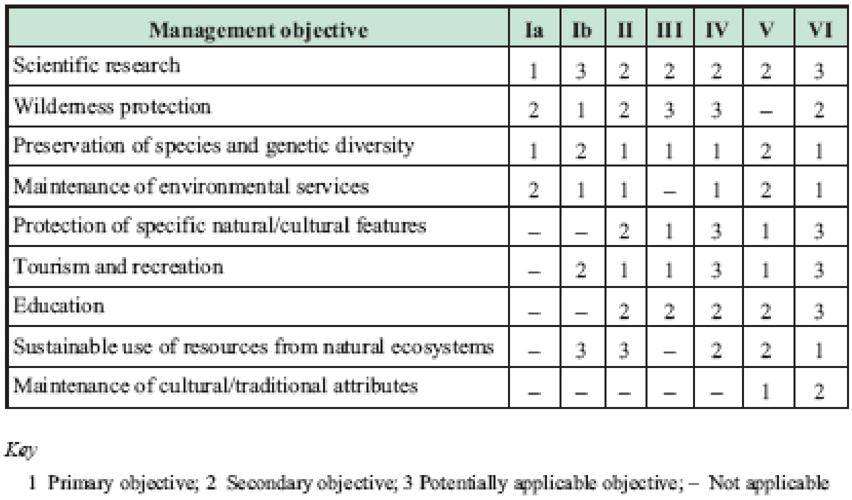
Once the management projects have been developed, for operational purposes it can be appropriate to compile the suite of management projects into an annual Operational Plan, which is designed to guide and assist in monitoring implementation.

h) Finally, objectives, prescriptions and management projects can be developed for public access and tourism in a site, based upon an approach similar to this planning process used for ecological features (see LAC's in Tourism component).

In addition to the above management plan framework, the following IUCN protected area (PA) categories are used to help assign the appropriate overall level of management/protection objectives (Table 6) for each site, i.e. its type of use and control (IUCN, 2004):

I. Strict protection area, which includes category Ia: Strict Nature Reserve, e.g. Flamingo Sanctuary and Ib: Wilderness Area, e.g. core pan area
II. Ecosystem conservation and recreation, e.g. the MPNP National Park
III. Conservation of natural features: Natural Monument, e.g. Baines Baobab
IV. Conservation through active management: Habitat/Species Management Area
V. Landscape/seascape conservation and recreation: Protected Landscape
VI. Sustainable use of natural ecosystems: Managed Resource Protected Area).

Table 6: Management objectives relevant to PA categories



Management objective	Ia	Ib	II	III	IV	V	VI
Scientific research	1	3	2	2	2	2	3
Wilderness protection	2	1	2	3	3	–	2
Preservation of species and genetic diversity	1	2	1	1	1	2	1
Maintenance of environmental services	2	1	1	–	1	2	1
Protection of specific natural/cultural features	–	–	2	1	3	1	3
Tourism and recreation	–	2	1	1	3	1	3
Education	–	–	2	2	2	2	3
Sustainable use of resources from natural ecosystems	–	3	3	–	2	2	1
Maintenance of cultural/traditional attributes	–	–	–	–	–	1	2

Key

1 Primary objective; 2 Secondary objective; 3 Potentially applicable objective; – Not applicable

Source: IUCN 1994.

A site-specific management framework for the top ten hotspots follow, outlining their individual outstanding ecological features, changes or likely changes in them and priority management objectives that will guide appropriate management planning at this scale.

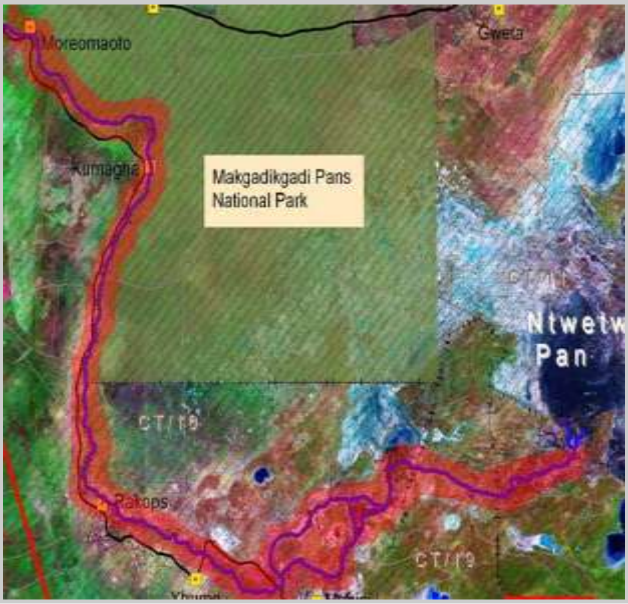
BIODIVERSITY HOTSPOT

BOTETI RIVER

Rank: 1

Location: From just east of Motopi to Ntwetwe Pan
Size: 265km long
Management Plan: partly under the MPNP 'Pans Parks' MP.
Physiographic type: Episodic River flowing from to the Okavango River to Ntwetwe Pan & riparian woodland
Existing Protection: Eastern side in the MPNP, west in tribal CT8
Endemic/Restricted Species: 2
Threatened & Protected Species: 33
Representative index: High (53)*
Species richness index: High (43)#
Habitat richness: 8
Ecological functions & services: 12
Habitat Loss/fragmentation: High
Keystone species: Zebra, Wildebeest, Hippo

LOCATION



Key Ecological Features	Influencing Factors	Management Objectives
- Variable/Episodic surface water flow from Okavango to Ntwetwe pan – important to long term hydrological dynamics and viability or population, - Important recharging of groundwater, - Connection with /extension of Okavango River, - Critical habitat for Zebra and Wildebeest migration & related game, - Riparian woodland is crucial habitat for wildlife and birdlife, - High fish and other aquatic species diversity, - Hosts 33 threatened & protected species (4 plant, 13 bird & 16 mammal species)	- Climate change - Changes to Okavango flood regime – damning or irrigation, - Access to river & water prevented by fencing and/or development (fields) - Restricted access impacts surrounding grazing, carrying capacity and wildlife, - Excess pressure, disturbance and erosion of riparian habitat by grazing and browsers, - Over fishing, - Water quality degradation, Agricultural & waste pollution, - Poaching and poisoning of threatened spp.	IUCN PA Category II (East side), and IV (West side) – see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain the natural episodic hydrological dynamics/flow all the way to Ntwetwe Pan, - Maintain the water quality of the river by minimising pollutants and waste contamination, and over-utlisation - Maintain optimal adequate access to the river by wildlife and livestock and people, - Maintain and restore riparian woodland habitat by altering fence alignment for better river access by game, and reducing livestock pressure. - Maintain biodiversity by maintaining population and breeding of threatened species.

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

BIODIVERSITY HOTSPOT

Makgadikgadi Pan National park

Rank: 2

Location: NG 52 & CT9, east of Boteti River, to CT11 and Ntwetwe Pan.
Size: ~2500km squared
Management Plan: 'The Pans Parks' MP (2006).
Physiographic type: Predominantly saline grassland savannah, with shrubbed grassland savannah and woodland on old palaeolake floors
Existing Protection: National Park, with a small portion protected in the CT11 WMA in the east.
Endemic/Restricted Species: 2
Threatened & Protected Species: 34
Representative index: High (57)*
Species richness index: High (50)#
Habitat richness: 7
Ecological functions & services: 13
Habitat Loss/fragmentation: Low
Keystone species: Zebra, Wildebeest, Lion, Lappet-faced Vulture

LOCATION

Key Ecological Features	Influencing Factors	Management Objectives
- Open grassland savannah habitat - Seasonal wildlife migration link between the west - Boteti (dry season) and east - Ntwetwe pan (wet season), - Core area for Zebra and Wildebeest migration - Connectivity with other systems to the north and south, - Water in Boteti and small freshwater pans in the east (wet season) sustain wildlife, - Seasonal nutrient rich grazing in the east important for population viability, - Contains 34 threatened & protected species; 2 plant, 15 bird and 17 mammal species	- Climate change - Changes to Boteti flood regime – damming or irrigation, - Fences blocking migration and access to river in dry season, - Overgrazing rangeland round reduces quality of grazing, - Constant pressure on rangeland in east negates seasonal recovery, - Problem animal control and poisoning threatens predator and scavenger population - Excess tracks and visitor numbers disturb wildlife and birdlife breeding	IUCN PA Category II Ecosystem conservation & tourism – see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain the natural dry season water availability at the Boteti or waterholes nearby, - Maintain sufficient access to the river along the park fence, - Maintain the link to the wetland systems to the north, - Maintain wildlife access to important freshwater pans in east, e.g. MPNP pans 6 'wetspots', - Maintain rangeland quality throughout, - Reduce human – wildlife conflict and resulting shooting, trapping & poisoning, - Maintain sufficient refuge areas and inaccessible nesting areas for wildlife/birdlife

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per ecoregion, from the BSAP stocktaking report.

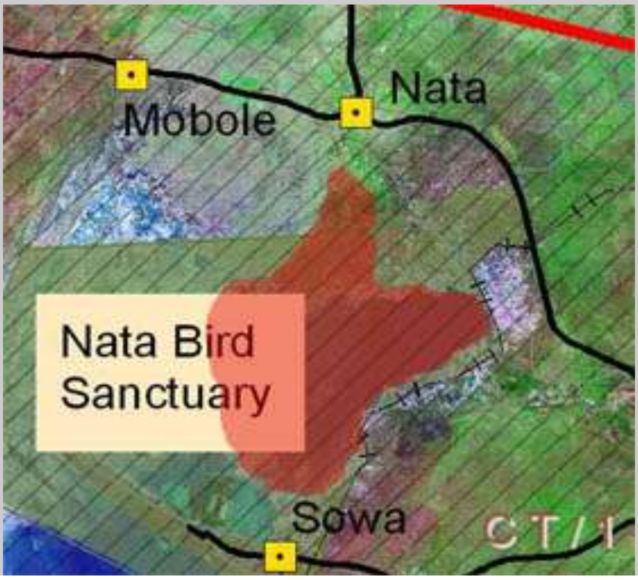
BIODIVERSITY HOTSPOT

Nata Sanctuary

Rank: 3

Location: CT7- NE part of Sua Pan
Size: ~200 km squared
Management Plan: Nata Bird Sanctuary MP (2008).
Physiographic type: Open saline pan, saline grassland savannah, and river delta.
Existing Protection: Yes – Sanctuary with protective management zones.
Endemic/Restricted Species: 4
Threatened & Protected Species: 24
Representative index: High (52)*
Species richness index: High (42)#
Habitat richness: 10
Ecological functions & services: 10
Habitat Loss/fragmentation: Low
Keystone species: Flamingo & Pelicans

LOCATION



Key Ecological Features

- Key surface water 'wetspot' with input from surface & ground,
- Freshwater input from Nata River and rainfall increases biological diversity,
- Unique water chemistry & seasonal variation contributes unique biological communities,
- Longest standing surface water in the whole system – occasionally sustains birdlife & breeding all year round.
- River delta habitat contributes important nutrients and productivity,
- Key habitat for wildlife and birdlife & breeding site for wetland birds,
- Hosts 24 threatened and protected species - 1 plant, 15 bird, & 8 mammal spp
- Groundwater depth and capillary fringe sustains pan surface equilibrium – dust and grass encroachment,
- Nata River bed is an important aquatic habitat and maintains wildlife in dry period (high water table - aestivation of fish, reptiles and amphibians)

Influencing Factors

- Climate change
- Changes to hydrological flood regime regime of Nata River & delta – damming, bunding or irrigation,
- Continuous groundwater pumping & drawdown in the water table – impacts on hydrology & pan surface stability/equilibrium,
- Extraction induced change in surface water chemistry & biology,
- Pollution of water in catchment & edge of pan from domestic & industrial waste/effluent,
- Reduced sediment/ nutrient loading as a result of excessive sand mining and weirs,
- Disturbance of sensitive bird breeding habitat in delta from tourism activities,
- Poaching and poisoning wildlife and birdlife,
- Reduction in the normal rainfall – discharge - flood regime relationship

Management Objectives

IUCN PA Category II Ecosystem conservation & tourism – see respective overall management priorities in Table 6, above & in IUCN (1994).

- Maintain natural hydrological regime of Nata & Semowane Rivers,
- Maintain shallow groundwater levels & pan surface equilibrium,
- Maintain unique chemical composition & variation,
- Maintain protected and refuge areas on the Nata River delta for wetland bird breeding,
- Maintain carrying capacities of tourist (NBS MP, 2008) and ensure their effectiveness,
- Maintain Nata River bed integrity,
- Maintain water quality in rivers and on pan surface,
- Restock sanctuary with game & maintain to carrying capacity (NBS MP, 2008)
- Reduce poaching and poisoning in the reserve to a minimum
- Maintain threatened species populations & breeding

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

\# The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per ecoregion, from the BSAP stocktaking report.

BIODIVERSITY HOTSPOT

Nxai & Kudiakam

Rank: 4

Location: NG45, north of the MPNP
Size: ~1250km squared
Management Plan: 'The Pans Parks' (2006).
Physiographic type: Open grassed pan surrounded by woodland, and open saline pan on palaeolake floor.
Existing Protection: National Park
Endemic/Restricted Species: 1
Threatened & Protected Species: 29
Representative index: High (44)*
Species richness index: High (37)#
Habitat richness: 8
Ecological functions & services: 8
Habitat Loss/fragmentation: Low
Keystone species: Zebra, Springbok, Lion, Cheetah, Kori Bustards

LOCATION

Key Ecological Features	Influencing Factors	Management Objectives
- Important source of water for game – pans and waterholes, - Important Open grassland savannah, provides habitat/core area for plains game and associated predators, e.g. Cheetah & Wild Dog, & grassland Birds, - Connectivity with MPNP and with Okavango & Chobe-Linyanti River system in the north, - Seasonal (wet) nutrient rich grazing conditions drives migration to area, - Open salt pan system at Kudiakam provides seasonal waterbird habitat, - Important habitat for 29 threatened and protected species - 1 plant, 15 bird, & 13 mammal species. - Contains national monument in the form of Baines Baobabs	- Climate change - Blocking key migration to and from the area e.g. fences, ranches - Constant pressure on rangeland around waterholes reduces grazing & browsing & negates seasonal recovery, - Reduced water availability at waterholes threatens wildlife, - Problem animal control and poisoning threatens predator and scavenger population on periphery, - Excess tracks and visitor numbers disturb wildlife and birdlife breeding, - Excess erosion of soil and trees at Baines baobabs by tourists	IUCN PA Category II Ecosystem conservation & tourism – see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain migration routes and connectivity with MPNP & other nearby systems, - Maintain waterholes pumping rate and efficiency, - Reduce human-wildlife conflict on the park periphery, - Maintain LACs in park with regards roads and tourist numbers, - Maintain hydrological regime and integrity of wetland at Kudiakam for waterbirds, - Maintain control of visitor impact at Baines Baobabs & refer to management objectives for Category III: Conservation of natural features (IUCN, 1994), - Maintain threatened species populations & breeding

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

\# The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

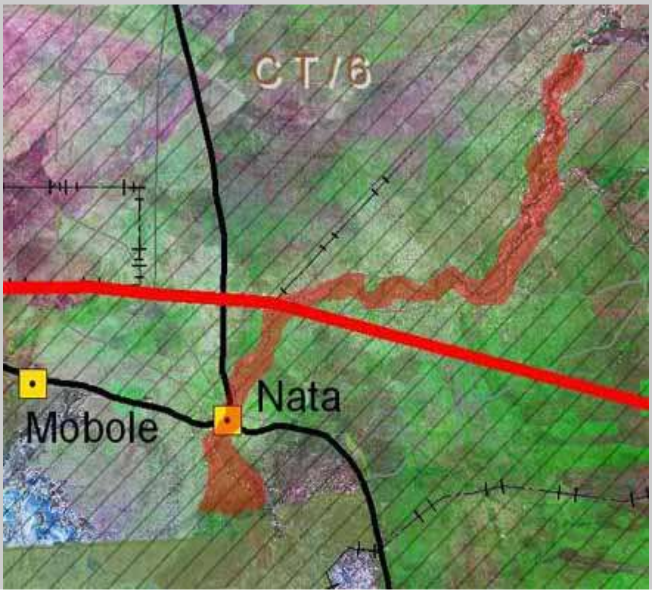
BIODIVERSITY HOTSPOT

Nata River

Rank: 5

Location: From the river delta near Sua Pan - the Nata Sanctuary to its catchment northeast of CT7 & 18.
Size: 25km inside MFMP area
Management Plan: No.
Physiographic type: Seasonal River with 26,000 sq km catchment
Existing Protection: None afforded apart from river delta in Nata Sanctuary
Endemic/Restricted Species: 1
Threatened & Protected Species: 25
Representative index: High (53)*
Species richness index: High (43)#
Habitat richness: 10
Ecological functions & services: 6
Habitat Loss/fragmentation: High
Keystone species: Zebra, Wildebeest, Hippo

LOCATION



Key Ecological Features	Influencing Factors	Management Objectives
- Key Hydrological Input to Sua Pan (surface & ground), - Large Riparian habitat, - Large catchment (26,000 sq km), - Important nutrient contribution, - Important to Fish and amphibian species, as well as Hippo and wetland birds, - River bed aquatic habitat exists all year round – important for sustaining biological community, - Provides water for many surrounding wildlife, - Hosts 25 threatened and protected species - 1 plant, 13 bird, 11 mammal spp. - Much of the catchment lies in Zimbabwe	- Climate change - Changes to flood regime – daming or irrigation, - Reduction in water quality from domestic, agricultural & industrial waste/effluent, - Grazing and development pressure on riparian woodland habitat, - Excess sand mining in river bed, - Upstream impacts on nutrients/sediment, and pollution, - Human – wildlife conflict & associated shooting, trapping and poisoning reducing threatened species, - Over harvesting of fuel wood - deforestation	IUCN PA Category IV Habitat/species protection area through active management– see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain Hydrological regime to the pans, - Maintain water quality, - Maintain river sand bed integrity, - Maintain riparian woodland habitat, - Maintain threatened species populations & breeding,

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

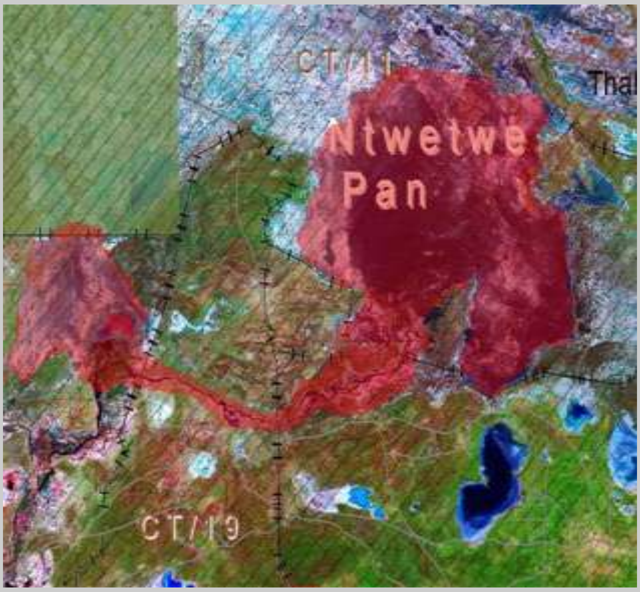
BIODIVERSITY HOTSPOT

Boteti delta

Rank: 6

Location: NE of CT 10, and SE of CT11, on Ntwetwe Pan.
Size: ~300km squared
Management Plan: No.
Physiographic type: River delta and open pan 'wetspots'
Existing Protection: WMAs: CT10 (wildlife&pastoral) & CT11 (photogr)
Endemic/Restricted Species: 1
Threatened & Protected Species: 20
Representative index: High (44)*
Species richness index: High (36)#
Habitat richness: 8
Ecological functions & services: 6
Habitat Loss/fragmentation: Moderate – MPNP southern border fence & drift fences
Keystone species: Meerkats, Brown Hyaena, Lappet faced vulture, Martial Eagle

LOCATION



Key Ecological Features

- Hydrological Input (surface & ground) from the Boteti River,
- Connection with Okavango River system,
- Groundwater maintains 'wetspot' for sustained periods and pan surface equilibrium,
- Freshwater input from Boteti and rainfall increases biological diversity,
- Unique water chemistry & seasonal variation contributes unique biological communities,
- River delta habitat contributes important nutrients and productivity,
- Key habitat for wildlife and birdlife & breeding site for wetland birds,
- Hosts 22 threatened and protected species - 12 bird & 8 mammal species

Influencing Factors

- Climate change
- Changes to Boteti flood regime – damming or irrigation,
- Change in water quality from domestic, agricultural and industrial pollution.
- Change to groundwater level & quality as a result of overuse in surrounding wellfields,
- Degradation of delta habitat by overgrazing and soil erosion,
- Threatened species population decrease as a result of human-wildlife conflicts, resulting PAC & poaching,

Management Objectives

IUCN PA Category IV Habitat/species protection area through active management– see respective overall management priorities in Table 6, above & in IUCN (1994).

- Maintain hydrological Input to delta and pan.
- Maintain groundwater table sustainability levels and quality,
- Maintain surrounding rangeland condition and integrity,
- Maintain water chemistry and quality,
- Maintain threatened species populations & breeding,

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

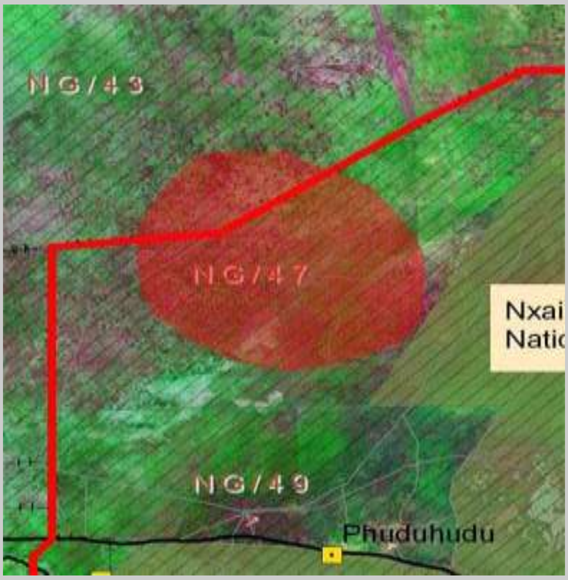
BIODIVERSITY HOTSPOT

NG 47

Rank: 7

Location: Directly west of Nxai Pan (northeast corner of MFMP area.
Size: ~225km squared
Management Plan: No.
Physiographic type: Kalahari sandvelt Shrubbed woodland savannah and grassland savannah in inter-dunal zones
Existing Protection: WMA
Endemic/Restricted Species: 0
Threatened & Protected Species: 20
Representative index: High (41)*
Species richness index: High (39)#
Habitat richness: 2
Ecological functions & services: 4
Habitat Loss/fragmentation: Low
Keystone species: Zebra, Elephant, Martial eagle, Lappet faced vulture

LOCATION



Key Ecological Features	Influencing Factors	Management Objectives
- Open dry grassland and woodland savannah habitat, - Seasonal wildlife migration link between MP&NPNP (wet season) and Okavango & Chobe-Linyanti systems (dry season), - Wet season core area for Giraffe, Eland, Gemsbok, Duiker, and Buffalo - Woodland refuges on the dunes, - Small pans in the inter-dunal depression are important in sustaining water-dependant game in the wet season, - Hosts 20 threatened and protected species - 4 bird and 16 mammal species	- Climate change - Obstacles to migration corridors/routes – fences & ranches - Excessive Burning of woodland reduces refuge & browse capacity, - Reduction in threatened species as a result of hunting/poaching and disturbance.	IUCN PA Category IV Habitat/species protection area through active management– see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain important wildlife migration routes in and out to MPNPNP & wetland systems to the north, - Maintain good rangeland quality and integrity, - Maintain populations of threatened species, - Maintain network of small pan connectivity and integrity,

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

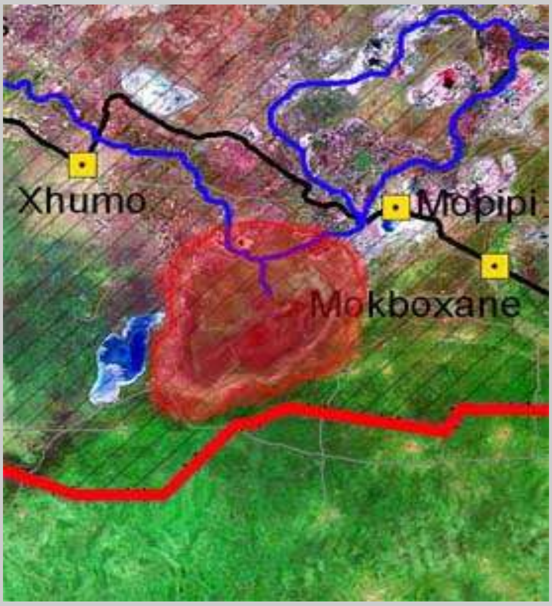
BIODIVERSITY HOTSPOT

Lake Xau

Rank: 8

Location: Southwest of Mopipi – CT8, the southern most extension of the Boteti River system.
Size: ~200km squared
Management Plan: No.
Physiographic type: Episodic fresh water lake and open grassland savannah
Existing Protection: None
Endemic/Restricted Species: 0
Threatened & Protected Species: 17
Representative index: High (37)*
Species richness index: Moderate (29)#
Habitat richness: 8
Ecological functions & services: 8
Habitat Loss/fragmentation: High
Keystone species: Reedbuck, Maccoa Duck, Pelican

LOCATION



Key Ecological Features	Influencing Factors	Management Objectives
- Very productive freshwater lake, - High concentrations of breeding water birds, - Important source of water for game – pans, - Important Open grassland savannah, provides habitat/core area for plains game and associated predators, e.g. Cheetah & Wild Dog, & grassland Birds, - Hydrological and biological connectivity with the Boteti River, - Nutrient rich soils provide good seasonal grazing and high aquatic productivity, - Important habitat for 17 threatened and protected species - 9 bird and 8 mammal species.	- Climate change - Altered hydrological regime/flow to the Lake, - Blocking key migration to and from the area e.g. fences, ranches, powerlines - Constant pressure on rangeland around waterholes reduces grazing & browsing & negates seasonal recovery, - Reduction in water quality as a result of upstream and site-specific water pollution, - Problem animal control and poisoning threatens predator and scavenger population on periphery, - Excess disturbance of breeding wildlife and birdlife breeding, - Over harvesting of fuel wood - deforestation	IUCN PA Category IV Habitat/species protection area through active management– see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain hydrological regime of Boteti to the lake, - Maintain water quality in lake, - Maintain migration routes and connectivity with Boteti & other nearby systems, - Reduce human-wildlife conflict on and around the lake, - Maintain habitat integrity and avoid excessive fragmentation, - Maintain woodland sustainability, - Maintain threatened species populations & breeding

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).
# The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

BIODIVERSITY HOTSPOT

Mosu

Rank: 9

Location: Southern escarpment of Sua Pan and adjoining CT 21 area
Size: ~280km squared
Management Plan: None – BLB currently mooting it.
Physiographic type: Salt pan edge, steep escarpment and eastern hardveldt.
Existing Protection: None
Endemic/Restricted Species: 1
Threatened & Protected Species: 16
Representative index: High (41)*
Species richness index: High (31)#
Habitat richness: 10
Ecological functions & services: 12
Habitat Loss/fragmentation: Moderate
Keystone species: Zebra, wildebeest, Hippo

LOCATION

Key Ecological Features	Influencing Factors	Management Objectives
- Important plant area (BSAP), - Hydrological Input to Sua Pan (surface & ground), - Perennial freshwater springs at foot of escarpment, - High physiographic heterogeneity and corresponding habitat type, - Freshwater pans in the area provide perennial water source for game and birdlife, - Hosts 16 threatened and protected species - 1 plant, 8 birds & 7 mammal species, - Pans provide important habitat for migrating wetland bird, e.g. Mea Pan, - Large concentrations of Baobab trees and sesame bushes in the area, - Good habitat for nesting raptors,	- Climate change - Changes to groundwater input – excessive pumping at Orapa wellfields, - Water quality degradation at springs and pans, - Overgrazing and over-harvesting leading to degraded flora, - Human-wildlife conflict and problem animal control - Poaching and poisoning of threatened and protected species, - Excessive disturbance to refuge site – pans, woodland and nesting areas, - Over harvesting of fuel wood - deforestation	IUCN PA Category IV Habitat/species protection area through active management– see respective overall management priorities in Table 6, above & in IUCN (1994). - Maintain integrity of groundwater and springs, - Maintain water quality in pans and springs, - Maintain sustainable plant harvesting, - Maintain rangeland integrity and sustainable use, - Reduce human-wildlife conflict on and around the lake, - Maintain habitat integrity and avoid excessive fragmentation, - Maintain woodland sustainability, - Maintain threatened species populations & breeding

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

BIODIVERSITY HOTSPOT

Rysana pan

Rank: 10

Location: East of Mopipi, CT8
Management Plan: No.
Size: ~240KM squared
Physiographic type: Saline pan - ‘Proto pan’ on palaeo lake floor, with surrounding woodland.
Existing Protection: None
Endemic/Restricted Species: 2
Threatened & Protected Species: 16
Representative index: Moderate (32)*
Species richness index: Moderate (27)#
Habitat richness: 5
Ecological functions & services: 7
Habitat Loss/fragmentation: Moderate
Keystone species: Chestnut banded Plover, Flamingo, Brown hyena

LOCATION

Key Ecological Features

- Large pan of prolonged flooding – a ‘wetspot’,
- Groundwater maintains ‘wetspot’ for sustained periods and pan surface equilibrium,
- Unique water chemistry & seasonal variation contributes unique biological communities,
- Pan contains important nutrients and productivity,
- Key habitat for birdlife & breeding site for wetland birds,
- Habitat heterogeneity around edge of pan provides enriched diversity,
- Hosts 16 threatened and protected species - 1 plant, 9 bird and 6 mammal species

Influencing Factors

- Climate change
- Change in water quality from domestic, agricultural and industrial pollution.
- Change to groundwater level & quality as a result of overuse in surrounding wellfields,
- Degradation of surrounding grassland and woodland habitat by overgrazing and soil erosion,
- Threatened species population decrease as a result of human-wildlife conflicts, resulting PAC & poaching,

Management Objectives

IUCN PA Category IV Habitat/species protection area through active management– see respective overall management priorities in Table 6, above & in IUCN (1994).

- Maintain groundwater table sustainability levels and quality,
- Maintain surrounding habitat condition and integrity,
- Maintain water chemistry and quality on pan,
- Maintain threatened species populations & breeding,

* Score includes habitats represented in its area and the species richness index (combined relative score of plant, bird and mammal spp richness).

The species richness was an index score from combined species identified in the Bird Atlas, overlaying large mammal species distribution and number of vegetation species per km, per eco-region, from the BSAP stocktaking report.

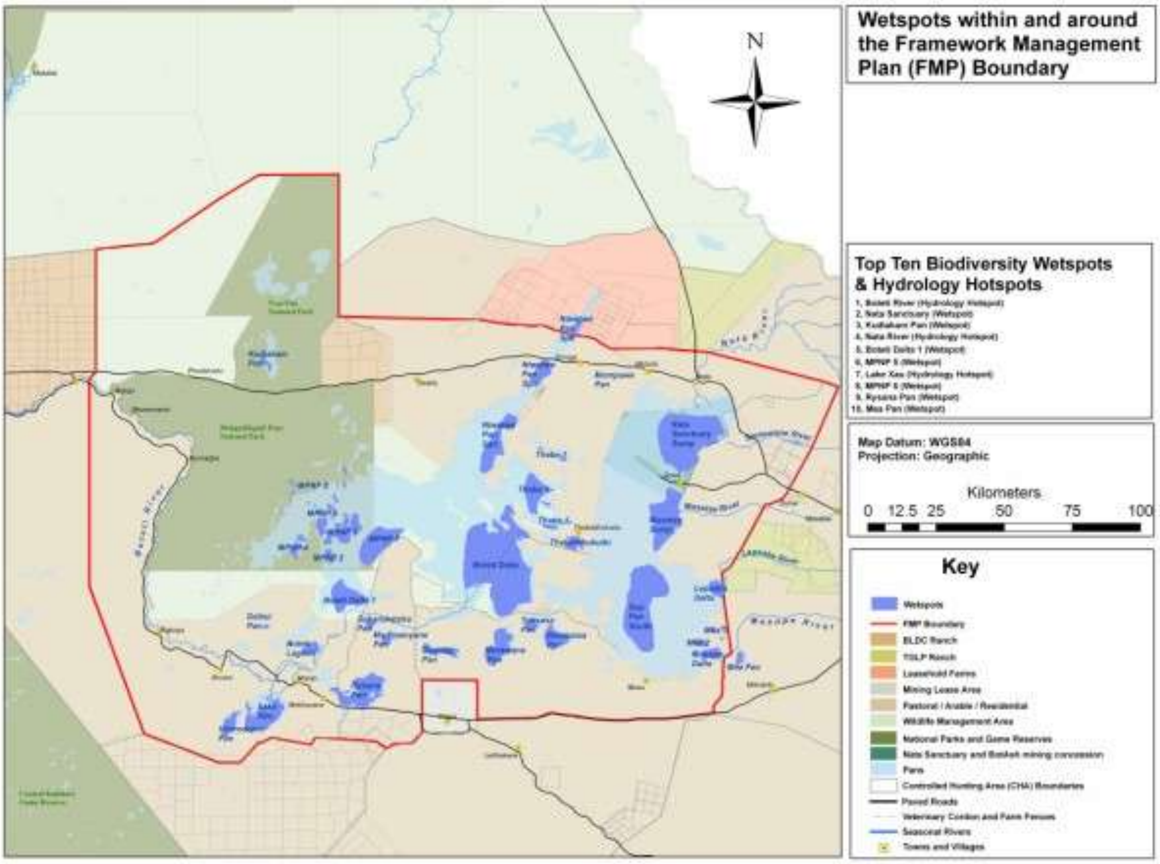
Note: ***Category IV protected areas*** may use traditional management approaches to maintain associated species and habitat as part of a management plan. They frequently play a role in “plugging the gaps” in conservation strategies by protecting key species or habitats in ecosystems. They could, for instance, be used to protect rare or threatened habitats; Secure stepping-stones or breeding sites; Provide flexible management strategies and options in buffer zones around, or connectivity conservation corridors between, more strictly protected areas that are more acceptable to local communities and other stakeholders. They rely on regular management intervention and, therefore, require appropriate resources from the management authority and community participation. Because they usually protect part of an ecosystem, successful long-term management of category IV protected areas necessitates careful monitoring and an even greater than usual emphasis on overall ecosystem approaches and compatible management in other parts of the landscape. (IUCN 1994).

3.2.2 Minor Findings

3.2.2.1 Important Biodiversity 'Wetspots' and Mammal population Cores areas

Of the 'wetspots' that were identified and analysed in the MCA (Figure 16), those ranked the highest, in order of rank, were the Boteti River, the Nata Sanctuary, Kudiakam Pan, Nata River, Boteti Delta 1, MPNP 5, Lake Xau, Makgadikgadi Pans National Park small pans group 6, Rysana Pan, and Mea Pan. The largest rivers; the Nata and Boteti Rivers scored highest on many criteria, as they provide both important habitat diversity in, on the edge of, and nearby the rivers and provide much needed water for the surrounding wildlife that concentrate near them in the dry season, particularly the Boteti when in full flood. The deltas of these rivers also provide important habitat diversification and hydrological and sediment/nutrient functioning to the system, with high productivity and species assemblages. Some of the smaller pans around the contemporary pans of Sua and Ntwetwe also scored high, owing to their prolonged flooding and importance to birdlife, aquatic species and surrounding plant and wildlife species richness.

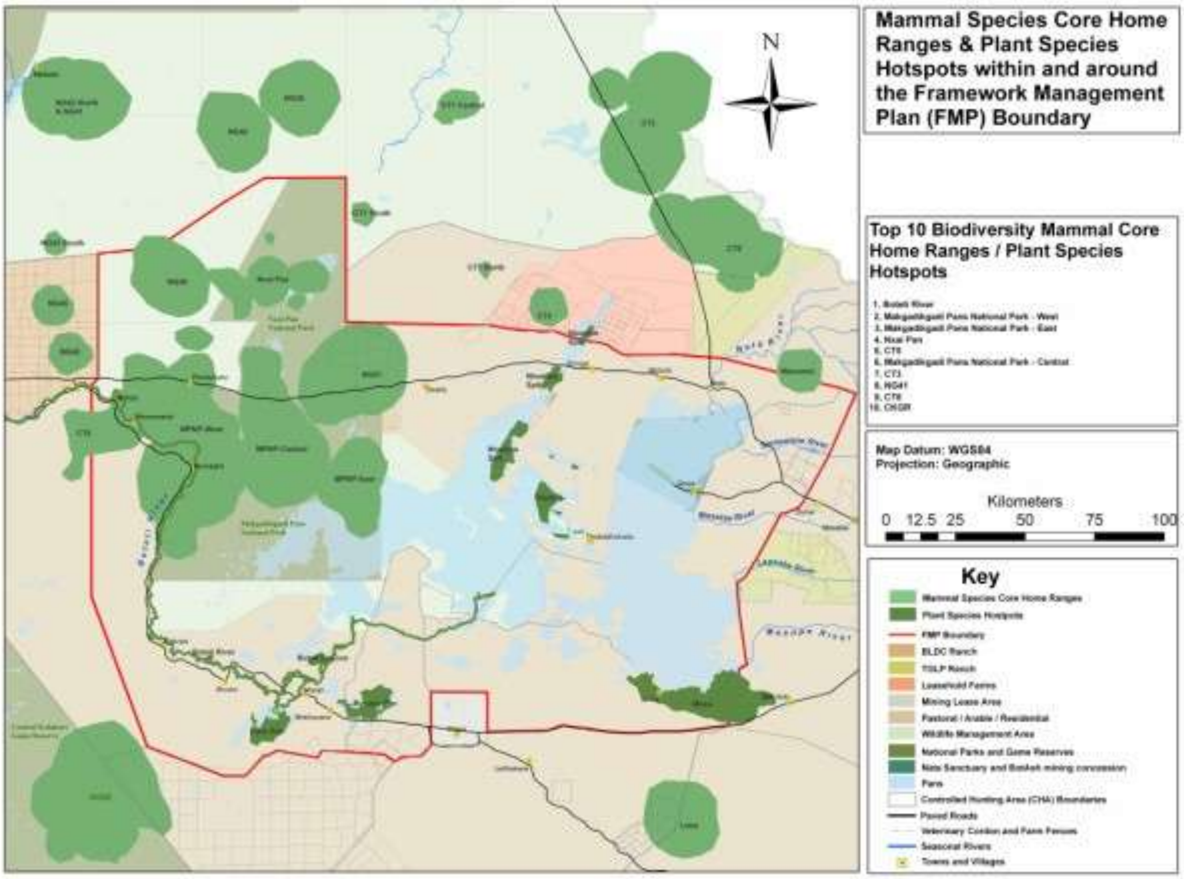
Figure 16: Hydrological 'wetspots'



Source: Chapter 8, this volume.

The top ranked core mammal concentrations and vegetation hotspots, in order of rank, were the Boteti River, Makgadikgadi Pans National Park (MPNP) West, MPNP East, Nxai Pan, CT8, MPNP Central, NG47, NG45, Mosu escarpment and NG51 (Figure 13). The vast majority of large mammal species populations in the MWS occur in these areas, some providing important areas on migration routes, linking the MWS with the Okavango and Chobe-Linyanti wetland systems, for example, e.g. NG47. The Boteti system is crucial to sustaining mammal congregations in the dry season and its link, via the central MPNP, to the eastern side of the MPNP, where the Zebra and Wildebeest populations migrate in the wet season, sustains one of last great large mammal migrations left in southern Africa. The Mosu escarpment scores the highest among the important plant areas on account of its diverse topographic heterogeneity and related habitats, large stands of Baobabs and Sesame bushes, and occurrence of a number of red data list species in the area.

Figure 13. Mammal distribution core ranges and plant species hotspots (Red Data List species distribution) in the MFMP area



Source: Chapter 5, this volume.

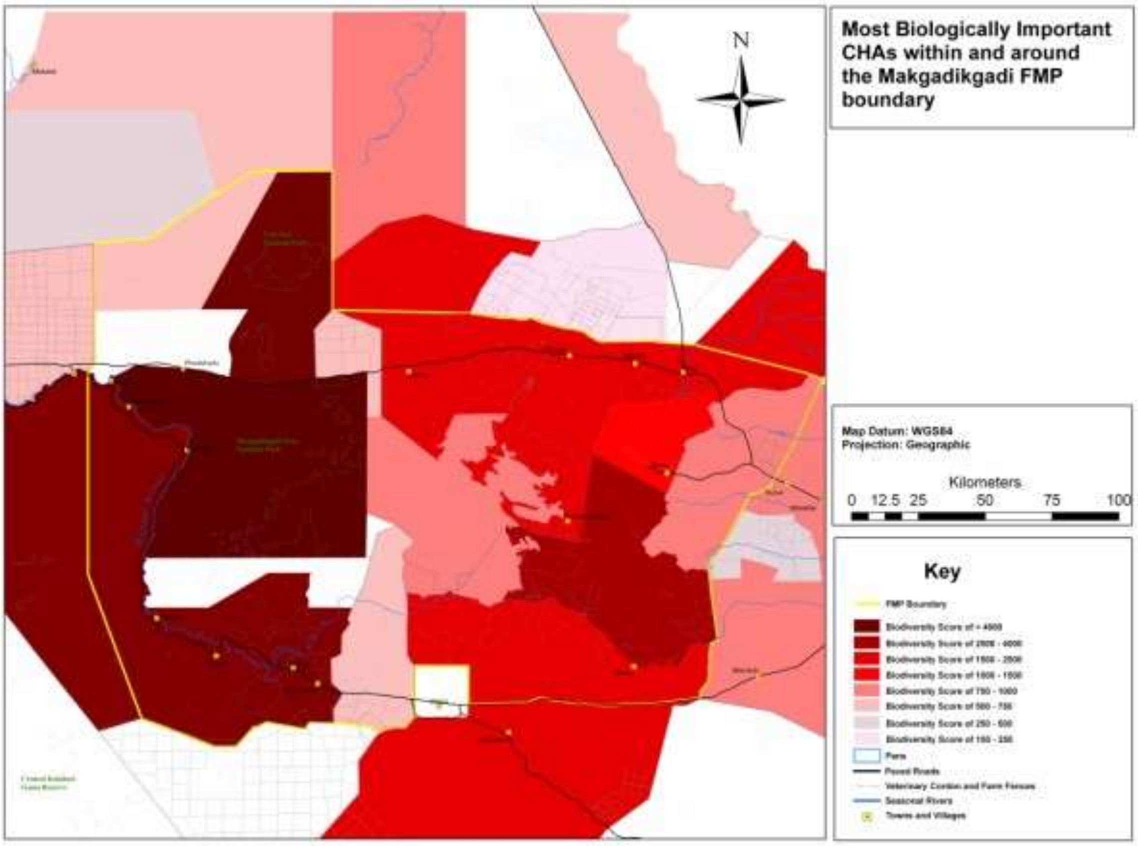
3.2.2.2 Important CHAs for biodiversity

On a broader land use area scale, those CHA areas most important for the protection of biodiversity were ranked according to the combined scores of the BD hotspots within each, and listed in order of rank in Table 7, below. Of the top three CHAs for biodiversity, the Makgadikgadi Pans National Park (CT9 & NG52) scored highest, while CT8 and CT13 are unprotected, being un-designated tribal land (Figure 17). Of the top ten CHAs, a total of six fell outside protected areas (National Park or WMA). This analysis emphasizes the importance of appropriate management and conservation of biodiversity in unprotected areas, and the need for strategic management of protected BD hotspots in the MWS to maintain biodiversity.

Table 7. CHAs ranked according to the combined score of the hotspots occurring within them from the MCA, with CHA land use descriptions.

CHA	Score	Land use
MPNP (CT9 & NG52)	4264	PA
CT8	2506	Communal
CT13	1639	Communal
CT21	1448	Communal
CT7	1410	Communal
CT12	737	PA
CT11	672	WMA
CT14	522	Communal
CT19	463	Communal
NG47	327	WMA

Figure 17. CHAs ranked by MCA analysis as the Top Ten biodiversity hotspots of conservation important



3.2.2.3 Biodiversity Hotspots in overall ecosystem management

It is important that Biodiversity (BD) Hotspots need to be placed in the correct context of the management of the wider MWS, and the following are important to consider in this regard:

- As a starting point, it needs to be clear where hotspots fit with overall conservation and management measures, and to articulate their role clearly to policy advisers.
- Identification of hotspots will contribute to land use zoning and thinking is, therefore, needed on the role of hotspots in Spatial Planning;
- The hotspots approach needs to be linked to ecosystem-based objectives;
- Hotspots may not deliver the Ecosystem Based Approach, but could provide locations used to monitor change including as reference sites and indicators representing the broader ecosystem integrity;
- What is an 'ecologically coherent network' of conservation hotspots? We need to better understand connectivity is important to ensure ecosystem-whole benefits;
- Biodiversity 'hotspots' may be important for ecosystem functioning and that importance needs to be taken into account in management (hotspots may not be congruent with areas important for ecosystem functioning);
- Identification of hotspots might encourage public interest but other stakeholders, especially public representatives, need to be mobilised;
- Conservation can have major economic value, as well as consumptive/exploitive activities.
- Governance structure is a major issue and it is unclear who will manage protective measures, if they are indeed required for these hotspots.
- Ownership is a challenge, particularly if consumptive/exploitive uses are not recommended in highly sensitive areas;
- The identification of hotspots, as undertaken in the above exercises, ignores some populations of lesser-known species;
- All of the above points need to be taken into account to ensure organisational and community buy-in, which means that we have to understand their needs and concerns in designing appropriate management strategies.

3.2.3 Conclusions

- ➢ Biodiversity hotspots facilitate conservation planning by identifying areas of highest conservation priority, thereby directing limited resources in a strategic manner to protecting biodiversity;
- ➢ They represent key biodiversity areas and provide ideal monitoring reference points within the system;
- ➢ Their inter-connectivity within the system and their overall role in the functional integrity of the system as a whole should be emphasized;
- ➢ The top ten BD hotspots are, in order of rank/priority, the Boteti River, The Makgadikgadi Pans National Park, Nata Sanctuary, Nxai & Kudiakam Pan, Nata River, Boteti Delta, NG47, Lake Xau, Mosu and Rysana Pan;
- ➢ Site specific management plans should account for their site specific ecological features identified in per site, and the important processes and functions that contribute to overall ecosystem functioning and connect them to other hotspots and the rest of the system;
- ➢ Those CHA areas most important for the protection of biodiversity were ranked according to the combined scores of the BD hotspots within each, and included in order of rank MPNP (CT9 and NG52), CT8, CT13, CT21, CT7, CT12, CT11, CT14, CT19, and NG47. Four of the top five CHAs are unprotected communal tribal lands.

Gaps in our knowledge:

- The ecological features in many of the BD hotspots and the pressures/threats to them are not fully understood/inventoried;
- The inter-connectivity of these Biodiversity hotspots and their importance in the overall functioning of the system is also not fully understood;
- The site-specific boundary and an adequate protective buffer zone for each site is not yet clearly defined – site-specific management plans.

3.2.4 Follow up work

The MFMP should, therefore, recommend the need for immediate protection and management of the top ten priority hotspots, identified in the E&H report. These sites should be appropriately considered in spatial planning for the purposes of land use planning, e.g. zoning, and in development designing – see Land Use activities (Land Board, Department of Lands, councils). It is recommended, therefore, that hotspots specific management plans for these hotspot areas, of their appropriate management provision for inclusion in CHA management plans be conducted, three per year over the next three years, according to their order of rank, or when the opportunity arises, e.g. proposed management plans to be developed for all statelands in the MFMP area. A valuation element of these hotspots should be incorporated into this management planning to clearly identify their potential benefits to local communities.

It is important to recognize hotspots in the context of their place in the overall ecosystem. Adopting this approach to conservation strategy needs to be linked to ecosystem-based objectives, whereby hotspots are seen also as providing locations used to monitor change; including as reference sites and indicators representing the broader ecosystem integrity. In addition, there needs to be an ‘ecologically coherent network’ of conservation hotspots to ensure connectivity and robustness. Building and integrating the concept of “Hotspot” conservation into the overall protection and conservation of the MWS requires significant further attention to highlight these links with and importance to other hotspots, the system as a whole, and the ecological functions that maintain ecosystems’ integrity.

These top ten hotspots should provide priority locations/reference sites for monitoring change to the systems biodiversity, according to the responsibilities and action required under the agreements of the CBD, UNCCD and UN Climate Change agreements. Good indicator species within these BD hotspots are the threatened and endangered species that occur in each site.

The FMP concentrates on the top ten sites in order to prioritise strategic action during the FMP implementation, but it is also important to consider the other important biodiversity target hotspots (61 in all – Table 2 above) that were used in the multi-criteria analysis to identify the most important targets.

The MFMP implementation should also include cross-checking the list of biodiversity hotspots with the communities in order to make use of indigenous knowledge as to where they believe the most important areas are for wildlife, birdlife and other biodiversity aspects. This could be done as a biodiversity study, or incorporated into the management planning process in the development of the priority hotspot management plans. Examples of areas that came up in the community consultations were Lenao la ga Kwalabe, near Kedia in CT8, Sexhara and Thabatshekwe pans near Zoroga that were suggested as important wildlife areas by their respective community members.

3.3 Ecosystem Functioning

3.3.1 Major Findings

In general, the most important function that maintains the ephemeral wetland nature of the MWS is the surface water hydrological regime of the wetland, i.e. the seasonal input from rainfall, rivers, and groundwater and subsequent loss to evaporation. Under this broad function, many sub-functions exist that maintain the wetlands integrity. Groundwater recharge, via palaeo lake ‘proto pans’, fossil rivers, fault lines and general shallow groundwater through-flow, is essential to the maintenance of groundwater (one of the most important resources in the system) as well as capillary fringe control of pan surface topography, Aeolian deflation and chemical/mineral dissolution and leaching.

River discharge from the Okavango system is also a very important hydrological function, contributing a vital source of water and habitat heterogeneity to the system. This has become particularly apparent in light of the recent recurrence of the Boteti’s surface discharge to Lake Xau for the first time in thirty years. Seasonal differences in flood regimes between these river systems and MWS, contributes important seasonal variation in resource availability and for large mammal population sustainability, and an important connection exists among the wetlands of the north.

Connectivity and mobility within the system and between it and other ecosystems in northern Botswana, and in the case of birds, across the continent and the globe is, therefore, a crucial process in the biological functioning of this wetland. Unpredictable and highly variable changes in rainfall, flooding and associated conditions drive the movement of mammals and birds in and out of the system.

The origin and geomorphology of Makgadikgadi’s closed basin drainage system provides the mineral salts and nutrients that control the biological component of the system. A unique chemical composition and high nutrient contents from the catchment contributes a unique biological composition and a highly productive aquatic system. These conditions also control the type and extent of grasslands surrounding the pans, and the seasonal productivity that supports and maintains large herbivore populations and their associated predators and scavengers.

Aeolean erosion and transport of soils drives soil structure and sensitivity in the Kalahari sandveld, contributes salts and nutrients to the grassland and groundwater table downwind of the pans, and plays a major role in the Aeolian deflation of the pan surface and shaping of its topography.

Five main land systems, which comprise discrete sub-units of uniform physical and ecological character and associated processes were identified (Table 8). A detailed list of the various ecological processes and functions of these main land systems follows:

3.3.1.1 Kalahari Sandveld (Rangeland/Woodland)

- The Zambezi and Okavango river systems provide hydrological input to surface (Boteti River) and groundwater from;
- Input of nutrients and sediments to the north eastern extension of the MFMP area from the same systems provides more fertile soils in NG 43 and, therefore, higher productivity;
- Seasonal differences in flood regimes between these river systems and MWS, contributes to important seasonal Wildlife movements among them; and for large mammal populations, an important connection exists among these three wetlands;
- Aeolean erosion of soils and transport drives soil structure and sensitivity in Kalahari sandveld;

- Well drained sandy soils and deep groundwater table favours tree growth - important for browsers;
- Tree clusters on sand ridges provide wildlife refuge and habitat variety;
- Higher rainfall areas in the north of IMP area support Miombo woodland on sandveld;
- Small pans provide vital seasonal water source that facilitates utilization of Kalahari by water dependant mammals;
- Historically, fire reduces Miombo woodland range, facilitates germination among some plants, e.g. Mokolwane Palm, and controls bush encroachment, but inversely bush encroachment reduces risk of fire;
- Fault lines and fossil drainage provide important groundwater recharge foci;
- Fossil drainage line provide shallow groundwater tables and high nutrient soils, and, therefore, increased grassland with higher productivity, important wildlife hubs;
- Increased scrub/bush encroachment may lower groundwater table and increase competition for water among woody plant spp –can lead to die offs;
- A general lake of ground water year round promotes desert adapted species among the wildlife community, and constant movement through this rangeland/woodland;

3.3.1.2 Palaeo lake floors and beaches (Rangeland/Woodland)

- Well drained, low salinity soil provides increased diversity among woody species – good wildlife refuge habitat;
- Overgrazing in grasslands increases bush encroachment;
- Shallow groundwater tables on calcrete and sicrete caps provide improved access to water for woody species – promotes dense and diverse woodlands, and tree clumos on ridges, and important for browsers;
- Recruitment amongst most tree species appears constant, but episodic flooding reduces woody encroachment, while promoting the recruitment of some tree species, e.g. Burkea, Ricinodendron and miombo species;
- Shallow soil depth promotes open shrubbed grassland and reduces tree growth;
- Fossil delta or fluvial clay deposits in soil increases soil moisture and nutrient status, and therefore better productivity/grazing potential – foal grazing areas for wildlife and cattle and good arable land;
- Karstic (chemical weathering and leaching of mineral rock with water infiltration) processes in clacrete and sicrete caps produces perched pans above groundwater table – important recharge foci to groundwater and vital water resource for wildlife and livestock;
- Drought reduces groundwater table and increases woody vegetation die-off;
- Fine lacustrine derived saline soils promote flooding and are sensitive to erosion and aeolean deflation in overgrazed conditions;
- Shallow Calcrete and silcrete caps promote perched freshwater aquifers, shallow wells and pans, and the proliferation of Combretum imberbe woodland – habitat variation on low open shrubbed grassland;
- Episodic wet and dry events is followed by increased wetland grasses in wet periods and annual in dry periods, and this change promotes pioneer and weedy species;

3.3.1.3 Saline Grassland (Rangeland)

- Soil salinity is maintained by Aeolian deflation of the salt pans and transport and deposition downwind;
- Salinity controls floral species diversity, which has a knock-on effect on biodiversity, Saline tolerant species dominating, e.g. *Odyssea*;

- High pH increases nutrient solubility, leading to nutrient being bound up in clay complexes and unavailable, and increases SiO^2 solubility, promoting silcrete formation;
- Freshwater drainage lines and ponding (including man-made, e.g. roads) promotes scrub encroachment;
- Episodic wet and dry periods change the area and location of the fringe zone with scrub; shrubs invading in dry years and dying off in wet, and control the level of diversity – increased diversity during bigger floods;
- A lower groundwater table, e.g. on ridges, promotes leaching of salts, increased diversity and woody growth;
- Low plant biomass and unconsolidated fine lacustrine soils render it very sensitive to destabilization and aeolian erosion;
- Riverine deltas provide critical fluvial soil and nutrients to an otherwise low nutrient soil composition – high productivity areas;
- A general lack of fresh surface water, combined with high saline conditions provides for unique species in the biological composition.

3.3.1.4 Riverine Wetland

- Hydrological input to surface (Boteti River) and groundwater comes from the Zambezi and Okavango river systems;
- Nutrient and sediment input from the Okavango occurs along the Boteti River and Ntwetwe Pan;
- River flow frequency, intensity and duration, and recharge into the alluvial and lacustrine sands is the major controlling factor to productivity in the inflowing riverine habitat;
- The resulting higher groundwater table controls water availability to the riverine woodlands and the extent of floodplain Acacia woodland from river;
- More water and increased nutrient loading in fluvial soils increases productivity and provides an important habitat for wildlife and livestock, as well as for arable farming;
- High intensity utilization here impacts understory riverine vegetation and reduces recruitment – also leads to increased soil erosion;

3.3.1.5 Main Pan Wetland (ephemeral lake)

- Groundwater level and the capillary fringe determine the pan/lake bed level on the pans, and keeps them free of vegetation. It also stabilized the pan surface sediment – a drop in levels increases sediment destabilization and increased deflation and dust;
- Aeolian deflation is material deficient in equilibrium – any new material that gets destabilized will be transported downwind;
- Saline groundwater table of the pan is linked to and recharged by surrounding groundwater table through-flow – this connection means saline borehole water surrounding the pans – this impacts vegetation in surrounding area;
- Groundwater comprises significant input to pan surface water hydrology and influences the length of the flood period, especially in the middle and south of Sua Pan;
- Pan salinity produced by constant discharge (surface and groundwater), and evaporation, but not much salt clustering – high clay content reduces salt crusts;
- Salt weathering/chemical processes comminutes material to make it fine enough to assist in providing material for Aeolian deflation of pan surface when dry;
- Shallow groundwater has limited link with deep water brines and therefore, pumping deep brines lowers shallow groundwater table;

- Freshwater input onto the main pans, via rivers and direct rainfall contributes higher species diversity early in the season and in the deeper sumps;
- Large episodic flooding of the pans increases freshwater habitat and, as a result, biodiversity, e.g. fish and increased aquatic algae and invertebrate diversity – the amount, extent and period of flooding positively correlates with species diversity;
- Large floods, generally, also sustain increased breeding frequency and success among water birds, e.g. flamingos and pelicans;
- Independent flooding of Ntwetwe Pan by Boteti, from the Okavango may influence species composition here and at Lake Xau and increases biodiversity of the MWS;
- Unique chemical composition of flood waters and large seasonal variation in both flooding and water chemistry contributes to a rare aquatic habitat and a associated biological community, including endemic species;
- Large aquatic primary productivity results from a considerable number of physical and biological interlinking factors, including high nutrient concentrations (in the sediments - released during flooding), shallow, light abundant lakes, high CO2 absorption, high temperatures and Lesser flamingo grazing (Figure 19);
- Microbial component is likely an important player in the pan ecosystem; their role in decomposition, nutrient cycle, carbon cycle and productivity is, however, relatively unknown;
- Seasonal flooding is the predominant factor that maintains grassed pans like Kgama Kgama and Nxai Pan, with woody species encroaching during droughts and woody species die-off in wet periods;
- Recruitment of tree clusters of unknown origin here is presumed to be episodic;
- Groundwater discharge points at the interface of groundwater table and pan edge slopes, e.g. along shorelines provide important freshwater in an otherwise saline dominant environment, right through the dry season;
- The MWS wetland provides a key seasonal feeding and breeding ground for many wetland bird species, and comprises an important link as one wetland ecosystem in a large network of wetlands that spans the entire continent and beyond – this connectivity is another key function in maintaining MWS integrity.

Figure 18. Simple food chain of the main components that make up the biota of the aquatic saline ecosystem on Sua pan.

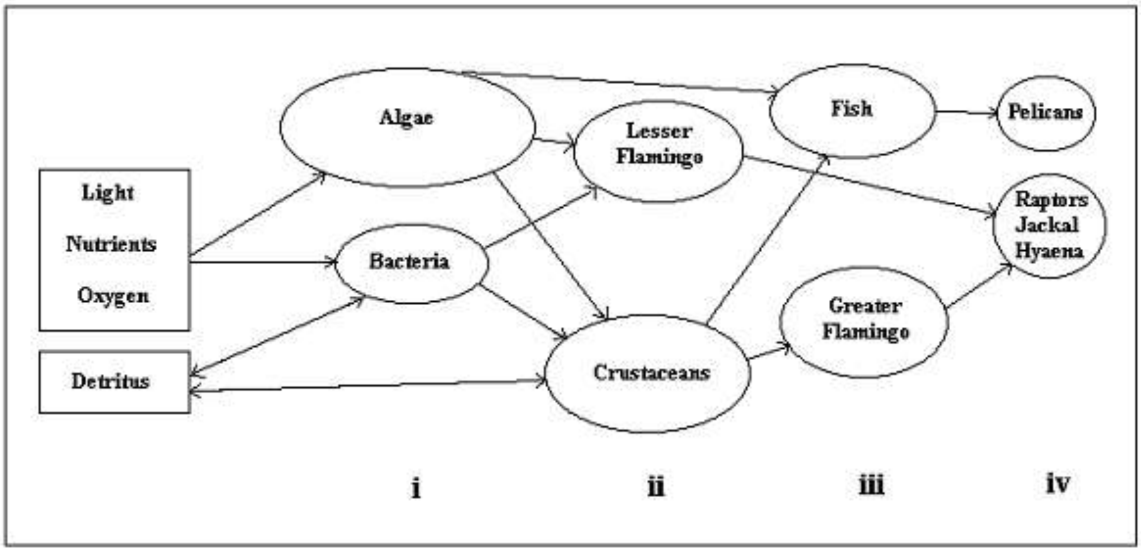
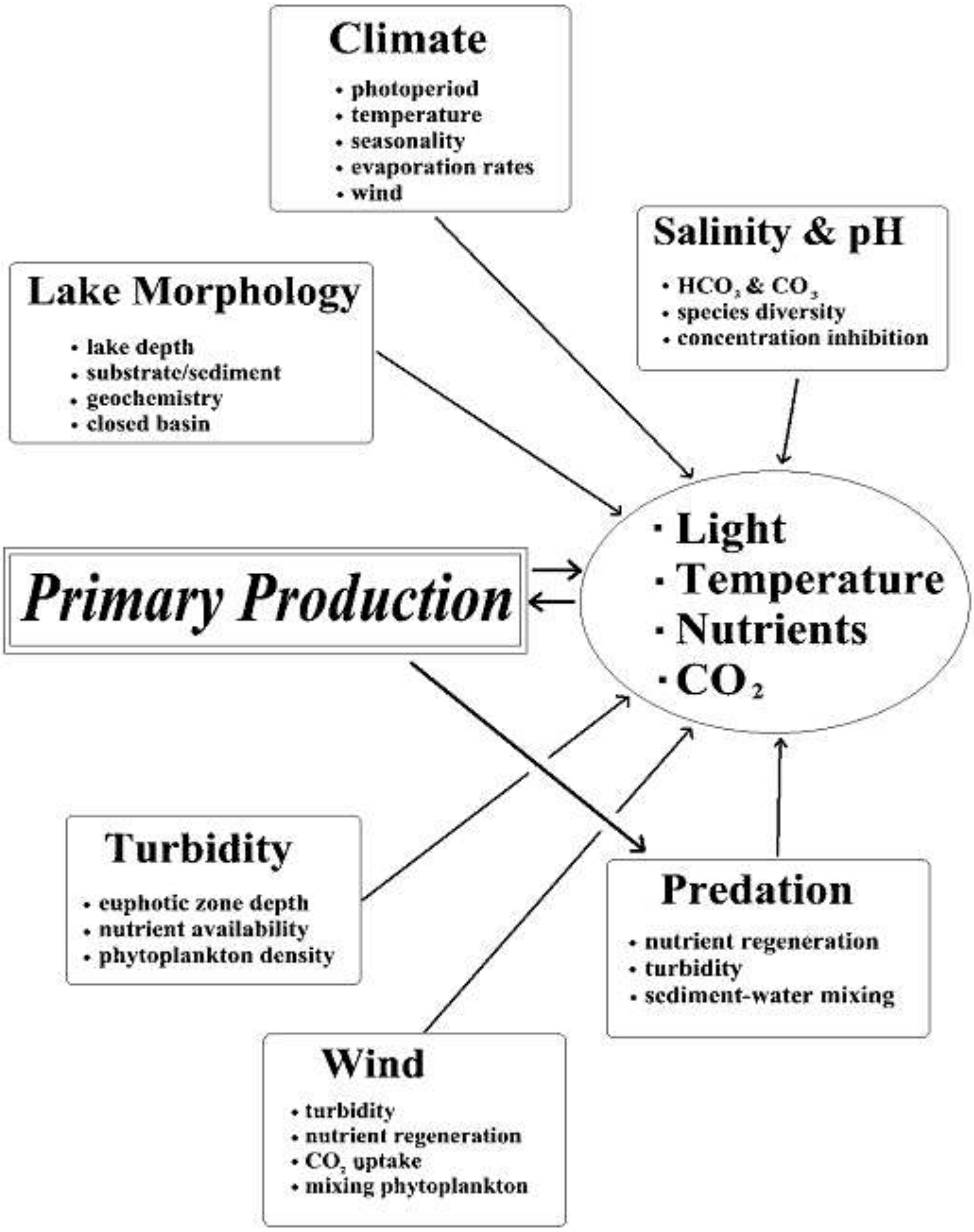


Figure 19. **Flow diagram of the important physical and chemical factors controlling net primary production on Sua pan**



Source: McCulloch, 2003.

3.3.1.2 Ecosystems Goods and Services

Many goods and services are provided for by the MFMP area and form an essential component of its ecological character and its use value (Table 8).

Table 8. Ecosystem services provided by the MFMP area.

SERVICE CATEGORIES	SPECIFIC SERVICES	Services provided
Provisioning	Food	Rangeland and woodland provides wild game, fruits, and grains Rivers provide fish
	Fresh water	Surface water in rivers and small pans is an important freshwater resource both seasonally, and in the case of the Boteti annually; Storage and retention of water in the groundwater table provides an important freshwater resource for domestic, industrial, and agricultural use; Karstic formations in the palaeo lake floors provide both important freshwater sources and groundwater recharge foci
	Fibre and fuel	Woodlands provide logs, fuelwood, and fodder for livestock; Rangelands provide an important source of thatching grass
	Biochemical	Deepwater brines under Sua Pan provide the raw material for the production of soda ash and salt, and sustaining a local economy; Salt mineral precipitation on the pan surface provides salt for salt licks and domestic use
	Genetic materials	Unique biological assemblage on in the MWS provides genes important in evolutionary as well as population viability; MWS may hold potential for biotechnology development and resistance to plant/animal pathogens etc; Flamingos and Zebra are keystone and flagship species of the MWS
Regulating	Climate regulation	Rangelands and Woodlands in particular are a carbon sink for greenhouse gases; MWS also influences local and regional temperature, precipitation, and other climatic processes
	Water regulation (hydrological flows)	groundwater recharge/discharge is an important process in controlling the hydrology of the MWS; pan flood extent and flood period is influenced by surface drainage and groundwater input
	Water purification and waste treatment	retention, recovery, and removal of excess nutrients and other pollutants occurs along ephemeral rivers, mainly in the deltas and associated reed beds, and with movement through sand
	Erosion regulation	Grass and woody vegetation cover contributes to retention of fine lacustrine soils and sediments; Riverine habitat is particularly prone to erosion by sheet wash, if undercover is removed; Groundwater level and capillary fringe maintains pan surface erosion/deposition equilibrium
	Natural hazard regulation	Wetland vegetation and riverine woodland contributes flood control, storm protection
	Pollination	MWS provides a varied habitat for pollinators
Cultural	Spiritual and inspirational	source of inspiration for scientists, and entrepreneurs; cultural and spiritual attachment to some of its features, e.g. Kubu Island religious values to aspects of wetland ecosystems, e.g. freshwater pools and springs at respectively Mea and Mosu
	Recreational	opportunities for recreational activities on the pan are abundant

	Aesthetic	many people find beauty or aesthetic value in the MWS's unique vista and environment
	Educational	opportunities for formal and informal education and training are abundant
Supporting	Soil formation	sediment retention and accumulation of organic matter occurs at the fluvial deltas, the river floodplains, and on the main pan surfaces
	Nutrient cycling	On the pans, seasonal flooding and drying contributes a cycle of storage (in sediment), unlocking (mixed with water and O2), recycling though the primary producers (algae) and their grazers (e.g. flamingos), processing (secondary productivity, e.g. flamingo chicks), and acquisition of nutrients (from the catchment) Wind deposition provides sediment and nutrients to the grasslands downwind of the pans; Termites are important recyclers of nutrient from the saline grasses back into the soil;

3.3.2 Minor Findings

3.3.2.1 Eco-region links and connectivity of the MFMP area

It is important to be clear about the phyto-chorography of the Makgadikgadi Region as it has profound implications for the status, importance and conservation of the area. Unfortunately the vegetation types of Africa comprehensively portrayed by White (1983) have often being misrepresented in the plethora of generalised 'vegetation' maps that have followed from it. As such it is important to go back to the original. White's (1983) original map serves to emphasise the in between nature of the Makgadikgadi System, lying directly between the Zambezian and Kalahari Highveld domains, the latter strikingly following a north-western boundary defined by the Boteti River.

Floristic connectivity with both domains is striking and was significantly also reflected, until the end of the last century, by the movements of the key ungulate populations – wildebeest and zebra. Relative to established phytochoria the Boteti River is thus a key divide across which the change from Kalahari-Highveld to Zambezian occurs. Many species are thus at the edge of their distribution along this boundary, with linkage between the two centres of Endemism important with respect to climate change and the ability of species to track the environmental conditions to which they are adapted. It follows that linkage between the Kalahari-Highveld (and therefore also the Karoo-Namib) and the Zambezian Centres is important at a landscape level. It is a link that has been severed by the layout of fences with as yet unknown consequences.

Connectivity is also vitally important among the wildlife and birdlife of the MWS and considerable attention and detail is provided on a species by species account in the Wildlife and Birdlife component report of the MFMP. The linkages between the MWS and wetlands to the north, e.g. the Okavango and the Chobe-Linyanti river systems, via, respectively, NG 47 and Nxai Pan and CT7 are vital to the long-term viability of many of the large herbivore species and their associated predators. Keeping these migration routes/corridors free to allow safe passage is therefore crucial. For Birdlife, this connectivity requires protection of the flyways that connect the MWS with a large wetland habitat throughout southern, with the rest of Africa and beyond to Eurasia.

De Querioz (n.d) points to landscape or ecosystem level degradation of rangeland due to the loss of the nutrient dispersal (particularly phosphorous) and enrichment mechanism, centering upon pans and depressions, caused by thousands of wild ungulates converging on them in the wet season, and then dispersing throughout the Kalahari in the dry. Certainly, the basic mode of ecosystem functioning has changed radically, following the complete loss of the key wild ungulate species from the area and their replacement with domestic stock, permanently grazing around wells and boreholes (and the Boteti River).

3.3.3 Conclusions

- The most important function that maintains the ephemeral wetland nature of the MWS is the surface water hydrological regime of the wetland, i.e. the seasonal input from rainfall, rivers, and groundwater and subsequent loss to evaporation.
- Groundwater recharge, via palaeolake 'proto pans', fossil rivers, fault lines and general shallow groundwater through-flow, is essential to the maintenance of groundwater (one of the most important resources in the system) as well as capillary fringe control of pan surface topography, Aeolian deflation and chemical/mineral dissolution and leaching;
- River discharge from the Okavango system is also a very important hydrological function, contributing a vital source of water and habitat heterogeneity to the system.
- Connectivity and mobility within the system and between it and other ecosystems in Botswana and elsewhere is also a crucial process in the biological functioning of this wetland.
- A unique chemical composition and high nutrient contents from the catchment contributes a unique biological composition and a highly productive aquatic system.
- Aeolean erosion and transport of soils drives soil structure and sensitivity in the Kalahari sandveld, contributes salts and nutrients to the grassland and groundwater table downwind of the pans, and plays a major role in the Aeolian deflation of the pan surface and shaping of its topography.
- Other sub-functions and processes were identified according five main land systems, which comprise discrete sub-units of uniform physical and ecological character.
- The goods and services provided by the MWS were identified under four categories; provisioning, regulating, cultural and supporting services.

Gaps in our knowledge

- The are many gaps in our knowledge and understanding of the main ecological functions and processes, i.e. the relationship between rainfall, river discharge and flood amount and period that control flood regime is not fully understood; as is the importance of groundwater through flow from the catchment and its contribution to surface water flooding;
- There is little knowledge of the detailed links that maintain connectivity within the MWS and between the system with and other systems in Botswana and elsewhere; and
- The sustainability of the services provided by the ecosystem is also not fully understood.

3.3.4 Follow up work

It is important that the above functions, goods and services need to be recognised and supported through management and, therefore, consideration to the main ecosystem functions in the management planning and development activities during implementation of the MFMP is required. In addition, further understanding of the list of functions and processes, above, and of other functions not listed here is required to improve effective management.

The most important function that maintains the ephemeral wetland nature is the surface water hydrological regime of the wetland, i.e. the seasonal input from rainfall, rivers, and groundwater and subsequent loss to evaporation. Implementation of Integrated Water Resource Monitoring (IWRM) at the key discharge rivers and the pan ‘wet spots’ across the MFMP area is required to ensure adequate monitoring and effective management.

Improved monitoring of groundwater at specific, strategically positioned groundwater well points on the pan and areas adjacent to the pan is required in order to get a better understanding of the processes of ground water through flow/input. In addition, river discharge from the Okavango system is also a very important hydrological function, and monitoring of the hydrological regime, seasonality and period of the river is required.

3.4 Indicators in adaptive management

3.4.1 An Ecological Monitoring Framework for the MFMP area

Monitoring is defined by Ramsar (Ramsar Wise Use Handbook 12 and 16) as a “Collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing appropriate, adaptive management”. A monitoring programme should, therefore, form an integral part of the Framework Management Plan for the Makgadikgadi wetland management plan.

Table 9 summarises indicators for the state of the ecosystem. Birds are valuable bio-indicators of ecosystem functioning and integrity and the success of key ‘trigger’ species, particularly when breeding, can prove very useful in monitoring programmes. The Lesser Flamingo has been identified by Birdlife Botswana as the trigger species for monitoring the integrity of the MWS. For the past twelve years, a monitoring programme indicates that significant breeding success occurs only during years of average to above average rainfall. Lesser Flamingo breeding success is therefore a great indicator of hydrological variability and vice versa, and indicates a balanced ecosystem.

Other indicators can be used to identify changes to the hydrological regime, pollution and other anthropogenic impacts that threaten the system and it biodiversity. Here too biological indicators can be used to provide ‘tools’ in rapid assessment monitoring techniques. Algae are good indicators to pollution and eutrophication of wetlands and respond very quickly to any changes as a result of waste water pollution or chemical pollutants from mining effluent. Changes in water chemistry as a result, for example, of brine extraction and effluent disposal on the pan surface could be detected using the community of crustacean that exists in the lake waters. This community is made up of a number of species (12 in all) each with different tolerances to varying salinities and chemical composition. Sampling this community can flag chemical variations in the system outside the normal variations with reliable significance. A reduction in sweet perennial grass species and an increase in species associated with bush encroachment like *Acacia mellifera* and *Dicrastachys cineria* are good indicators of rangeland degradation.

Where unacceptable change to the ecological character of a wetland occurs, identified by a negative impact on the related indicator/s, the local management authority, e.g. DEA / DWNP / DWA, local communities, and private institutions should intervene to correct those negative impacts through interactive, flexible and feasible management interventions/mitigation methods.

Thresholds of acceptable change for each indicator will change according to land use, e.g. tourism development zones (see LAC s in tourism component), and management objective, e.g. BD hotspot protected area. For over all resource use indicators, thresholds of acceptable change should be guided by standard nation-wide regulations (e.g. BOBS water quality standards) and/or estimated sustainable levels of off-take. Monitoring should be participatory and encourage multi-sectoral engagement in the activities required for efficient, cost effective monitoring. Indeed, much of the monitoring required (outlined in the table below) can be incorporated into existing government, NGO and private institutions' monitoring programmes. Orapa and Letlhakane management, for example, already have a good effective monitoring program, which will continuously look at new ways to combat the growing loss of groundwater resources and extraction requirements.

Table 9. A monitoring programme framework for the MFMP area by management objective.

MANAGEMENT OBJECTIVE	Sources of Change/ Pressures	Indicator	Method	Data availability	By Who / Responsibility
Maintain overall Ecosystem integrity: main ecosystem functions ; Hydrological input, Groundwater recharge, Groundwater table and pan surface equilibrium and grassland-woodland interface Physico-chemical controls, and impact on biological community, Trophic level links, Migration and movements around MWS and between MWS and other systems, Hydrological and chemical variability in maintaining species diversity, Rangeland degradation by overgrazing and fire	Surface Water abstraction (dams, irrigation, mining), Groundwater exploitation (increased boreholes, mining offtake, mining brine, & municipal), Deep pan brine mining Pumping brine onto pan, Catchment soil erosion and pollution, Altered water levels or pollutant, Fences, roads and powerlines creating fragmentation and obstacles, Climate change altering hydrological regime	Keystone indicator species – Zebra, Elephant, Flamingo, Pelicans, crustacean community, Borehole Water Chemistry and draw-down level at key well point sites, e.g. BotAsh & surrounding the pans. Daily rainfall – river hydrology - flood extent relationships. Borehole density vs. livestock numbers, Fire occurrence and dust emissions, Biodiversity - BD hotspots threatened species populations	Key stone species population counts (DWNP aerial surveys resumed, & BLB, private research/institution). Borehole level monitoring at BotAsh & strategic peizometer readings of shallow ground water at conflict sites, e.g. BotAsh wellfield (DWA & BotAsh) Conductivity, pH, & nutrient measurements from Identified Conflict areas & top ten ‘Wetspots’ (E & H Component) (DWA) Strategic sampling of algae and invertebrate community at key conflict sites, e.g. BotAsh, Mosetse Dam basin and Dukwi Copper mine food waters (DWA), Daily rainfall events analysis and modelling in climate change models (DMS& researchers), Fire occurrence and scar monitoring, concentrating on sensitive areas, e.g. MPNPNP (DFRR, DoA, DGS), Borehole and livestock numbers and carrying capacities monitored, concentrating on high impact areas, e.g. Rakops (DoA– statistics & DFRR)	DWNP aerial survey data for mammals Wetlands, International Bi-annual waterfowl counts for birdlife, Independent research baseline data for Elephant, Zebra, Flamingo and Sua crustacean community. DGS and independent study (see site inventory) borehole data, Botswana Ash pumping data, DMS and DWA annual monitoring database for rainfall (data for 11 stations since 1960’s) and river discharge (data for 4 rivers since 1970’s)	Lead: DEA Implementation Unit in collaboration with the Wetlands Stakeholders Committee.

Maintain Biodiversity	Hydrological alterations, Pollution, Disturbance (physical and chemical) Habitat loss or fragmentation	Biodiversity at BD Hotspots, Threatened species, e.g. Wattled Crane, Flamingo, Chestnut banded Plovers, Vultures species, Lion and Brown Hyena, Development Footprint (Land Use GIS Map) Habitat state in relation to important/threatened species	Monitoring key threatened species at biodiversity hotspots, and assessing threat from habitat loss, pollution and other disturbances (DWNP, community conservation officers, Private tourism operators and researchers). Updating development footprint – from Land Use (Dept of Lands, Tribal boards, and councils),	Background literature and data on some key indicator species through DWNP surveys and independent studies, Need for biodiversity hotspot assessments during FMP to establish 'status quo' as baseline	DEA to lead with input from stakeholders and community initiatives
Maintain hydrologic regime	Altered surface water flow, e.g. dams, irrigation Groundwater exploitation Climate change Boteti River Flow – natural variation	Flow magnitude, timing, & duration in relation to rainfall, Flooding extent and period in relation to rainfall, Pan dusts increase from pan Borehole level drawdown, on pan and surrounding rangeland, municipal and mining boreholes, Daily Rainfall data and temperatures, Change in rainfall in relation to corresponding climatic events – modeling daily rainfall events, Salt bush (*Suaeda merxmuelleri*) encroachment on pan surface, with nebka dune formation	GIS remote sensing (free MODIS imagery) analysis of flood extent in relation to daily rainfall events and river discharge (DGS & DMS – statistics, & research), Piezometer groundwater monitoring at top ten 'Wetspots' (E & H Component), (DWA with help from BotAsh and Debswana). Improved River Discharge at all inflowing rivers – increase number on each & increase info collected to include chemistry and nutrient samples (DWA), Borehole levels and recharge (DGS & DWA) Opportunities and constraints presented by recent Boteti River flow and their impacts to local livelihoods (Community Consultations - Statistics)	DMS rainfall and temperature (data for 11 stations since 1960's). Botswana Ash borehole record database since 1991. DGS borehole data – initial depth and pump rate. DMS temperature data from 11 Met stations around MWS, since 60's Observation data in BotAsh reports and independent observations and reviews. DWA to monitor amount, extent and period of river flow, and DWNP to monitor fish population and offtake. Indigenous knowledge and related existing literature & reports	DWA to lead – also include UB / HOORC / Researchers DMS to lead climatic monitoring, with input from UB / HOORC / Researchers DWA to monitor Boteti, DWNP to monitor fish and independent study could look at the impact of the river on local livelihoods
Maintain water quality	Development: Housing, Lodges, and other tourism infrastructure, sewage and other pollutants, Groundwater abstraction, Industry, including Mining – sewerage and chemical pollutants,	Water Chemistry in conflict areas Phytoplankton Rapid assessor developed and used in conflict areas Invertebrate (*Crustaceans & Odonata)* rapid assessors developed and used in conflict areas (DWA & researchers)	Monitor mining operations & activities at other development Strategic targeted Chemical tests at impact sites (DWA), Rapid assessment tests of phytoplankton and invertebrates at target impact sites & key functioning hotspots (DWA – researchers). Strategic BLB waterfowl counts and targeted breeding success monitoring (BLB & researchers)	Land Use maps and plans, Independent study database on water chemistry, phytoplankton and crustacean communities (see site inventory) Biannual Wetlands International waterfowl counts and independent studies on flamingo	DWA to take lead, involving Stakeholders, e.g. mining companies, UB/HOORC/Researchers BLB

	Commercial agriculture – fertilizers & pesticides	Keystone Bird numbers and avian diversity and breeding success in key conflict areas (BLB & researchers)			
Maintain sustainable tourism related activities	Disturbance from Tourism activities, including game drives and associated impacts lodge & campsite footprint and associated impacts	Environmental LAC'S identified by the tourism component, according to different tourism zones, Tourist/bed night Carrying capacities derived in tourism report	Wildlife observations and disturbance (BTO, community conservation officers and private operators) Pan surface disturbance – grass encroachment or dune formation, (BTO, community conservation officers and private operators) Road maintenance and state (BTO, community conservation officers and private operators) Visitor satisfaction and feedback (BTO, community conservation officers and private operators)	Indigenous knowledge and DWNP reports, Indigenous knowledge and related literature Initiate observation database	DEA/BTO to lead with Operators - Observations by guides and managers (DWNP or private and/or community operators),
Reduce the level of Conflict	Conflicts between pastoral and arable, Wildlife Conflicts, e.g. between agriculture (pastoral and arable) and wildlife Conflicts between mining and tourism Conflicts between tourism and agriculture	Agricultural conflict in land use planning, Livestock and Wildlife mortalities in PAC records, Crop raiding in PAC records, Mines and tourism licensing overlap - conflicts, Community benefit from and perception of tourism industry on resource benefits,	Monitor the frequency and extent of agricultural overlap (DoA) PAC record analysis and conflict type and frequencies (DWNP & researchers) Monitor the impact of mining on community and tourism through visitor satisfaction, amount of support from mines and operator feedback (DoM, DEA, Tourism-community partnerships (formal and informal) and social responsibilities projects (BTO)	PAC records from DWNP Department of Agriculture records and land use planning for agricultural sector plans Mining responsibilities and impacts from literature and Mining licenses Tourism report on location and improved community-private relationships/partnerships	DWNP to lead wildlife conflict monitoring, DoA to lead agricultural monitoring BTO to lead tourism conflict monitoring,
Maintain morphology and topography (terrestrial and on pan)	Mining	Topographical pattern changes around or on the pans, e.g. open cast mining, new sumps or altered pan surface water hydrology	GIS remote sensing analysis, Ground observations	Archive remote sensing data, e.g. MODIS since 2000 Need for good topographical DEM to form baseline	DWA to lead with input from BotAsh (Pty) Ltd, Debswana & other mines,
Maintain chemistry in water and/or soil	Mining of deep water pan Brine – pan surface, BotAsh bitterns pumped onto pan surface, Drying or abstraction of Rivers.	Lake Conductivity and pH, Crustacean community composition; River conductivity & pH, Groundwater/borehole conductivity and pH,	Conductivity & pH meter readings of river, pan surface water and borehole, Invertebrate sampling methodology and microscopy at strategic sites	Brine and groundwater pump rates and resource management database from BotAsh and Orapa DGS borehole database for the MWS area and independent study of groundwater chemistry (see site inventory)	DWA to lead, with key involvement and input from Orapa and BotAsh

	Groundwater alterations /extraction				
Maintain sediment regime	Water Abstraction, Development upstream, Overgrazing and Soil erosion in catchments, Dams	Land use change indicators on Land use plans and remote sensing images, e.g. dams and irrigation agriculture Turbidity and total suspended solids Benthic community (algae & invertebrate) composition	GIS analysis of remote sensing data & ground observations of new developments Turbidity and nutrient rapid testing kits Annual sampling of algae and invertebrate community	Land Use plans and maps, MODIS archive form 2000 – comparisons, Literature on dams and irrigation schemes	DWA to lead, with input from UB / Researchers
Maintaining Rangeland quality and integrity	Overgrazing the rangeland Soil alteration / erosion from overgrazing and or arable farming, Excessive Fire Exotic species Excessive watering points (borehole) – piospheres	Borehole/well density vs. livestock free areas, Increase in 'Increaser' grass species, forbs and bush encroachment along on both sides of fence – wildlife & livestock impacts Exotic species, e.g. castor oil plant Vegetation recovery analysis through NDVI/EVI remote sensing Fire and Dust emissions through remote sensing	Conduct Ground observations – key strategic observation/reference sites in affected & unaffected areas that should be identified and monitored regularly, Conduct NDVI/EVI GIS analysis bi-annually, DWNP wildlife counts, Ground observation of wildlife movements and distributions (DWNP & Tourism camps), GIS analysis of remote sensing data on dust & fire, and NDVI/EVI	DWA Registered Boreholes in the area and additional current numbers using archive remote sensing imagery e.g. MODIS, Data on thresholds of increasers and bush encroachment from literature and from existing reports for the area, see Rangeland report, Fire database at DFRR and MODIS archive and independent dust studies (see Hydro(geo)logical report)	DFRR to lead with involvement from Community participants, DWNP UB / HOORC
Loss of Wildlife migration routes	Land Use Fencing Powerlines (Birds)	Number of obstacles like fences and powerlines Zebra & Wildebeest mortalities Water bird mortalities	GIS analysis of current and planned fences and powerlines, Migration studies, Strategic surveys of fences and powerlines	Independent studies e.g. Zebra and flamingo research studies, local area management plans and DWNP reports. AEWA Critical site network tool (wingsoverwetlands.org) identifying flyways	DWNP to lead with input from researchers / tourism operations BPC, BLB, researchers
Maintain sustainable harvesting of veld products	Subsistence overuse, Fire, Commercial exploitation	Dead trees standing, Tree felling, Thatching grass harvest season and amounts, Rangeland community	Strategic surveys in high impact areas with implementation of harvest thresholds and timing, Strategic assessment of rangeland composition at harvesting sites, Survey of dead trees and felled trees in wood harvesting area,	DFRR management thresholds, e.g. monthly wood allowances for sustainable use,	DFRR to lead with input from DoA, UB/ HOORC.

		composition changes	Small tree roosting mammal survey		
Maintain social benefits and livelihoods improvements through systems goods and services	Over-consumption and degradation of local natural resources Pressure on existing subsistence land from mining, tourism etc.	Increased dependency among local livelihoods; Reduced land availability for subsistence agricultural practices, Community perception - conflict	Monitor the amount and extent of impact on livelihoods from loss of natural resources and land – statistics Community consultation feedback re livelihood dependency and conflict with development in the area	Indigenous knowledge and area specific land use and management planning reports	DEA to lead

3.4.2 Indicators

What follows are details of appropriate indicators included in the monitoring framework above and their monitoring implications/techniques required. Other potentially useful indicators with associated management objectives are also included and may be developed further to improve the monitoring and, ultimately, adaptive management of the MWS:

3.4.2.1 Invertebrate Indicators

Invertebrates are commonly used as bio-indicators of ecosystem health, and can be tested for rapid assessment of catchment impacts, e.g. pollutant loads and ecosystem health. Focus has been mainly on aquatic groups, including large branchiopods, chydorids and ostracods as well as more “well known” macro invertebrates. Sampling invertebrates does however require specific equipment and methodology, and samples need to be taken back to a lab for their identification under a microscope. Stakeholders in the MFMP area however, have access to such equipment, e.g. Botswana Ash, and should facilitate with the sampling, identification and data compilation and analysis as part of their monitoring programme, in collaboration with UB.

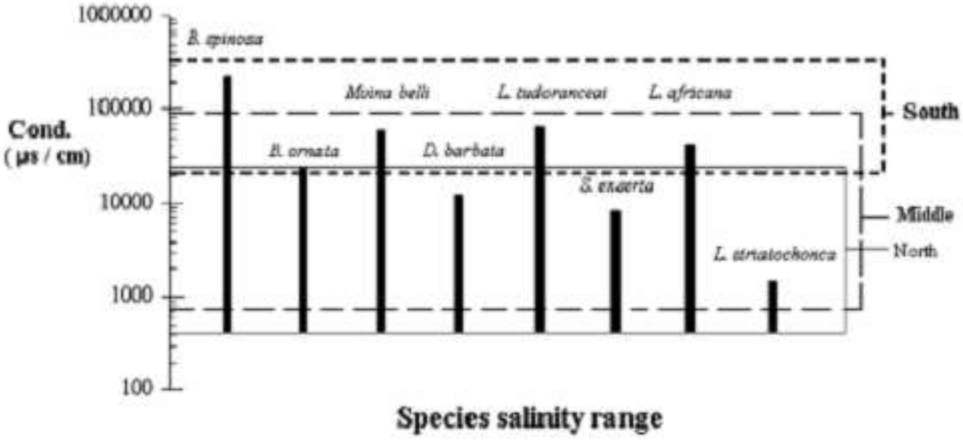
South Africa has a well-developed bio-monitoring system (using invertebrates) for water quality in rivers. Development of the use of riverine groups, include response to a range of environmental variables that are associated with environmental degradation: including oxygen regime, sediment load, nutrients and alterations in hydro-morphology and associated salinity. Use of invertebrates as indicators in this way, however, requires a considerable amount of further understanding, through research, in order to fully understand the natural ecological variations in the community’s species and populations, and identify threshold levels according to management objectives.

Species of Odonata also provide great potential as rapid assessment indicators and have been receiving increasing attention in Africa (for a recent discussion, see Smith *et al*., 2007, Suhling *et al*., In Prep). Due to their semi-aquatic life cycle they are sensitive to degradation and/or pollution in aquatic as well as in terrestrial habitats. In general, there is a strong correlation between diversity of vegetation and habitat structure and Odonata biodiversity – highlighting their potential as good ‘ecosystem level’ indicators. Dragonflies are comparatively easy to sample and with training and practice, easy to identify in the field from a distance using close-focus binoculars.

Much research is required in this field and detailed work on developing these indicators according to different variables and management objectives, e.g. pressure detection, is still required. Bio-indicator metrics, for example, account for seasonality and reliability and expertise is required here to develop multivariate and multi-metric models for ecological assessment before they can be used effectively to identify impact. Little is known, or has been done in this field for inland surface waters, particularly, saline ephemeral wetlands.

An early warning indicator that can be used in the MWS is the crustacean community of Sua Pan. A relatively small number of species comprise the community assemblage of the pan and species-specific salinity tolerances have been identified among the species (Figure 20). Changes in salinity during and between flood periods, therefore, significantly alter the community composition of these crustaceans (McCulloch *et al*., 2007). Monitoring this community assemblage, therefore, offers great potential for their use in identifying changes in the surface water chemistry on Sua Pan as a result of, for example, soda ash mining activities by Botswana Ash and resulting changes in chemical composition and salinity of ground and surface waters. Further targeted research and experimentation, e.g. response toxicity tests, could also uncover likely thresholds in toxicity levels and early warning indications of impacts from chemical pollutants in situ.

Figure 20. Salinity ranges for the crustacean species on Sua Pan.



Source: McCulloch *et al*., 2007.

3.4.2.2 Phytoplankton Indicators

Owing to their nutritional requirements, their position at the base of aquatic food webs, and their ability to respond rapidly and predictably to a broad range of pollutants, phytoplankton represent perhaps the most promising early warning indicators of change in ecological character of wetlands as a result of chemicals/pollutants. In addition, their sensitivity to changes in nutrient levels makes them ideal indicators for assessing eutrophication.

They can be used in toxicity bioassays described for rapid response toxicity tests and direct toxicity assessments. Such methods are rapid, inexpensive and sensitive, and can be carried out in the laboratory or in the field, using either laboratory cultured algae or natural phytoplankton assemblages. For example, algal fractionation bioassays (AFB) assess the effects of pollutants on the functional parameters (for example, C14 uptake, biomass) within a natural assemblage of algae. Structural indicators, such as species composition and size assemblage shifts have also been found to be particularly sensitive to some pollutants.

The phytoplankton and periphyton community of Sua Pan, for example, contains both freshwater and saline water species that can be developed into suitable rapid assessment pollutant detectors, as described above. Once again, further work is required here to define the parameters and toxicity sensitivities, but Botswana Ash conduct daily monitoring of the algae in their solar ponds and could perhaps facilitate such testing and indicator development in their microbiology lab and use as part of their monitoring strategy, in collaboration with UB.

3.4.2.3 Rangeland Indicators

Nine groups can be used to indicate the ecological status of a rangeland (e.g. Trollope et al. 1989):

- **Decreaser** –species that dominates a good rangeland, but decreases when there is mismanagement. Hence, a decrease in these species indicates that the range condition is deteriorating.

- **Increaser I** –species that dominates poor rangelands and increases with understocking. Hence abundance of the species indicates understocking in the rangeland. Two variants of this form are recognised:
- **Increaser IIb** - species that increases when there is moderate overgrazing
- **Increaser IIc** - species that increases when there is severe overgrazing
- **Invader** –species that is alien to an area, i.e. weeds like the Castor oil plant.

Abundance of the species in a particular locality indicates a detrimental state of the rangeland or ecological region as it usually has a negative impact on the lives of the organisms indigenous to that locality. Based on the above definitions a number of herbaceous species can be identified as plant indicators for Rangeland in the MWS (Table 10).

Table 10. Some Herbaceous Indicator species in the MFMP area.

Indicator species	Ecological Indication
Andropogon huillensis	A good indicator of sandy wet sandy soil
Cenchrus ciliaris	Decreaser
Digitaria eriantha	Decreaser
Panicum coloratum	Decreaser
Panicum maximum	Decreaser
Schmidtia pappophoroides	Decreaser
Sporobolus ioclados	Decreaser
Stipagrostis ciliata	Decreaser
Stipagrostis obtuse	Decreaser
Aristida meridionalis	Increaser IIb
Cynodon dactylon	Increaser IIb
Eragrostis echinochloidea	Increaser IIb
Eragrostis pallens	Increaser IIb
Eragrostis rigidior	Increaser Iib
Aristida adscensionis	Increaser IIc
Aristida rhiniochloa	Increaser IIc
Aristida stipitata	Increaser IIc
Chloris virgata	Increaser IIc
Enneapogon cenchroides	Increaser IIc
Eragrostis nindensis	Increaser IIc
Eragrostis trichophora	Increaser IIc
Melinis repens	Increaser Iic
Schmidtia kalihariensis	Increaser IIc
Setaria verticillata	Increaser IIc
Sporobolus pyramidalis	Increaser IIc
Urochloa mosambicensis	Increaser IIc

Source: Van Oudtshoorn, 1992.

Commonly occurring sweet grasses include the following, many of which are perennials, *Anthephora pubescens, Brachiara nigropedata, Cenchrus ciliaris, Chloris gayana, Digitaria spp., Eragrostis rigidior, E.superba, Panicum maximum, P.coloratum* and *Schmidtia bulbosa*. Sour grasses include the aromatic genus Cymbogon and tall-growing coarse grasses such as Andropogon spp., and *Heteropogon melanocarpus. Eragrostis pallens* and many Aristida spp are unpalatable and the hard *Odyssea paucinervis* also falls into this category.

Bush encroaching species like *Acacia mellifera* and Moselesele (*Dicrostachys cinerea*) also provide good indicators of overgrazing and rangeland degradation. Although their occurrence indicates that the problem has already happened; the ecology has changed and mitigation/intervention action, i.e. reclamation are the only options.

The 'Limits of Acceptable Change' (LAC) concept is difficult to apply outside protected areas like the Makgadikgadi Pans National Park due to the context within which management occurs. Within the protected area itself there are a number of monitoring activities that can take place with clear management linkages:

- The management of artificial water points linked to a piosphere based monitoring system of the vegetation and in turn linked to changes in animal numbers and distributions – e.g. if rare species are becoming displaced by more common grazers, then it may be necessary to close waterpoints;
- An active fire management scheme linked to the reduction of fuel loads to protect vulnerable habitats (Boteti woodlands and grassland plains), and in turn linked to habitat monitoring and specific objectives such as a reduction in bush density and cover in bush encroached areas; e.g. If only a certain percentage of Makgadikgadi's different habitat types should be allowed to burn in any one year then fire hazard could be assessed and pre-emptive action taken (e.g. maintenance of fire-breaks, early dry season burns etc);
- The eradication and/or control of exotic plants via an active monitoring system; and
- Monitoring and management controls can be put in place to ensure tourism/vehicle densities should not exceed certain levels (or rates of encounter);

These are all activities that could be undertaken by the DWNP.

Pastoralists have often been viewed by researchers and policy makers as agents of land degradation through their profit-maximising and ultimately unsustainable behaviour, but with the rise of participatory research, a number of studies began to recognise the value of local pastoral knowledge in assessing land degradation and desertification (Reed *et al*., 2006).

Local communities who are affected by land degradation, particularly rangeland degradation, however, rarely participate in science-led 'top-down' approaches to land and/or resource management, or derive results that can improve the sustainability of their land management. However, it is clear that management decisions cannot be made on the basis of unverified local assumptions alone. Instead, there is a need to integrate and harness knowledge from within and between scientific and local knowledge bases, so that communities are able to fully realise their capacity to adapt to the challenges of land degradation (Reed *et al*., 2006).

The resultant 'hybrid knowledge' should allow scientists, local stakeholders and their different understandings to interact to produce useful policy and more effective land use management practices (Robbins *et al*., 2002; Fraser *et al*., 2006). Such co-operation has the potential to minimise the risk of conflicts, not only between ecological and economic values but also among multiple environmental management interests, as well as encouraging active participation in and rapid adaptation to management actions and interventions. This strategy could be adopted and developed further in the MWS, to optimise rangeland monitoring using widely agreed indicators, such as the grasses above and bush encroaching species like Moselesele and *Acacia mellifera*.

The challenge is, however, that methods of encouraging participation in such monitoring, e.g. through Management Oriented Monitoring System (MOMS), has very few tangible management benefits for doing so. Trusts also suffer sharing their resource base with effectively private and independent cattlepost owners, who will have different management goals to those to the Community Trust and gain from any improvement of range.

In addition, bush thickening or encroachment cannot be reversed by simply reducing or removing livestock, but may take 60-100 years for the coincidence of ecological conditions necessary to revert the savannah back to open grassland. LACs can therefore over simplify ecosystem functioning and create the impression that the physiognomy, structure and dynamics of the vegetation is up to the Park Manager, when in fact the opposite is true.

Also, and more importantly, the linkage between LAC's and 'indicator species' also currently, and for some time now, lacks effective management linkages (action on indicators), e.g. declining cover of sweet perennial grasses and the break-up of mats of *Odyssea paucinervis* led Blair Rains and Mckay (1968) to call for the immediate destocking of the area east of Rakops, and yet to this day, it has not happened. The expansion of kraals and cattleposts along the River could be actively monitored, although collecting information to purely document change is of little but academic value if, ultimately, little management action is taken to mitigate rangeland degradation.

The occurrence of exotic species, such as the castor oil plant, *Ricinus communis*, a species of flowering plant in the spurge family, *Euphorbiaceae*, that is evident along the lower banks of the Boteti River, should be monitored and actively eradicated.

3.4.2.4 Birds as Indicators

It has long been appreciated that waterbirds might function as indicators of ecosystems (Anonymous, 2009, Birdlife international, 2005); particularly wetland health. Since they often respond very quickly to changes in their environment, their status can be a powerful indicator of changes to other organisms in the ecosystem, which are more often difficult to measure.

Waterbirds are monitored in many parts of the world, both for their intrinsic conservation value and because they can act as indicators of biodiversity and ecological status (e.g. Owino *et al.*, 2001). Bird watching is an easy and enjoyable activity to participate and many sectors of society, from guides in safari camps to weekend holiday makers can contribute to monitoring and collate a wealth of information on the status and trends of waterbirds at wetlands.
Large raptors – the high trophic level status of large raptors means that they integrate functional disturbance at lower levels, and the large foraging ranges of most species make them highly sensitive to human disturbance. Densities for most species are, therefore, considerably higher in protected areas than in non-protected areas.

Piscivores - the high trophic level and specific hunting requirements (e.g., water clarity) of large fish-eating species (e.g., African Fish Eagle, African Darter and Great white pelicans) make them generally reliable indicators of human impact on aquatic systems and the presence or deterioration off fish stocks. These species are also particularly susceptible to the bioaccumulation of toxic pollutants in aquatic food webs.

Gamebirds and bustards – susceptible to hunting and snaring for food, and provide good indication of human pressure on birds as food resources. More sophisticated approaches to using birds in monitoring ecosystem condition include the development of community indices based on various behavioural and physiological response guilds (O'Connell et al. 2000), or the calculation of indicator values for various species based on their habitat specificity and fidelity (Dufrêne and Legendre 1997).

The Common Bird Monitoring Project is a BirdLife project that aims to build an internet based platform for the collection, storage and retrieval of bird observations worldwide. These data, particularly birdwatchers' day lists, can be used to augment monitoring databases, or to monitor particular species and have the potential as a management decision making tool for use in monitoring IBAs such at the MWS. Birdlife Botswana co-ordinates these counts across the country (www.birdlifebotswana.org.bw)

Wetlands sites are often IBAs because of their importance to congregatory waterbirds. Changes in waterbird numbers can indicate ecological changes at these sites, though because numbers are often very variable, long-term data from several years is needed to set a baseline. The International Waterbird Census (IWC), a major existing monitoring system coordinated by Wetlands International, provides the only in-depth IBA monitoring in many countries. Systematic waterbird counts have been conducted annually in the months of January and July at a variety of wetland sites around the MWS for the past two decades. The main goals include estimating waterbird population sizes, monitoring changes in waterbird number and distribution, providing information on the conservation status of waterbirds under threat, e.g. indicator species.

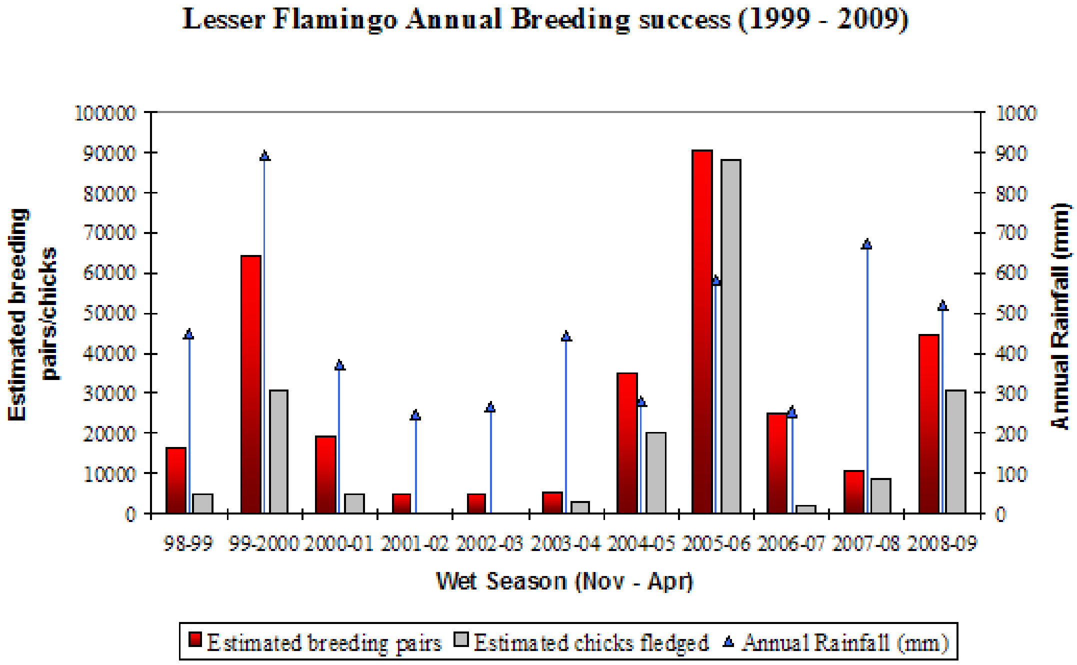
These bi-annual counts, co-ordinated by BirdLife Botswana, provide an important database and a useful tool for assessing the status of biological diversity in the MWS, which can be fed into national and international database and feed directly into national reporting for the CBD (Anonymous, 2007a) and other environmental conventions.

Key ‘Trigger’ Indicator species (or IBA qualifying species) are bird species that have been identified by Birdlife International and their National Partners, for IBAs for use as easily identifiable and site/ecosystem specific ecosystem level indicators. IBA scores are based on the ‘worst’ case indicator score (e.g. the most threatened species or the least intact habitat). This approach is precautionary and gives a simple decision rule to use when only incomplete information is available.

For Makgadikgadi, Birdlife Botswana has chosen the Lesser Flamingo as the IBA ‘trigger’ species. Monitoring of the population and, in particular, annual breeding success has been conducted for the past eleven years for this species (McCulloch *et al*, 2010). Large variation in annual breeding attempts and success was observed, and was, in general, dependent upon good rainfall (Figure 21). Although breeding may occur on an annual basis, their success depends on the period of flooding on the pan and this closely correlates with rainfall. On closer analysis of the data, there appears to be a rainfall threshold of approximately 450mm (the annual average rainfall for Sua Pan) (McCulloch, in prep). Breeding success in the population of Lesser Flamingos, therefore, provides a key indicator or ‘surrogate’ of overall ecosystem health and the state of its biodiversity.

Monitoring their breeding is however, costly, intrusive if not done correctly, and requires considerable expertise and resources. Instead, annual wet season rainfall amounts, and remote sensing of the amount of flooding on Sua Pan provide rapid indicators of the likelihood of breeding success. Long-term changes in such system flood dynamics would, therefore, flag conservation concerns about, for example, reduced discharge onto the pan or significant lowering of the groundwater table, and call for appropriate action to protect the species and the integrity of the wetland system as a whole.

Figure 21. Annual estimated breeding numbers (nesting pairs) and success (chicks fledged) for Lesser and Greater Flamingo (1999 -2009)



Source: McCulloch, in prep.

Similarly, Keystone species are good ecosystem level indicators that can be used to monitor ecosystem condition and health, or identify any deleterious impacts on the system. Zebra and wildebeest are good examples of keystone species and, therefore, provide ideal key indicators of rangeland quality and conflict in the surrounding grasslands of the MWS. Through their seasonal and episodic migration patterns they also provide a good indicator of connectivity between the MWS and the freshwater river systems to the north and northwest.

3.4.2.5 Small Mammals Indicators

Tree-roosting small mammals, particularly Chiroptera (Bats), are valuable indicators of the structural integrity of woodland habitats. As argued by Fenton *et al*. (1998), this includes several species of rodents (e.g *Graphirius murinus, Thallomys paedulcus* and *T. nigricauda*) and treeroosting bats, including Scotophilus. The relative abundance of these species appears to reflect directly on the availability of suitable cathedral woodlands (Acacia, Mopane and Mopane) to provide daylight domiciles. The Climbing mice (*Dendromys spp*.) provide an analogous suite of indicator species, because these tiny rodents require tall grasslands (thatching grass) in which to build their nests. Sampling and identification of these species does, however, require skill and considerable expertise, and specific equipment.

3.4.2.6 GIS and Remote Sensing Indicators

Remote sensing now has the potential to produce environmental classifications and detect characteristics of ecosystem change. There are, however, several things environmental managers need to know for a practical understanding of the scope and potential of remote sensing, before placing true confidence in its abilities to monitor indicators, e.g. What exactly does the information from a particular satellite sensor represent? How can this information be translated into a useful indicator? and what conditions affect this accuracy?

The Secretariat of the Convention on Biological Diversity, NASA-NGO Biodiversity Working Group, and the World Conservation Monitoring Centre of the United Nations Environment Programme conducted an in depth review on the overall role that remote sensing can play for developing and monitoring biodiversity indicators relevant to various strategic components of the Convention on Biological Diversity (CBD) in an attempt to identify specific, relevant uses of remote sensing data for biodiversity monitoring and indicator development (Strand *et al*., 2007).

They identified indicators based on the list identified for immediate testing (Table 11) and found that remote sensing data makes a strong contribution to six of the areas of interest identified by the CBD: (1) trends in extent of selected biomes, ecosystems and habitats; (2) coverage of protected areas; (3) threats to biodiversity; (4) connectivity or fragmentation of ecosystems; (5) trends in populations of selected species; and (6) potential human development indicators. In addition, trends in environmental conditions associated with biodiversity; phenomena such as surface air and water temperatures, and others can be measured successfully via satellite, e.g. UNEP's Atlas of Our Changing Environment (UNEP, 2005).

Table 11. Provisional Indicators for Assessing Progress towards the 2010 Biodiversity Target, relevant to the MFMP area

Focal area	**Headline Indicators**
Status and trends of the components of biological diversity	* Trends in extent of selected biomes, ecosystems, and habitats * Trends in abundance and distribution of selected species Coverage of protected areas * Change in status of threatened species Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance
Sustainable Use	Area of forest, agricultural and aquaculture ecosystems under sustainable management Proportion of products derived from sustainable sources * Ecological footprint and related concepts
Threats to Biodiversity	* Trends in invasive alien species
Ecosystem integrity and ecosystem goods and services	Marine Trophic Index * Water quality of freshwater ecosystems Trophic integrity of other ecosystems * Connectivity / fragmentation of ecosystems Incidence of human-induced ecosystem failure Health and well-being of communities who depend directly on local ecosystem goods and services Biodiversity for food and medicine
Status of traditional knowledge, innovations and Practices	Status and trends of linguistic diversity and numbers of speakers of indigenous languages Other indicator of the status of indigenous and traditional knowledge
Status of resource transfers	Official development assistance provided in support of the Convention Indicator of technology transfer

Source: CBD Decision VIII/15. Indicators considered ready for immediate testing and use (green), and indicators confirmed as requiring more work (red). Where remote sensing can make on important contribution to monitoring indicators, they are marked with a star (Strand *et al*, 2007).

Remotely sensed images from the raw inputs, from which indicators can be constructed. For example, the signal to remote sensors can be associated with a particular vegetation cover type (such as forests). Data manipulation within a GIS environment can then help produce the maps and statistics needed to create an indicator that can be understood by decision makers and the general public. An example of a simple indicator for biodiversity created from remote sensing data might be "area of x land cover (as a surrogate for habitat) over time."

A complex indicator is composed of multiple variables, e.g. Sanderson et al.'s State of the Wild (2002) assessment demonstrated how to combine global data sets on human population density, land transformation (derived from remote sensing), accessibility (distance from major roads, rivers, and coastlines), and electrical power infrastructure to create an index of human influence on land and to map relative wildness (or intactness) at one-kilometre resolution.

Other examples of successful RS monitoring programmes include NOAA-AVHRR remote sensing data, compiled for UNEP's Global Desertification Atlas, used for effectively collecting data on catchment characteristics in semi-arid Africa (www.yale.edu/ceo/Documentation/africa_metadata.pdf), and the first two phases of the South African National Land Cover 2000 project, in which seasonal Landsat 7 ETM satellite images were analysed with remote sensing and GIS software, identified ca 40 categories of land cover and vegetation, with changes in surface water availability and vegetation responses recognised using seasonal comparative analyses.

By collaborating with existing expertise in southern Africa, remote sensing can be enhanced as a tool for addressing sustainable water use and resource management issues in the MWS. The authors of the Hydro(geo)logy specialist report and the Vegetation map conducted for this FMP has already clearly demonstrated the exciting potential for the use of remote sensing techniques to assess cheap satellite imagery in the development of rapid 'from your desk' assessments of indicators of change. He has already identified indicators of, changes in its habitats, and the potential to identify changes occurring in its biodiversity and ecosystem functions. Examples include:

- the physical characteristics of the system: the surface pan hydrology, its extent and dynamics, using Daily MODIS satellite images;
- the ecological condition and status of certain habitat types, e.g. 'wetspots' of pronounced surface water flooding and riparian woodland habitat, using Landsat imagery to build an historical assessment of past trends and current state;
- key ecological functions; again the presence of surface water on the pan and at the wetspots, and groundwater recharge seepage points at groundwater interface points around the pan, and;
- the vegetation mapping exercise highlighted the potential for using Landsat images, in an EVI analysis to assess rangeland condition and response to degradation by fire and cattle.

3.4.3 Capacity & stakeholder participation

To undertake a comprehensive monitoring program there needs to be an institutional framework to support and deliver it. The number of sites that will require monitoring will determine the man power and resources that are required. The capacity for delivering the monitoring program should be present in the government department whose remit it is to regulate, for example, water, rangeland and forestry, and wildlife; in this instance the monitoring team would be structured and resourced by, respectively, the Department of Water Affairs, (DWA), the Department of Forestry and Rangeland Resources, and the Department of Wildlife and National Parks (DWNP).

Delivering the monitoring program through a government body will ensure: Monitoring is regulated; Resources are made available and work is acknowledged to deliver government policy; Monitoring has no bias; Data is centrally collected; National monitoring programs are developed by the same institution, and; Data can be utilized in policy decision making. The process of capacity building needs to be an iterative process between the government and appointed consultants if so required. The government needs to be fully involved in how the process is going to operate and be an active part of decision making.

A number of studies have recognised the value of local participation in monitoring programmes, for example, pastoral knowledge in assessing land degradation and desertification (Reed et al., 2006). Local communities who are affected by land degradation, particularly rangeland degradation, rarely participate in science-led 'top-down' approaches to land and/or resource monitoring and management. While, it is clear that management decisions cannot be made on the basis of unverified local assumptions alone, there is a need to integrate and harness knowledge from within and between scientific and local knowledge bases, so that communities are able to fully realise their capacity to participate in their resource monitoring and adapt to the challenges (Reed et al., 2006).

The resultant 'hybrid knowledges' and capacity (including local indigenous knowledge) should allow scientists, local stakeholders and their different understandings to interact to produce useful and more effective land use management practices, including monitoring. This strategy could be adopted and developed further in the MWS, to optimise rangeland monitoring using widely agreed indicators, such as the grasses above and bush encroaching species like Moselesele and *Acacia mellifera*.

As far as possible, monitoring should also involve the local community and other stakeholders in collecting data. As well as considerations of expense and sustainability, there may be several good reasons for this: Sharing responsibility; Building and validating participation in management and a sense of ownership; Building trust; Providing a means for feedback and encouragement; and Creating new skills. Strategy 3 of the draft Wetlands Policy and Strategy (Anonymous, 2001), for example encourages active participation of civil society in wetland resource management, including its monitoring. Indicators of ecosystem functioning and sustainable use should also be developed with communities so that they incorporate any relevant indigenous knowledge and to encourage active participation in monitoring, which is, therefore, more likely to happen at a local, de-centralised scale (Smith and Maltby, 2003). Rapid monitoring and assessment techniques would greatly facilitate this participation from local communities and civil society. Examples of such participatory monitoring exist elsewhere.

The Event Book System, a grass-roots monitoring programme adopted by 30 communal conservancies in Namibia, provides a good model that can be adapted and applied in this context (Stuart-Hill *et al*., 2005). While it was developed primarily to enable communities to share information, data can be aggregated across communities to feed into a basin level or national monitoring database for use in management decision-making. However, it is driven predominantly by the priorities of the community and comprehensive assessment of ecological character is, therefore, not necessarily adequately provided.

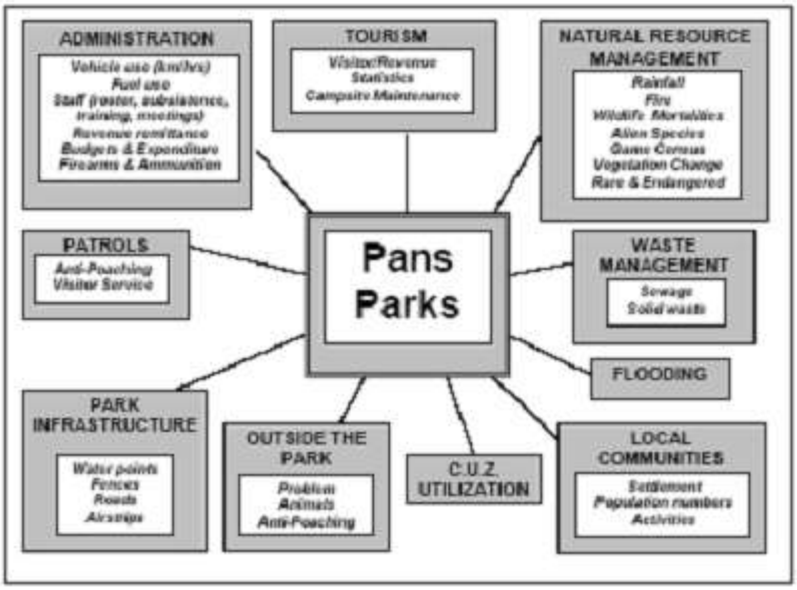
The challenge is to find ways to combine community and scientific monitoring, and provide incentives for community involvement therein. For example, interests such as bird-watching associations may raise funds for training communities in data collection methods and to participate in rapid assessment procedures, using indicator or 'trigger' bird species. Birdlife Botswana is currently actively involved in training community members from CBOs and other tourism initiatives around the MWS on how to participate in, and contribute to bird monitoring, through their GEF funded PSPA project (Birdlife Botswana).

The Department of Water Affairs are required to plan and implement water conservation activities through joint efforts and in partnership with other relevant agencies and stakeholders, including communities groups and individuals (Anonymous, 2004). The idea is that focal persons in cities, towns, districts and in important commercial and industrial establishments throughout Botswana be identified to participate in the collection of national water resources. Where necessary, additional staff; water conservation officers may be required at some stations and offices of water supply authorities to facilitate information exchange and co-ordination. Information from this collaboration would then be made available to the DEA for use in updating the National Water Accounts, for example, or to facilitate future reviews on water use projections.

The Management Oriented Monitoring System (MOMS) was introduced to DWNP in 2003 and adopted in 2004 as an appropriate means for monitoring, recording, reporting and archiving management activities in Protected Areas as well as in CHAs and WMAs. The idea is that monitoring can be, effectively, undertaken by field staff in the course of their management duties. To this end the MOMS attempts to facilitate long-term monitoring of biodiversity and the condition of the ecosystem in protected areas such as the MPNPNP or 'Pans Park'. Where required or when impact 'flags' have been identified by such monitoring, more detailed or sophisticated research and monitoring will be designed and introduced in response to concerns identified. If the required expertise is not available within DWNP, assistance will be sought from outside.

The start up phase of MOMS comprised the development of a "mind map", shown below (Figure 22), which established management objectives and activities in the "Pans Park".

Figure 22. A 'Mind Map' of the Management Objectives on which the Pans Parks DWNP MOMs programme was based.



Examples of specific monitoring targets identified by the MOMs programme in the MPNP include:

a) Analysis of tree damage and a comparison of dry season grass cover;

b) Studies of impacts of the fence on migrating species and carnivores;
c) Surveys of community opinion in relation to the fence;
Management strategies should then be modified in relation to the outcome of these monitoring objectives.

From the MOMS mind map and management objectives, monitoring systems have been designed for the following subjects to support management activities within the Parks: Staff (planning and activities etc), Visitor service, Visitor statistics, Vehicle use, Fences, Roads, Soil/erosion, Water points (supply and pump status), Rainfall, Fire, Wildlife sightings on patrol (sighting success), Wildlife mortalities, Rare and endangered species, Vegetation status, Alien species, Wildlife-human conflict incidents, and Illegal activities.

In addition, research and monitoring was to be encouraged and facilitated in relation to the following priority topics: the large herbivore migration; human-wildlife conflict (lions and elephants); fence-related impacts and changes on soil erosion, vegetation and herbivores; water points/boreholes; water quality; impacts of elephant on vegetation/biodiversity; rare and endangered species; fire incidence and locations (mapping), and vegetation types (mapping) and changes.

Emphasis in this programme is placed on the fact that management activities will be adaptive by design and objective according to the outcome of research and monitoring. This programme should, therefore, be updated to include additional indicators identified in the monitoring framework above and focus should be given to the biodiversity hotspots in 2.2, above. In addition, capacity levels among the management staff should be assessed and augmented through training, where required, in order to ensure effective implementation of MOMs. Also, partnerships between DWNP and NGO’s could help improve the resource and capacity required to carry out MOMs in protected areas. Birdlife Botswana, for example, is currently conducting a project to enhance partnerships to improve protected area monitoring and management, and improved monitoring in the MWS is one of their target objectives.

3.4.4 Conclusions

- Where unacceptable change to the ecological character of a wetland occurs, identified by a negative impact on the related indicator/s, the local management authority, e.g. DEA / DWNP / DWA, local communities, and private institutions should intervene to correct those negative impacts through interactive, flexible and feasible management interventions/mitigation methods;
- Table 10 (above) outlines a comprehensive monitoring framework with appropriate performance indicators that will ensure effective adaptive management;
- Birds are valuable bio-indicators of ecosystem functioning and integrity and the success of key ‘trigger’ species, particularly when breeding, can prove very useful in monitoring programmes. The Lesser Flamingo has been identified by Birdlife Botswana as the trigger species for monitoring the integrity of the MWS - Flamingo breeding success is a good indicator of hydrological variability and vice versa, and indicates a balanced ecosystem;
- Other indicators identify changes to the hydrological regime, pollution and other anthropogenic impacts that threaten the system and it biodiversity and bio-indicators can be used to provide ‘tools’ in rapid assessment monitoring techniques. Changes in water chemistry as a result, for example, of brine extraction and effluent disposal on the pan surface could be detected using the community of crustacean that exists in the lake waters;

- A reduction in sweet perennial grass species and an increase in species associated with bush encroachment like *Acacia mellifera* and *Dicrastachys cineria* are good indicators of rangeland degradation.
- Remote sensing also has the potential to detect characteristics of ecosystem change, e.g. free MODIS satellite images.

Gaps in our knowledge

- Indicators familiar with and identified by local communities and indigenous knowledge;
- Thresholds for specific rapid assessment indicators, i.e. defining thresholds to identify unacceptable impacts from a pressure or stress to a species or community, e.g. invertebrate or algae community change threshold to pollutants;
- Links between key ecosystem state indicators (e.g. Zebra, flamingo) and sustainable development/ecosystem level change needs to be clarified;
- Indicators of social and biological vulnerability to climate change;
- Biodiversity hotspot specific indicators of state and impact;

3.4.5 Follow on work

- Indicators identified above need to be cross-checked with local communities and indigenous knowledge to identify their use potential at a local level and identify other suitable indicators identified by this process;
- Further research on specific rapid assessment indicators, e.g. invertebrate community and algae is required to build on their potential for use in various rapid assessment techniques, e.g. defining thresholds to identify unacceptable impact;
- Further development and use of key ecosystem state (e.g. Zebra, flamingo) and sustainable development indicators to facilitate adaptive management, e.g. bio-indicators and remote sensing indicators, and using indigenous knowledge;
- Development and use of indicators of social and biological vulnerability to climate change need to be developed;
- Develop indicators for the biodiversity hotspots so as to improve the monitoring of these key biodiversity reference sites;
- Expand and improve monitoring of conflicts and their socio and biological impacts, including conflict mitigation response monitoring.

3.5 Rangeland Ecology (see also chapter 11 for more details)

3.5.1 Major findings

3.5.1.1 Dominant vegetation types

The MFMP vegetation map captures the broad differences in vegetation types that occur within Makgadikgadi Pan National Park (Figure 23), although it is necessarily coarse due to the rapid juxtaposition of different plant communities over short distances (100-200 m). This is particularly the case for the shrub and tree savanna areas, where the dominant species can often be identified but the composition of the community itself is highly variable.

Figure 23. Broad (6-class) vegetation map of the MFMP area.

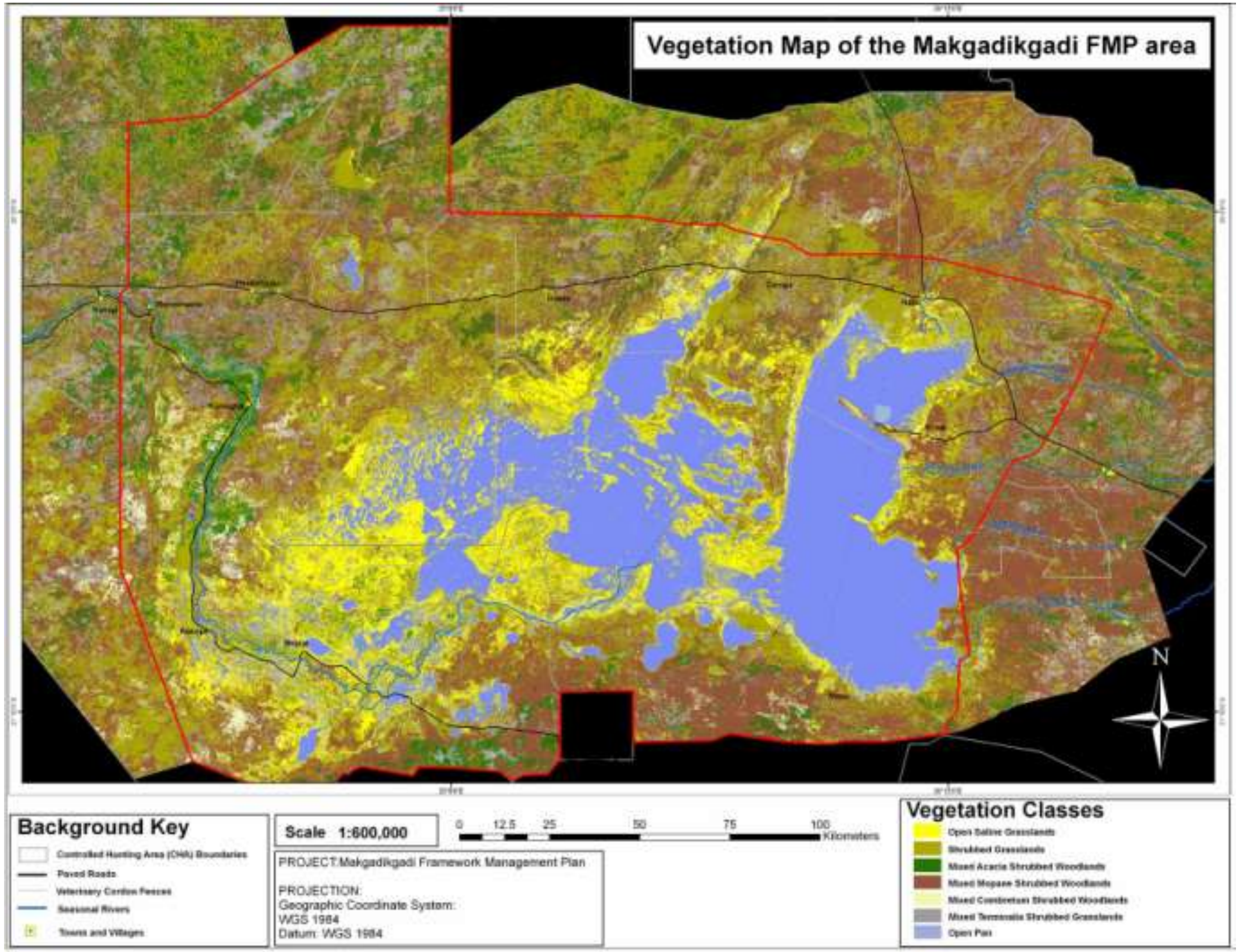


Table 12 lists these vegetation types, together with the equivalent physiographical land system units, on which they occur and a list of herbaceous (grass) and tree species found in each vegetation type. Saline grasslands are relatively species poor and dominated by few grass species, with small numbers of *Acacia tortilis, Hyphaene anthelminthica* and *Commiphora Africana*. These grasslands typify the landscape of the Makgadikgadi National park and elsewhere around the fringes of the Makgadikgadi salt pans.

Table 12. Vegetation classification for the MFMP area.

Vegetation Type	Landscape system Units	Predominant Species	
		Grasses	Trees
1. Saline Grassland	• Bare open salt pan • Scattered small salt pans • Low scattered Sand dunes	*Odyssea paucinervis* *Sporobolus africanus* *Sporobolus ioclados* *Sporobolus kentrophyllus* *Eragrostis echinochloidea* *Diplachne fusca* *Shueada (salt plant)*	*Acacia tortilis* *Commiphora Africana* *Hyphaene anthelminthica*
2. Shrubed Grassland	• Saline sands • Scattered small salt pans • River delta	*Odyssea paucinervis* *Sporobolus africanus* *Sporobolus ioclados* *Diplachne fusca* *Cenchrus ciliaris* *Eragrostis echinochloidea* *Eragrostis rigidior* *Digiteria eriantha* *Aristida congesta congesta* *Schmidtia pappophroides* *Stipagrostis uniplumis*	*Acacia tortilis* *Acacia mellifera* *Acacia erioloba* *Acacia hebiclada* *Terminalia sericea* *Grewia spp.* *Catophractes alexandri* *Acacia kirkii* *Commiphora Africana* *Commiphora pyrocanthoides*
3. Mixed Mopane	• Saline sands • Sand dunes • Old lake terraces (sand) • Deeper sandy soils over duripan • Low shallow clay/sand soils over calcrete	*Odyssea paucinervis* *Cenchrus ciliaris* *Stipagrostis hirtiguma* *Stipagrostis uniplumis* *Eragrostis echinochloidea* *Eragrostis trichophora* *Heteropogon contortus* *Eragrostis superba* *Cymbopogon plurinoides* *Panicum coloratum* *Aristidia congesta barbicollis* *Cenchrus ciliaris* *Enneapogon centroides*	*Colophospermum mopane* *Terminalia prunoides* *Acacia tortilis* *Acacia mellifera* *Acacia erioloba* *Combretum hereroense* *Combretum imberbe* *Grewia spp.* *Commiphora Africana* *Commiphora pyrocanthoides*
4. Mixed Acacia	• Main River distributaries (banks) • River Floodplain • Low-lying Fossil drainage	*Schmidtia kalahariensis* *Schmidtia pappophoroides* *Urochloa mossambicensis* *Stipagrostis uniplumis* *Digiteria eriantha* *Eragrostis rigidior* *Panicum coloratum* *Cynodont dactlyon* *Eragrostis trichophora*	*Acacia tortilis* *Acacia mellifera* *Acacia erioloba* *Acacia hebiclada* *Acacia kirkii* *Colophospermum mopane* *Terminalia prunoides* *Combretum hereroense* *Grewia spp.*
5. Mixed	• Low shallow lacustrine	*Cenchrus ciliaris*	*Combretum imberbe*

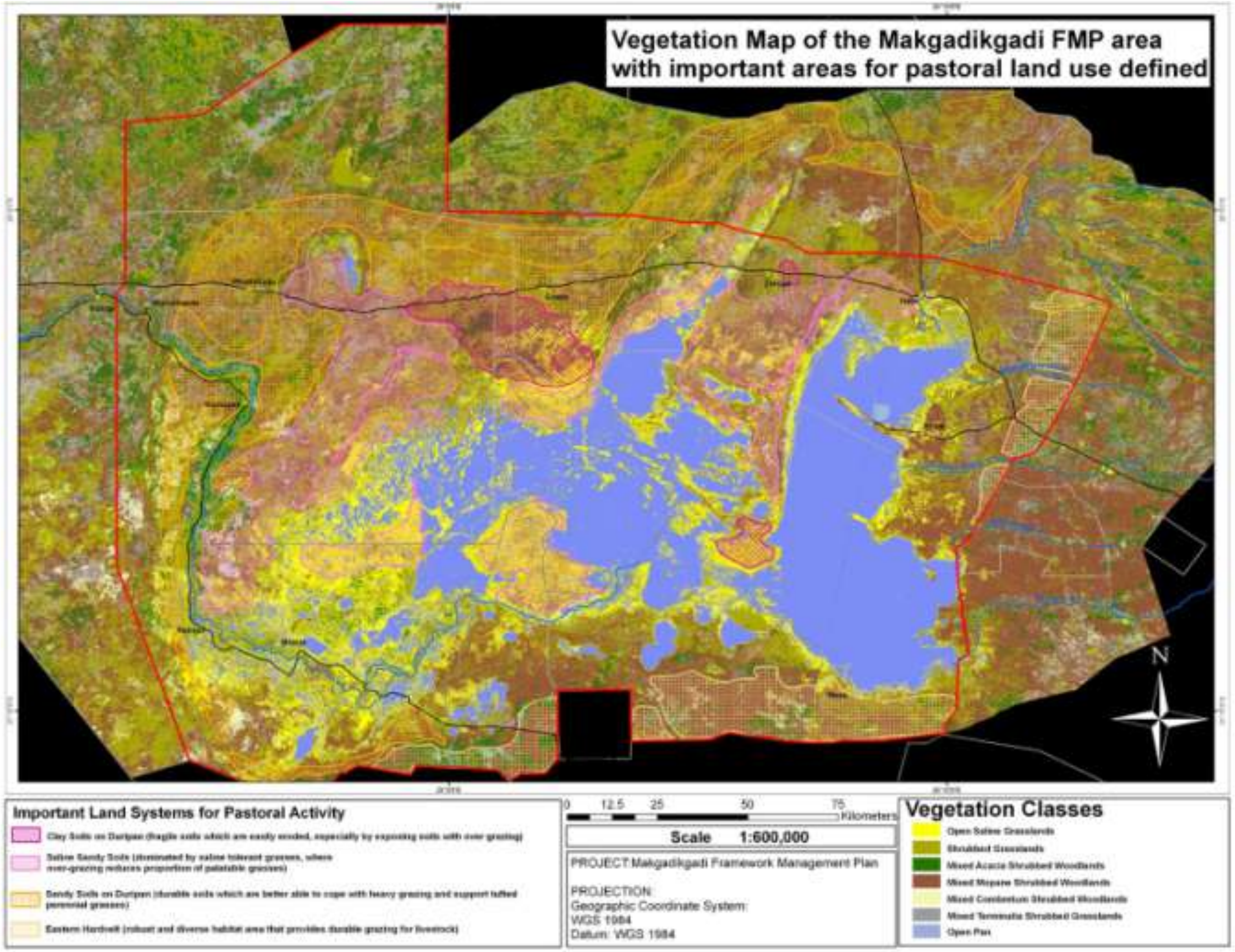
Combretum	soils over calcrete • Scattered small pans • Fossil Drainage lines	*Eragrostis echinochloidea* *Eragrostis trichophora* *Eragrostis rigidior* *Stipagrostis uniplumis* *Stipagrostis hirtiguma* *Schmidtia pappophoroides* *Digiteria eriantha*	*Combretum hereroense* *Colophospermum mopane* *Terminalia prunoides* *Acacia tortilis* *Commiphora pyrocanthoides* *Catophractes alexandri*
6. Mixed Terminalia	• Old lake terraces (sand) • Deeper sandy soils over duripan	*Cenchrus ciliaris* *Cynodont dactlyon* *Eragrostis trichophora* *Eragrostis rigidior* *Stipagrostis uniplumis* *Aristidia congesta barbicollis* *Enneapogon centroides* *Panicum coloratum* *Schmidtia pappophoroides* *Digiteria eriantha*	*Terminalia prunoides* *Terminalia sericea* *Colophospermum mopane* *Acacia tortilis* *Acacia mellifera* *Combretum hereroense* *Commiphora pyrocanthoides* *Grewia spp.*

Within the context of these broad vegetation classifications, a number of key vegetation types can be further defined, according to variations in the dominant vegetative species assemblages within them. For example, the DHV report (1980) identified the following vegetation types:-

- *Odyssea – Sporobolus spicatus* short grasslands, Dominating species: *Odyssea paucinervis, Sporobolus spicatus, S.smutsii, Panicum sp., Cymbogon sp.* On alkaline calcareous fine sands In Makgadikgadi lacustrine plain and some pan slopes;
- *Sporobolus spicatus – acinifolius* short grasslands, Dominating species: *Sporobolus acinifolius, S.spicatus, Panicum sp*. On saline and non-saline calcareous, fine sands associated with small pans within Makgadikgadi lacustrine terrace;
- *Hyphaene* palm tree savanna, Dominating species: *Hyphaene benguellensis, Acacia arenaria, Catophractes alexandrii.* On lacustrine terraces of Makgadikgadi Pans Game Reserve;
- *Digitaria-Antephora* grasslands, Dominating species: *Digitaria spp., Eragrostis pallens, Antephora pubescens, Eragrostis lehmanniana, Schmidtia pappophoroides*. Higher parts of lacustrine terrace of Makgadikgadi Pans Game Reserve;
- *Lonchocarpus-Terminalia* broad-leaved bushlands to savannas. Dominating species: *Lonchocarpus nelsii, Terminalia sericea, Bauhinia petersiana, Dichrostachys cinerea.* On Central Kalahari sandveld plains, especially in northern-central Kalahari. Higher parts of Makgadikgadi lacustrine terraces.

The underlying geomorphology and soil structure are important drivers of habitat type and it is important to consider the geophysical land system units as well, in order to understand the nature and characteristics of the vegetation type in the MWS. Vegetation types associated with the landscape units were also described in the DHV report (1980). Using the land systems and their sub-units, identified in the ecosystems functions section of this report, we can define habitat suitability and sensitivity to degradation based on their underlying soil and geomorphology and their associated ecological constraints. Four main land systems are thus identified and represent varying suitability to grazing pressure (Figure 24):

Figure 24. Vegetation map of the MFMP area overlain with the main habitat land systems to determine grazing sensitivity.



1. Makgadikgadi Clay soils on old palaeolake floor Duripan – these are shallow clay rich soils underlain by calcrete or silicrete layers, on the old palaeolake floors, particularly north of Ntwetwe pan e.g. area south of Gweta. Overgrazing here leads to reduction in cover, erosion of the hard soil crust and exposure to wind erosion;
2. Saline sandy soils– these are saline sandy soils around the perimeter of the contemporary pans that are seasonally nutrient rich and productive, where year round overgrazing leads to a reduction in the proportion of palatable perennial grasses and an overall carrying capacity reduction;
3. Saline sandy soils on palaeolake duripan - these are shallow sandy soils over calcrete or silcrete duripan, where the soils are more durable to heavy livestock grazing and that support tufted perennial grasses, and;
4. Eastern hardveld on sandy and shallow clay duripan – this is a robust and diverse habitat that provides sufficient woody cover to prevent wind erosion and is more durable to livestock grazing.

3.5.1.2 Forage value and recommended stocking rates

The entire Makgadikgadi region, with minor exceptions in the north and south, is poorly suited to cattle. The halophytic (salt-tolerant) grass *Odyssea* dominates the pan margins (i.e. within 4kms or so of the pan edge), but can be dangerous to cattle due to its high salt content. The fine silt-clay soils often on calcretes makes it one of the most erodible environments (by wind) in Botswana. For example, in the 1980's drought dust storms enveloped the area for up to 8 months of the year.

One of the earliest known estimates of carrying capacity for pan grasslands and margins by Blair-Rains and Mackay (1968) was 16.5 ha/LSU. Field (1977) placed the 300-400mm/yr annual rainfall zone within the 16ha/LSU range, with the area to the north, and including Nxai Pan, slightly higher at 12ha/LSU, and since then, there has been a striking convergence of independently made carrying capacity estimations for the area since then between 16 – 16.5 ha/LSU. Ministry of Agriculture carrying capacity map shows the carrying capacity of the Pan grasslands to be 2-4 ha/LSU. This figure may be achieved for short periods during the wet season, when there is standing (fresh) water after rains, but would not be sustainable on a permanent basis, and creates a misleading impression of the areas potential to carry domestic stock.

Murray, (1988) attributes a low Large Herbivore Biomass (LHB) in the Kalahari to that expected owing to two factors:-

(i) Extreme variability in rainfall, with large herbivore populations adapted to the utilisation of low primary production, and excess production being removed by fire, and;
(ii) A high proportion of the total biomass occurring in the rodentivore and insectivore communities and their prey populations, with termites (*Hodotermes sp.*) particularly significant in both their contribution to total animal biomass, and in plant material removed.

In contrast to a Large Herbivore Biomass (LHB) of 400 kg/km^2 found in the Kalahari system, the DHV (1980) report identified a biomass of 6 000 kg/km^2 for the Makgadikgadi population of zebra and wildebeest, which is equivalent to a stocking rate of about 8 ha/LSU (DHV, 1980). The availability of surface water all year round, with the seasonal migration from the Boteti (dry season range) and pools (wet season range), were identified as providing a boost to grazing animals.

A combined factor called 'edible forage' is typically deducted from the herbaceous peak standing crop to account for grazing efficiency, forage loss and a 'proper use factor' to account for sustainability. Access to forage for water dependent herbivores is limited by the availability of surface water, leading to many farmers' desire to increase borehole/well density. A common assumption in dryland ecology is that the peak standing crop at the end of a long rainy season represents the potential amount of forage for the long dry season, of which less than half is available as forage for large grazing herbivores. Forage availability in the long dry season in a dry year limits the maximum number of cattle that can be kept, and it is this dry season forage that is depleted if borehole densities become too high. The key to sustainability in the Makgadikgadi is, therefore, mobility, not at a ranch paddock scale, but a regional one, that enables the primary production that follows highly stochastic rainfall and fire events to be effectively utilized (DHV, 1980).

The migratory strategy of wildlife (Sinclair, 1979; McNaughton, 1985) and, that of pastoralists (Western, 1975, 1982, 1986; Homewood and Rodgers, 1987) is well documented as being capable of sustaining much larger populations on semi-arid savannas than is possible under year round residence (Jewell and Nicholson, 1989). Nicholson (1986) describes a three day watering system by the *Borana* that results in no loss of animal productivity but enables distant pastures to be reached, by breaking the daily watering cycle. Sedentarisation of both domestic and wild ungulates will therefore markedly reduce the carrying capacity of the ecosystem and risk range degradation.

3.5.1.3 Browse

Trees and shrubs survive harsh climatic conditions such as drought and are an important source of browse feed in the arid and semi-arid savannas of Africa. However, although tree leaves have high protein content, tannins and other secondary compounds may bind this protein, thus rendering it unavailable to the animal. Indeed, tannins and related polyphenolics may have negative effects on palatability and digestibility, and many are also poisonous. Increasing browse cannot therefore be viewed as a simple substitute for declining grass cover. Certainly in grazing areas browse can provide feed in dry seasons to cattle and other domestic stock when the grasses have a low nutritional value, or have all but disappeared. Along the Boteti *Acacia erioloba* pods, dry *Terminalia* leaves and browse were found in the dung deposits of wildebeest (DHV, 1980) suggesting the protein boost provided by such browse when graze values are low or negligible, may be critical.

3.5.1.4 Groundwater access

Access to forage is dependent upon available water, and therefore, deep borehole provision. In general there is a gradient of decreasing salinity as one moves outwards from the Pans into the surrounding savanna, with groundwater conditions changing from poor to fair.

As Blair Rains and Mckay (1968) point out, perched fresh water is an anomaly within what is otherwise a sea of salinity in terms of the groundwater resource. It has, however, enabled small cattleposts to occupy the area, albeit at little more than subsistence level. Livestock use of the area is therefore more an artefact of the available high water table than a function of the available grazing, which after good rains can be of high biomass, but consistently poor quality. Blair Rains and McKay (1968) also point out that "*The exploitation of groundwater appears to have often been on an ad hoc basis; little attention has been given to questions of 'carrying capacity' of the surrounding area and the ability to ensure stock limitations. Making water available so that livestock can be kept in an area on a year-round basis, where previously there was only restricted seasonal grazing by wild ungulates, introduces into the system an entirely new factor with far reaching consequences...... the provision of water in communally-held semi-arid grazing land has invariably resulted in a serious deterioration of the vegetation of the surrounding area in a relatively short time.' (p.49).*

Blair Rains and McKay (1968) also make the point that, *'Ideally cattle should not have to walk more than two miles to and from water; an area of 1mile radius is 800 ha and cannot safely carry more than 100 head of stock. Animals should certainly not walk more than a total distance of 5 or 6 miles*

(8 or 10 km) a day for water. Thus if we allow for a radius of 4 km and a grazing area of 5 059 ha then with a carrying capacity of 1 animal per 12 ha, the number at each borehole should not exceed 400 adult equivalents or a 500 head herd; because it is normally impossible to ensure that the more distant areas are fully grazed, lower figures than these may be recommended. Watering should be limited to every second day if it is necessary for steers and dry cows to walk more than 5 or 6 miles' (p.53).

3.5.1.5 Range degradation

Almost every livestock related study conducted over the past forty years has pointed to the ecological deterioration of the rangeland resource as a direct consequence of keeping excessive numbers of domestic stock. It is a contention that has received substantial support from a number of environmental studies and observations (for example, Campbell and Child, 1971; van Rensburg, 1971; van Vegten, 1981, 1983; Cooke, 1978, 1983, 1985; Carl Bro, 1982; Cooke and Silitishena, 1986; Skarpe, 1983, 1986abc, 1990ab; Arntzen and Veenendaal, 1986; Veenendaal and Opschoor, 1985; MOA, 1995), including also the analysis of satellite imagery (Ringrose *et al.,* 1990ab, 1996a).

All the above mentioned studies cite environmental criteria that Abel and Blaikie (1989) term as the 'conventional view' of range degradation, which are narrowed down to the following criteria:-

(i) decreases in palatable and nutritious plant species ('sweet' grasses), and increases in unpalatable and non-nutritious ones ('sour' grasses);
(ii) decreases in perennial grasses, and increases in annuals;
(iii) shrub/bush encroachment;
(iv) changes in soil structure - in particular those affecting available water capacity;
(v) soil erosion - the loss of mineral particles, organic matter and nutrients;
(vi) decline in the primary and secondary productivity of rangeland.
(from Abel and Blaikie, 1989; p.102).

It should be emphasised that the certainty that range degradation is occurring rests primarily on factors (i)-(iii), for which there is considerable evidence in Makgadikgadi. Indeed, compositional changes in density and cover as the herbaceous layer shifts from sweet to sour grasses is already evident, together with an increasing dominance of weeds. Bush encroachment has affected large tracts of rangeland in and around Makgadikgadi, particularly around waterpoints or piospheres and along the Boteti River.

The piosphere effect dictates that impacts are greatest at the waterpoint itself and decrease rapidly with increasing distance into the surrounding rangeland (Lange, 1969; Andrew, 1988). Regular patterns of impact therefore emerge over time, and are spatially manifested as distinct zones, which surround each borehole and differ significantly in both vegetation composition and structure (Perkins and Thomas, 1993ab).

Three zones are widely recognised as the:-

(i) bare ground area or 'sacrifice zone' (Stoddart *et al.,* 1975), typically of (0-400m) extent around the borehole, where concentrated trampling and grazing has resulted in the loss of all vegetation cover.
(ii) bush encroached zone, typically (400m – 2000m) around the borehole where bush cover exceeds 45 per cent, often forming impenetrable thickets.
(iii) grazing reserve, beyond 2000m from the borehole where the typical tufted perennial grasses of the Kalahari dominate.

Vegetation cover after very large rainfall events or following exceptionally wet rainfall periods provide a good indication of the extent of past grazing effects. Indeed, if recovery from grazing does not occur under these exceptional conditions, it is likely to be slow or non-existent in future years under more typical rainfall conditions. Consequently, in the early 1980s drought it was the lack of grazing around water at Mopipi that resulted in over ninety per cent wildebeest mortality, rather than the lack of surface water – wildebeest reportedly had to incur a round trip of 100kms in order to reach water and forage.

The expansion of the livestock industry has to a very large extent depended upon the exploitation of underground water by means of boreholes. In the Makgadikgadi, the availability of surface water has resulted in a pattern of cattle density around fixed watering points in the dry season and a dispersal in the wet season when access to foraging is enhanced by surface water in pans (Figure 25).

Adverse impacts can be minimised by proper planning and clustering of human activities and spheres. Properly managed rangelands may even serve as a surrogate for wilderness in regions where large blocks of protected areas do not exist. The key to their integrity is the restriction and control of access to humans, namely by limiting the number of tracks and roads, and the maintenance of mobility to wildlife, by keeping such areas open and unfenced. This is particularly important in remote areas that are not protected.

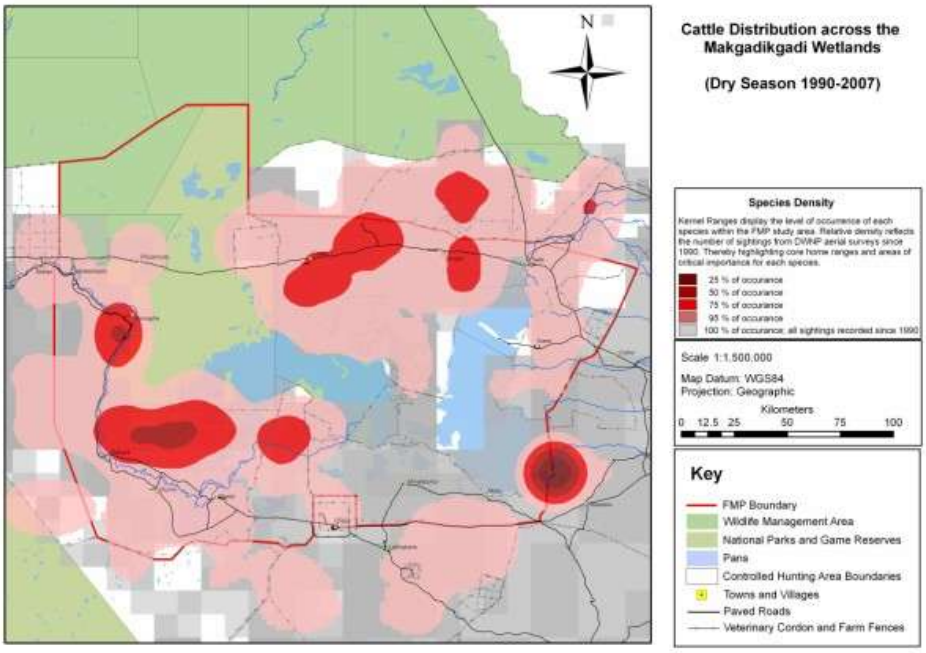
The rangelands around Rakops are widely regarded as degraded (Blair Rains and Mckay, 1968; Arntzen et al, 1993) with most studies emphasising the need for reduced stocking rates to allow for recovery of the pastures. The fine lake bed soils are easily picked up by the wind, with the ecosystem best suited to utilisation by large mobile herds of ungulates that grazed the system intensively in the dry season (when the floods arrived) and dispersed into the Kalahari (particularly the Schwelle) in the wet season.

Permanent grazing by domestic stock on Lake Xau and the former lake bed around Rakops has therefore radically changed the way in the ecosystem functions and has resulted in a markedly reduced animal biomass and pronounced range degradation (especially soil erosion), and an inter-related loss of livelihood and income generating activities. Blair Rains and Mckay (1968) emphasise that a large area north-east of Rakops has been reduced to a very sparse cover of the hard leaved rhizomatous grass *Odyssea paucinervis*, and near Rakops itself *Solanum incanum* is widespread. *Pechuel-loeschea leubnitziae* (Mokodi) or wild sage is common on disturbed areas, particularly road side verges.

As a consequence of this change, large areas of rangeland have become bush encroached and almost impenetrable by vehicle, and while the former lake beds (at Lake Xau and Rakops) remain open grasslands, permanent grazing results in severe dust storms for much of the year. The banks of the Boteti River are heavily grazed by livestock, the surrounding pastures bush encroached with *Acacia mellifera* and *Dichrostachys cinerea,* and while after good rains the herbaceous layer appears to have recovered, closer inspection reveals that the cover is dominated entirely by forbs (especially *Tribulus terrestris*). The tall *Acacia erioloba* and *Acacia nigrescens* and *Combretum imberbe* trees are still present, with livestock kraals situated under them and small lands areas adjacent to them, but it is impossible to reach the Boteti River due to impenetrable thorn bushes.

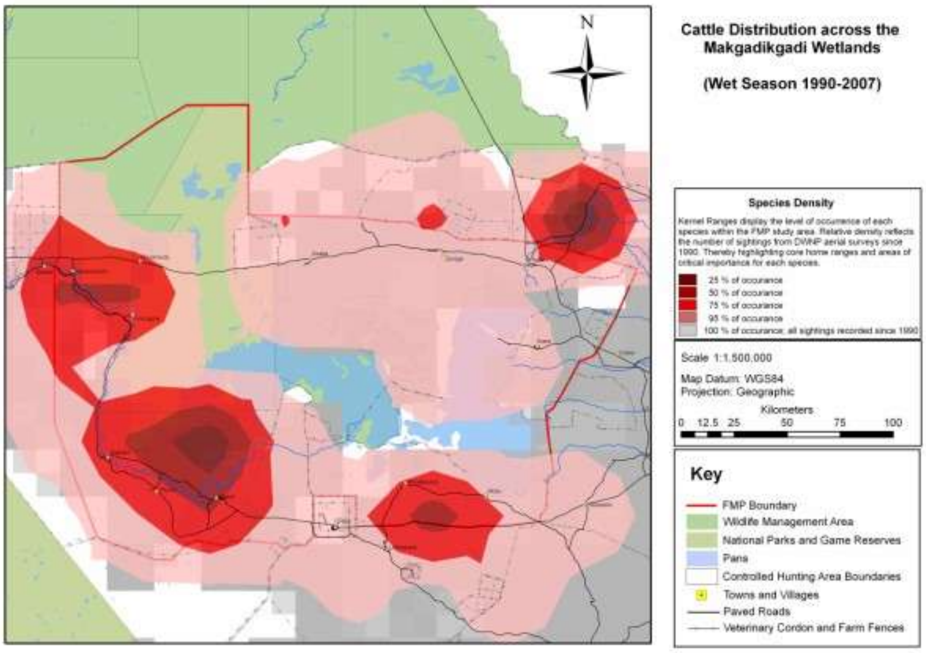
Figure 25. Cattle density and distribution within the Makgadikgadi wetland system.

i) Dry Season



Source: MFMP

ii) Wet Season



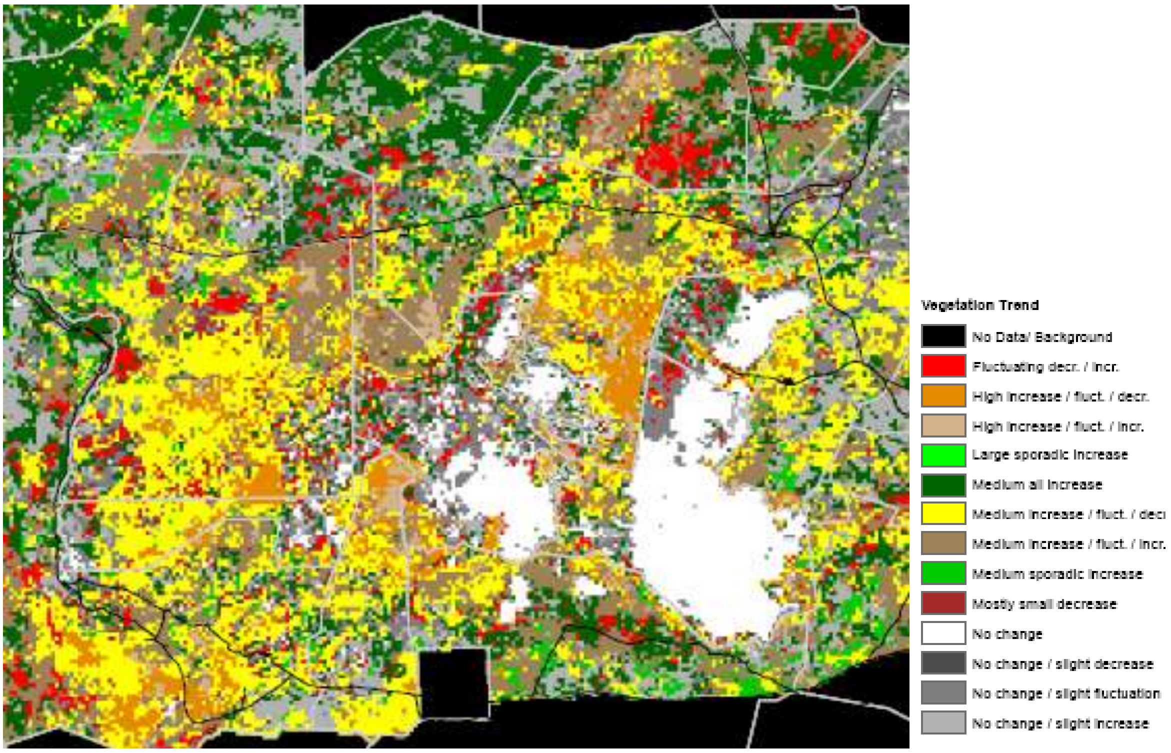
Source: MFMP.

The Enhanced Vegetation Index (EVI) Map of the vegetation recovery trend from 2002 – 2010 (Figure 26) highlights the extent of degradation, particularly around Rakops, Mopipi, west of the Boteti River and around Nata, where very little recovery in the vegetation cover (grey areas) has occurred since the drought period of 2002 owing to overgrazing and habitat degradation. There is also a striking resemblance to the areas of degradation and those with the highest densities of cattle in the dry season (Figure 25, above).

The EVI Map also shows the importance of the riparian zone along the Boteti River. The 2004 Fence is likely to lead to pronounced contrasts in the condition of the riparian zone. The primary effects of livestock grazing include the removal and trampling of vegetation, compaction of underlying soils, accelerated soil erosion and dispersal of exotic plant species. Zebra and wildebeest can also impact heavily upon the riparian zone, but the effect is seasonal (dry season only) with herds dispersing to the pans in the wet season. Livestock thus have a disproportionate effect on riparian areas because they tend to concentrate in them permanently due to the rich forage and close proximity to water. It seems likely that livestock impacts along the Boteti will become more pronounced and lead to increased bush encroachment and also bare ground. The NDVI will fluctuate with much of the greenness attributable to either thorn bushes or weeds. By contrast the riparian zones dominated by wildlife along much of the Boteti River are likely to rapidly accumulate herbaceous and woody biomass and become ravaged by fire – with pronounced changes to their structure and composition likely.

The cattleposts on the eastern, western and northern boundaries of the MNP have also resulted in pronounced bush encroachment, such that the area outside of the immediate waterpoint becomes almost impenetrable. The encroaching species varies widely depending upon the area but the aesthetics and productive value of the land, for livestock or wildlife is greatly reduced.

Figure 26. Enhanced Vegetation Index (EVI) Map of vegetation recovery trend 2002 – 2010



Source: MFMP project

3.5.1.6 Fire hazard within the MFMP area

Fire hazard is to a large degree the opposite of the dry season livestock distribution map (Figure 11) – whereby areas that are not grazed heavily by cattle will be prone to veld fires. This is especially the case within the Fenced boundary of the National Park – all along the Boteti River, but particularly in the north where the ungulates have been effectively excluded from the river bed by the alignment of the Fence. Indeed, with wildebeest and zebra populations are at such a low here, that the biomass that is not grazed along the riparian fringe and surrounding tree savanna will rapidly become a fire hazard – possibly driving the ungulates into the Game Proof fence, with high mortalities. Sefe *et al* (1997) found fire occurrence to be concentrated along the first 0-30kms south of Moreomaoto along the River, and then between 40-46kms. However, livestock encroachment into the Park no longer occurs such that biomass will undoubtedly build up rapidly and accumulate on the eastern side of the fence, resulting in severe fires driven from the east. Management will have to address this issue, through the strategic use of firebreaks, early dry season burns and strategic re-alignments of the fence itself. Otherwise fire will impact heavily upon the riparian zone and remove many of the trees that are undoubtedly over a century old.

Grassland areas within Makgadikgadi can also be expected to burn after good rainfall years, simply due to the low large herbivore biomass. Management should seek to break up the fuel load through early dry season burns, so that fire while not eradicated entirely, will burn the grasslands in a patchy manner, so producing a mosaic of habitats and forage. The accumulation of fuel all along the Game Proof Fence, and within its fenced corridor, is also a major concern that will need to be cleared or burnt in the early dry season, in order to avoid a fire hazard to the fence itself. This is shown on the vegetation trend map below (from FMP, 2010) which shows areas along the Boteti and southern boundary to have increased in biomass.

3.5.1.7 Water-point provision for wildlife

Along with the use of fire, culling and translocation, water provision remains one of the main intervention options available to managers of arid or semi-arid conservation areas supporting high densities of large herbivores (Owen-Smith, 1996). Smit and Grant (2009) clearly document how the scientific and management perception on artificial surface-water provision has swung like a pendulum from being the ‘solution’ to the conservation of the herbivore species in the Kruger National Park (KNP) to being the ‘cause’ of the System changes and associated herbivore problems.

Warning signs are already evident in the Makgadikgadi System that artificial water points are not addressing the key issues necessary for the conservation and restoration of the key ungulate species (cf Brooks and McCulloch, 2010). The idea that artificial water point provision can compensate for the loss of access to the Boteti River, also overlooks the fact that the past die-offs along the Boteti River have been caused by the combination of a lack of drinking water AND a lack of grazing around this water. In this respect the Boteti River bed and its banks were important for the floodplain and riparian forage resources that they offered, at a time of drought and/or the peak dry season. The provision of the surface water does not compensate for the lack of grazing.

Borehole provision in the Makgadikgadi should, therefore, mimic the natural system and so be placed along the river bed and pumped to reflect the natural cycle of water availability (i.e dry season pumping only along the Boteti River). Realisation of this management rationale will require strategic realignments of the Game Proof Fence – to open up more river bed and riparian grazing to wild ungulates. Permanent water provision runs the risk of increasing predator densities along the River and contributing further to declines of the key wild ungulate species (zebra and wildebeest). Indeed, the key is to maintain the mobility of wild ungulates and their access to key refuge areas.

The fact that semi-arid ecosystems managed for the mobility of their ungulate populations can support much higher populations, and carrying capacities, than more sedentary systems is well documented (Western, 1975; Sinclair and Fryxell, 1986). It applies to both livestock and wildlife populations.

Elephants had already started to move down to the waterpoints that were provided along the Boteti River before it started flowing again. They exact a heavy toll upon infrastructure and the riparian woodland and as the Boteti River appears to be entering a renewed cycle of increased flows again, the elephant population will be a new and powerful dimension to the ecological dynamics of the area. Flooding and elephant impact will undoubtedly damage the Game Proof fence along the Boteti, and in turn will compromise the livestock disease control function it has now come to perform. Indeed, it remains to be seen if the return of flows to the Boteti River will lead to a questioning of the sustainability of the current Policy of effectively isolating the communities on the western bank of the Boteti River from the wildlife resource, that offers the most realistic and immediate prospect of increasing their incomes and improving their livelihoods.

3.5.2 Development Options

The ad hoc manner in which livestock have expanded, on the basis of suitable groundwater, has compromised optimal land use planning around Makgadikgadi and resulted in:-

(i) the excessive concentration of cattle on marginal land with very little gain to the livestock sector and rural livelihoods, while incurring a heavy, if not fatal blow, to the potential to develop wildlife based economies over extensive areas.

(ii) the exclusion of wildlife from key refuge areas, along the Boteti and northern Ntwetwe pan, by the utilisation of the available water by livestock.

(iii) a dearth of economic diversification potential around the margins of Makgadikgadi Pans National Park due to the polarisation of land uses between wildlife benefits that accrue entirely to the State and livestock benefits that accrue to the individual. Unsurprisingly, much of the marginal land surrounding the MPNP is defended passionately by the rural people found there for, the albeit, small livestock related benefits they can obtain for themselves, rather than the largely non-existent wildlife related benefits that remain only a distant promise.

This state of affairs is limiting rural livelihoods and damaging both the wildlife and livestock sectors. A radical change to this situation is proposed by effective land use planning and zoning, that re-opens dominantly marginal areas of rangeland to wild ungulates and reserves areas with the most potable groundwater and surrounding grazing land exclusively to livestock. Trade-offs are necessarily required from both wildlife and livestock sectors, as the current ad hoc expansion of the latter is of little benefit to the majority of rural people and the sustainable development of the area. Wildlife cannot simply fit around the areas utilised by livestock and people and be expected to contribute meaningfully to rural livelihoods. Similarly, the livestock sector should not be developed in a manner that places it in direct competition with wildlife, particularly problem animals such as elephants and predators, and excludes large areas of land from any form of meaningful production (either livestock or wildlife).

The rangeland ecology study fully endorses the findings of Brooks and McCulloch (2010) and would emphasise the following:-

- Fenced ranch blocks on the grazing areas surrounding potable groundwater should be developed – this includes the current Nata Ranches block which should be fenced and form an effective southern extension of the Veterinary cordon fence (encompassing parts of Areas A-C on the Blair Rains and McKay, 1968) map (Figure 27). The rationale behind this is that wildlife can find their way around discrete ranch blocks that are adjacent to fences and effectively channel them into low/no conflict zones,
- The alignment of the Game Proof fence along the Boteti River should be altered so as to maximise the returns to both the wildlife and livestock related economies. The Fence should maximise CBNRM opportunities along the River and follow the crest of River Cliffs. Currently prime CBNRM sites for ecotourism have been fenced for livestock access and wildlife has little or no access to the River bed due to the tendency of the Fence to follow the eastern boundary of the riparian zone, rather than the River bed.
- Marginal land currently grazed by livestock around northern Ntwetwe pan should be vacated for wildlife.
- The situation concerning the BDLC ranches should be rationalised and where possible the land integrated into the MPNP, by re-allocating ranches as a form of compensation for those affected by the potential loss of grazing lands in the stateland WMAs – i.e. CT11.
- It is also recommended that a fenced livestock free corridor from the Boteti River to the central Kalahari Game reserve is established.

3.5.4 Follow on work

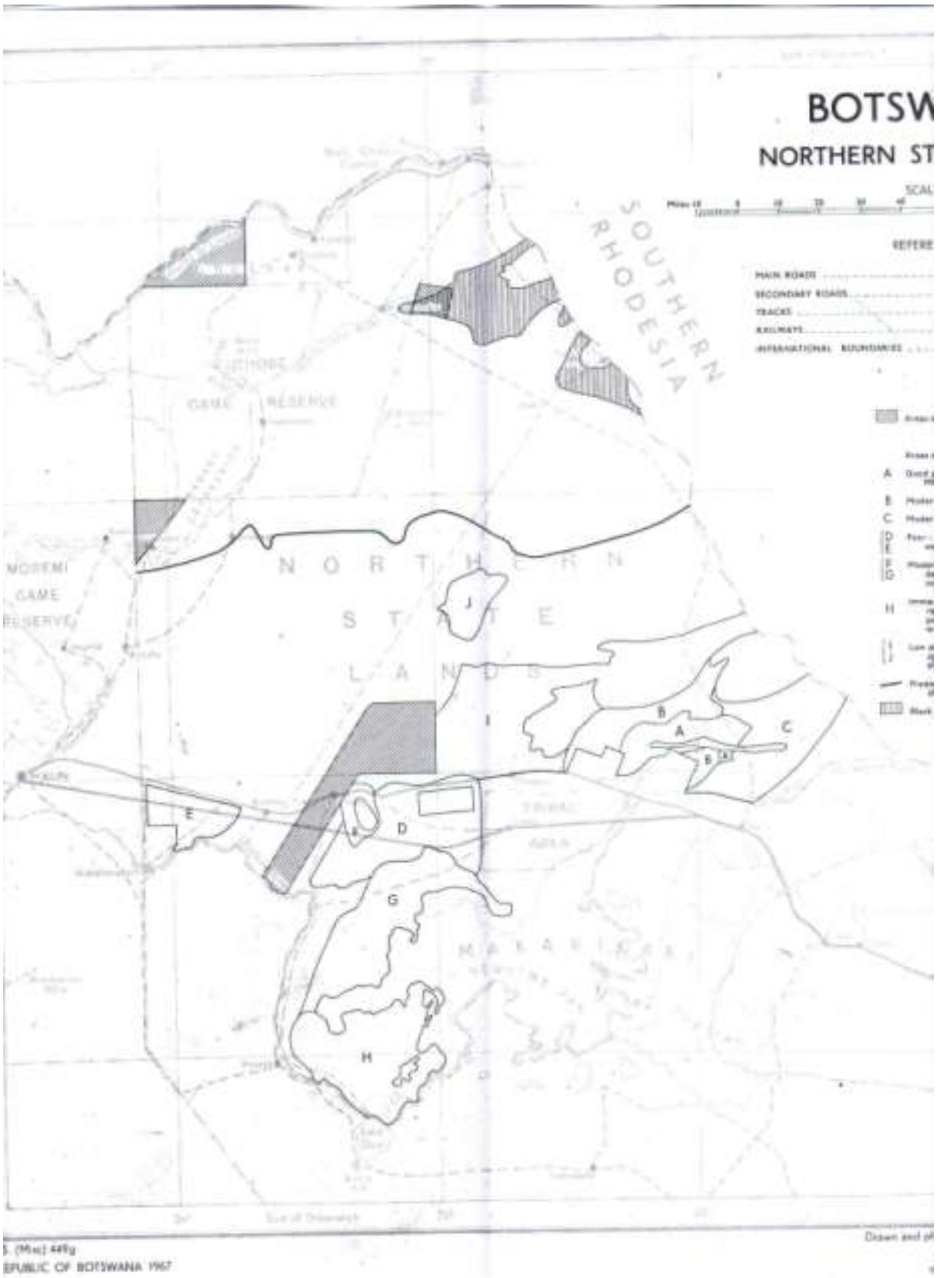
3.5.4.1 Corridor provision to the Central Kalahari Game Reserve

The role that natural grassland/wetland systems like Lake Xau have played in the maintenance of large herds of wild ungulates was unfortunately never quantified, as the die-offs preceded any studies. Today, lake Xau/Mopipi and the grazing on the former Lake bed around Rakops is dominated by domestic stock. In the late 1980s it was possible to see springbok and the occasional wildebeest on the former lake bed, especially its western most edge, together with domestic stock. Today the landscape is dominated entirely by cattle.

The persistence of wildlife at ‘ecologically effective’ densities (sensu Soule´ *et al.*, 2003) is a crucial component of healthy ecosystems and is currently lacking from both the Makgadikgadi and Kalahari ecosystems. Strategic habitat protection of a wildlife migratory corridor linking the two protected areas would strengthen their existing conservation status and help hedge against projected future conditions at relatively modest costs in terms of additional land. Currently, the ability of both protected areas to maintain viable populations of the key ungulates species (wildebeest and zebra) has been greatly diminished by isolating their populations from key resource areas and fragmenting the previous connectivity that existed between the Makgadikgadi and Kalahari ecosystems.

DHV (1980) made the point that, “Enhanced game use is seen as the best way to raise the standard of living of the greatest number of people ...... particularly those who are the poorest.”(p.45). A solution would, therefore, be to connect up the Makgadikgadi Pans NP and the CKGR through a fenced, livestock free, corridor between them and to develop CBNRM wildlife based activities in the area.

Figure 27. Rangeland carrying capacities



Source: Blair Rains and Mckay (1968)

It is recommended that a separate study is commissioned to look into the most viable option for the location of this fenced, livestock free migratory corridor. The options appear to be:-

(i) the route the wildebeest are known to have taken in the early 1980s, from the north-eastern CKGR to Mopipi/Lake Xau – except this area is now full of fenced livestock ranches;

(ii) the shortest route to the Boteti from the NE corner of the CKGR, i.e. from CKGR to Rakops – except this area is now quite densely settled with people and livestock;

(iii) a longer route from the northern CKGR through the Hainaveld farms to an area around Xhumaga – except this requires the consent of the affected Hainaveld Farms and the creation of a livestock free corridor to the River.

3.5.5 Conclusion

It is becoming increasingly clear that there can be no provision for wildlife except on livestock free land. An active drive for the promotion of CBNRM with an emphasis upon wildlife related economies could rapidly change this situation, but currently it appears that the boundaries of the protected areas in general, and Makgadikgadi in particular, are increasingly forming hard edges, where the livelihoods of communities are tied to subsistence agriculture and the fate of wildlife populations outside of the protected areas is at best uncertain. Within this context, porous boundaries can do little more than increase problem animal control activities and harden already dominantly hostile, community attitudes to wildlife. It is recommended on the one hand that key refuge areas are secured for wildlife to enable the recovery of their populations and that on the other fenced ranches are consolidated around Nata and on the southern side of the buffalo fence.

The urgent need to promote CBNRM around the Makgadikgadi wetland system is emphasised, within which the renewed flows down the Boteti and probably in the 2010 flood year to Mopipi/Lake Xau should be used to provide some impetus and a more visionary look at sustainable livelihood options, beyond those provided by cattle and crops. Stocking rate estimates, made independently from a diverse array of authors, all indicate that the rangelands are marginal for livestock keeping due to poor forage on halomorphic soils and dominantly saline groundwater.

The management of natural resources through Community based trusts has considerable potential to address the key problems afflicting the region; structural poverty and poor management of communal resources. Security of tenure is, however, essential if such initiatives are too succeed requiring the issues of effectively private cattleposts on communal land, and dual grazing rights, to be addressed.

With zebra and wildebeest populations at historic low, large parts of the MPNP will remain ungrazed, creating a fire hazard to wildlife populations within the MPNP – as the prevailing winds will drive the fire towards the fence. Active management will be required if extensive areas of riparian woodland and Pan grasslands are to be protected from fire. Livestock populations dying on the western side of the fence despite a large standing biomass of forage within the protected area, remains a distinct possibility in the future – i.e. during the next drought, and in the absence of meaningful CBNRM activities will undoubtedly harden attitudes to wildlife conservation and put pressure on the Game Proof Fence itself. The latter, through strategic realignments should be used to promote CBNRM and provide for economic diversification within the area.

Management within the Makgadikgadi wetland system itself should seek to re-instate or mimic the natural variability of the ecosystem, with the provision of artificial waterpoints managed within this context. Climate change presents a potentially severe threat to biodiversity, with the phyto-chorology of the area suggesting that the linkage between the Boteti River and the Kalahari system may well be critical in order for species to disperse rapidly through fragmented and keep pace with the changing climate.

Current management of the Makgadikgadi wetland system runs the risk of creating spatially and temporally varying environmental conditions that bear little resemblance to historic patterns and are ill-suited to the conservation of the key wildlife resources under predicted climate change scenarios. These changes can be mitigated by the protection of ecosystem integrity and functioning and the strategic incorporation of key wildlife refuge areas into the protected area system, including the provision of a livestock free migratory corridor to the CKGR. The changes recommended within this report, when coupled with the strategic development of fenced livestock (or game) ranches will serve to strengthen the livestock production and disease control aspirations of the Ministry of

Agriculture on the one hand and the promotion of wildlife conservation and sustainable rural livelihoods on the other.

3.5.5.1 Summary of Recommendations

1. Promotion of CBNRM wildlife/tourism based activities around the boundaries of Makgadikgadi Pans wetland system:- Strategic realignment of the Game Proof fence to allow for CBNRM activities and to rationalise livestock and wildlife access to the Boteti River and other key refuge areas – in particular by fencing the top of river cliffs on the bank on which they occur, rather than on the opposite bank. Secure prime ecotourism sites for CBNRM activities before they become bush encroached due to livestock related impacts.
2. Increase wildlife access to ‘natural’ waterpoints and grazing within the Boteti River through strategic realignment of the Game Proof fence to allow wildlife more strategic access to the River bed and riparian grazing resource.
3. Develop a fenced wildlife migratory corridor from the Boteti River to the Central Kalahari Game Reserve.
4. Decrease livestock pressure on the marginal rangelands around Makgadikgadi Pans by consolidating the Nata Ranch Block and strategically relocating cattlepost owners to it.
5. Active fire management within the Makgadikgadi Pans NP to prevent its most vulnerable habitats (Boteti woodlands and plains grasslands) being ravaged by fire.
6. Active maintenance of the Game Proof fence.
7. Improvements to animal husbandry (herding and kraaling) through the formation of CBNRM Trusts and diversification of the rural economy through tourism related ventures.
8. Management of the artificial waterpoints within the MPNP so as to mimic the natural system (i.e. dry season pumping only along the Boteti River) and wet season pumping in the Pans.
9. Actively monitor and manage exotic species within the Makgadikgadi wetland system.
10. Maximise CBNRM activities following the renewed floods down the Boteti River and the rejuvenation of the wetland system – including the new opportunities for fishing and veld product harvesting.
11. Rationalise the BLDC ranches and where possible incorporate them into the protected area.

3.6 Climate Change

3.6.1 Impacts of Climate Change

Climate change prediction relies on several models, for both precipitation and temperature likely changes. Model outputs do vary- with most indicating hotter and drier conditions for southern Africa in general. For the Makgadikgadi Wetland System (MWS), there is an acute shortage of studies that have modelled climate change and its impacts on the area. From other studies in the region, local or regional differences may occur in likely impacts e.g. onset of wetter conditions, but the spatial resolution remains a big challenge in the region.

A study of the Okavango wetland system, for example, by Milzow *et al* (2010) has indicated the following, based on a number of different models used in that study;

Worst case scenario –dry (HADCM3) – i.e. hot and dry scenario:

  a. Water reduces by 61-62%.
  b. Dense grasslands and floodplains generally decline by about 60%.
  c. Woodlands are minimally impacted.

Median Scenario - represented by NIES99

  a. Water declines by 25-31%.

b. Floodplains, dense grasslands decline by 19-21%, and occasionally flooded grassland declines by 13%.
c. Woodland is impacted slightly, with incremental trends (less than 10%) and so is grassland, except for the occasionally flooded grassland.

Wet scenario - represented by CSIRO

a. Water increases by 180-628%.
b. Only negative changes are in woodlands, open grasslands and low dense shrub land.
c. Floodplains, dense grasslands increase by 120-165%.
d. Sparse dry grassland decreases markedly (25- 35%).

In general, a hotter and drier model is the most widely adopted for the region (IPCC 2007; UNFCCC 2007; UNEP 2009). For the purposes of predicting likely impacts on the Makgadikgadi Wetland System, this study focuses on this ‘hotter and drier’ model.

Southern Africa will face increasing temperatures; likely decreases in rainfall; and increases in frequency and intensity of extreme wet and dry events – some of these events occurring in areas otherwise currently unaffected by extremes. The resulting sectoral vulnerabilities include increasing water stress; a reduction in yields from rain-fed crops, which could be halved by 2020, and; disease vector transmission may increase spatially and temporally, e.g. malaria, meningitis, cholera and fever.

Ecosystems offer services that add to human well-being and in the Kalahari, as droughts increase in both severity and frequency, ecosystem services are likely to be reduced. Furthermore, the occurrences of extreme weather events on ecosystems, e.g. high rainfall variability, may alter some C3/C4 grasslands from being net sinks to being sources of CO2. Even though a non-linear response is predicted, high rainfall variability may result in a reduction in grassland productivity. A 10% reduction in some tall grass prairie productivity and a 13% decline in soil respiration is predicted with a 50% increase in dry spell duration. Thus extreme weather events (e.g. droughts, floods) impact ecosystem functioning more than the global average trends (Jentsch and Beierkuhnlein, 2008). In general, the thresholds of ecosystems may shift and effects on diversity, productivity, reproduction, phenology, nutrient cycling and community resistance to invasion may be altered.

Current debates no longer just concentrate on land use, habitat loss and fragmentation as drivers of biodiversity loss - the impacts of climate change on ecosystem functioning now posses a major threat to biodiversity in the southern Africa. The terrestrial ecosystems, for example, would be challenged by rangeland degradation and desertification; and about 25-40% of animal species in national parks in sub-Saharan Africa will be added to the endangered list as a result.

Woody C3 plants are more favoured by CO_2 fertilisation and are much more efficient at accessing and using water compared with C4 grasses. A decrease in rainfall of about 5-10% may, therefore impact the tree/grass ratio of savannah ecosystems whereby woody species are favoured. However, this analysis has not included the influence of increasing temperature, which promotes C4 grasses growth.

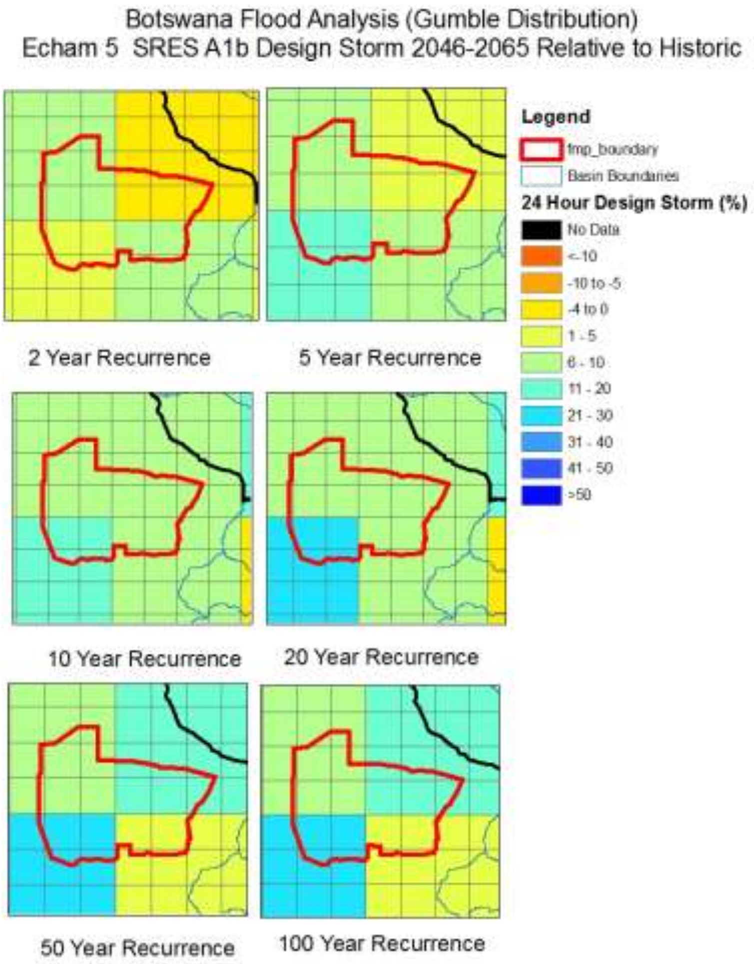
Likely impacts on climate change on the MWS – a hotter and drier climate change scenario; The impacts of climate change, for the MWS, are summarised in terms of the following categories: most likely impacts; likely and uncertain future impacts, under a drier and hotter climate. The other climate scenarios e.g. wetter, is not likely to lead to much negative impacts, as is shown in historical records, that about 150yrs ago, it was wetter and most water dependent mammals extended into the Makgadikgadi plains. Thus, what is presented here, is the worst case scenario. For the biodiversity indicators, a few key species were selected e.g. Lesser Flamingos to represent the birds; elephants, blue wildebeest and zebra to represent the mammals. A limited number of indicator species, helps to indicate the trend.

Climate scenarios are numerous and highly variable, but the consistent message form GCMs is;

a) There will be a change in daily precipitation intensity – more extreme,
b) A change in inter-storm arrival – extreme and unpredictable,
c) Hightened seasonal and spatial variation.

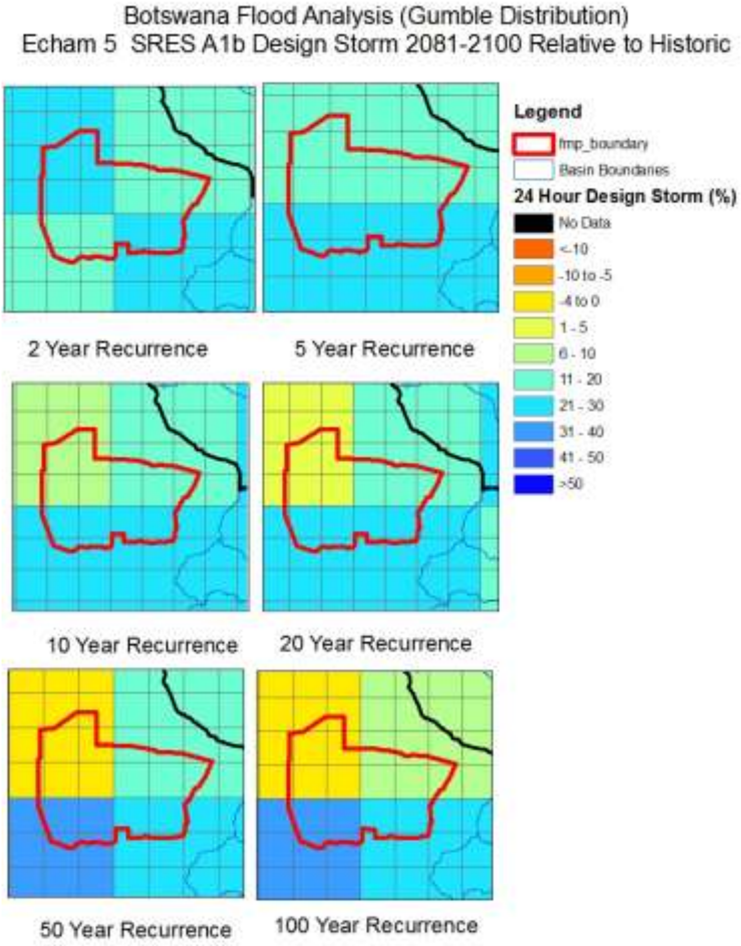
Climate change is, therefore, likely to impose dramatic variability on Botswana's climatic events, resulting in more frequent extreme events, compared to most other locations. This will be manifested in both droughts and floods alike and reflected in multiple climate indices – increase in droughts and in daily flooding. Historical storm design, based on extreme value (Gumble) distribution of rainfall from 1961 to 1990, provides estimates of rainfall depth for a return period and indicates the rate of recurrence of rainfall storms of variable quantities (mm); 20 – 30mm storms are frequent throughout the MWS every 10 to 20 years (Figure 28). The historic trend for storm events and droughts is already extreme, suggesting that storage of water is more important that is typical for the area.

Figure 28: 2050 peak flow from Historic 24 hour precipitation ratio of GMC – Blue indicates higher future flow estimates.



Future predicted GCM increases in 2hour precipitation events relative to historic events indicate higher flood intensity recurrence - more frequently (Figure 29).

Figure 29. 2090 Peak flow from 24 hour precipitation ratio of GCM, based on historic comparison



Note: blue indicates higher future flow estimate.

The potential threats to increased flow events are flood damages, higher design costs, and higher velocities, which will cause more erosion in catchment and impact vegetation on ground. A projected annual exceedance of flood indicator (q10), from MPI ECHAM 5 A1B, GCM indicates that there will be a significant decrease in runoff and a lower likelihood of flooding in the MWS between 2030 and 2050. There is also a likely change to the frequency and intensity of drought, as indicated by the 2090 drought month change relative to historic data (Figure 30).

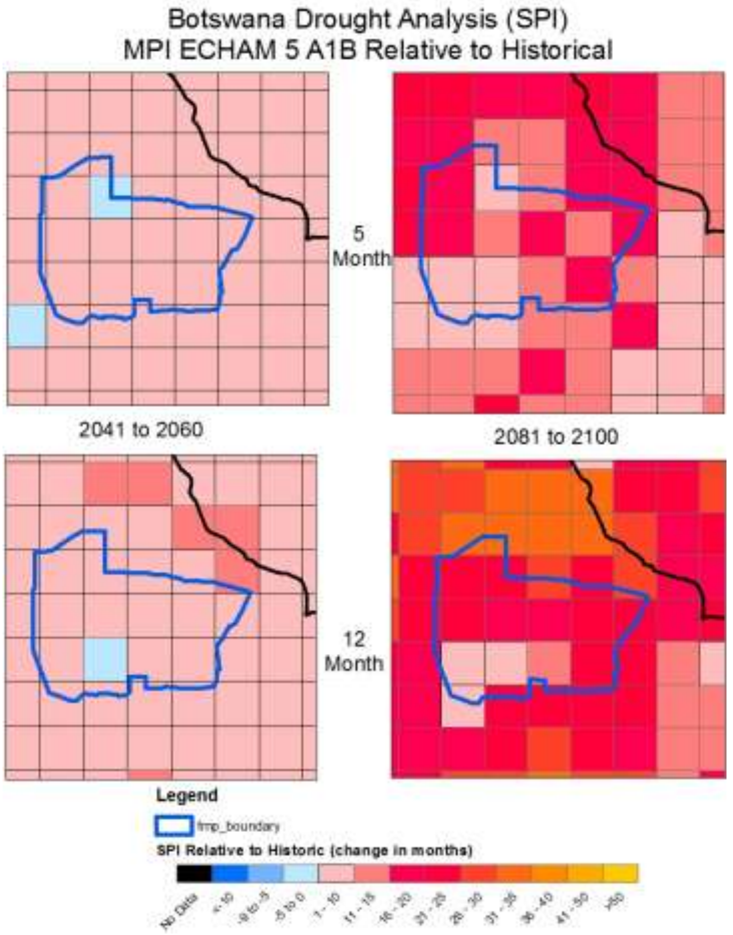
Potential impacts from increased droughts will be realised through reduced rain-fed crop yields (more failure) and reduced irrigation and municipal water supply, as a result of decreased surface water storage and groundwater recharge. A projected annual exceedance of drought indicator (q90), from MPI ECHAM 5 A1B, GCM indicates that there will be a significant increase in droughts between 2030 and 2050.

The implications of climate change on the MWS when planning for development are –

a) Need for storage is exacerbated;

b) Need for watershed management, including institutional arrangements is heightened;
c) Value of improved agricultural practice via research and technology is heightened**;**
d) Need for sustainable water resource practices;
e) Value of actions should be quantified via modelling to find optimal and feasible solutions.

Figure 30: 2090 SPI droughts, change in drought months relative to historic.



Note: Red and yellow indicate worse droughts

3.6.2 MFMP area Vulnerabilities to Climate Change

The likely vulnerabilities due to climate change are quite complex. For instance, in comparing C3 vs. C4 plants, the woody C3 plants are more favoured by CO_2 fertilisation. In addition, the C3 plants are much more efficient at water use efficiency as compared to C4 grasses, based on the Kalahari study (Wang *et al*., 2010). While on the other hand, the grasses are more competitive at using nitrogen, with the trees using their deeper rooting to be more competitive at water use efficiency. Thus a decrease in rainfall of about 5-10% may favour more tree growth i.e. affect the tree/grass ratio, hence savannah vegetation composition (Wang *et al.,* 2010). However, this analysis has not included the influence of increasing temperature, which promotes C4 grasses growth. Thus, climate change influence on vegetation composition remains one of the major challenges.

Despite the foregoing, some vulnerabilities have been documented in the MWS, even before the climate change impacts are included. The vulnerabilities would only be considered for certain key species, so as to present a manageable list.

3.6.2.1 Geomorphic, climatic, rainfall, river flows and groundwater vulnerabilities

- Geomorphic - a pan dominated landscape that is dependent on rains and inflows, hence most sensitive to precipitation/temperature changes i.e. it has very high open pan evaporation.
- Geomorphic – the area is indicated to be a dust source during dry periods, thus contributes to lowering environmental quality. Some 1m high dunes exist on dry parts.
- Geomorphic – a saline system, with extensive pans and grasslands of low forage quality i.e. limited productivity.
- Climatic – semi arid systems are by their nature limited in their productivity due to rainfall variability, deficiencies and incidences of droughts.
- River flows – the Boteti River last flowed in 1991; Nata river flows have strong links with ENSO and presence of surface waters on pans; thus it is affected by El Nino events.
- Groundwater – Boteti/Letlhakane has saline waters, with Gweta/Dukwi having fresher waters; yet the actual amount of recharge is unknown, with the brine data showing no inputs of fresh/rainwater recharges. Evapo-transpiration is very high in the system.
- Groundwater (brine) – industrial exploitation of brine, with inadequate understanding of likely environmental impacts. This may lead to desiccation (lowering of water tables) thus remove the protective moisture that binds surface vegetation, hence drier and vulnerable conditions for dust sources.
- Water conflicts – wetspots and water take-offs still uncertain, but northern/central Sua specifically Nata river, Mosetse catchment (planned dam) and Dukwi wellfields (high groundwater extraction) require special attention as brine extraction is increasing. However, this is the most visited by tourists (Nata Bird Sanctuary).

3.6.2.2 Land use and rangelands

- More increasers (indicators of poor range condition) in the MWS, than decreasers. Increasers are 32 of total 42 species = 76%. Increase in woody vegetation over grass, and increase in CAM plants, i.e. succulents.
- Land use conflicts currently exist, for example between ranchers and small farmers; wildlife and agriculture and the fences. Grazing resources at the centre of this will decrease in quality.
- There are water shortage conflicts; and most of the key birds and mammals are water dependent, as well as cattle.
- There is evidence of land degradation in the MFMP area, thus limiting water, grazing, environmental quality and alternative livelihoods for the people.
- Abandoned past settlements indicate encroachment – and even with wildlife re-colonisation. The outcome is a changed type of wildlife that uses the area.

3.6.2.3 Bird species vulnerabilities

- These are the trigger species for MWS as chicks fledging is dependent on flooding on the pans, and this correlates well with rainfall.
- Rainfall of 450mm is critical; below this level, there is poor breeding or none at all.
- The birds use MWS as one of only three sites in Africa where they breed. Their presence indicates ecosystem integrity. They are classified as near threatened.

3.6.2.4 Large mammal vulnerabilities

- Elephants – they require adequate food and water. MWS currently limits their range due to water shortages. MWS hosts 1.2% of national herd.

- Elephants – they cause damage to crops therefore causing conflicts with property owners, and sensitive ecology like palms and baobabs and riparian woodland may be damaged as well. Moreover, the annual population growth of elephants is high.
- Zebra – they are adaptable grazers, but one of the most water dependent species. Limited water in MWS currently limits their range. The MFMP area constitutes 40% of national zebra herd. Apparent conflicts include grazing competition with cattle, water and long foraging distances, but the fence has reduced these challenges.
- Wildebeest – they require good grazing and fresh water, hence pans are vital for their survival. The MFMP area has 30% of the national wildebeest herd.
- Wildebeest – decrease in open plains, increase in grazing/water competition, led to big population fluctuations (e.g. 3 000 to 20 000).

3.6.3 Conclusions

What we know:

1. Ecosystem decline is most likely, due to climate change, specifically affecting processes and vegetation distribution and patterns.
2. The depth of groundwater has been demonstrated to affect vegetation distribution, thus changes to recharge dynamics and groundwater fluctuations is likely to lead to changes in vegetation distribution.
3. Wildlife extinctions are likely to occur, in line with the projected regional trend, due to reduction in rainfall, which reduces the availability of both water and herbage resources, especially for the selective grazers and most sensitive fauna and flora e.g. tsessebe.
4. The MFMP area is highly vulnerable – dominated by hotspot zones, thus climate change most likely to enhance/worsen vulnerability of these hotspots.
5. Human use, occupation and anthropogenic factors stress the ecosystems leading to negative impacts on the wetlands' ecosystem vulnerability indices, species richness and rarity. These impacts will worsen under climate change.
6. Lowland wetlands are especially vulnerable, thus these landscape units are the most likely to be most affected by changes in the climatic conditions.
7. The mitigation of climate change e.g. UNFCCC, would be best suited if ecosystems /biodiversity conservation, sound agricultural and range management strategies were practised. It has been shown that the ecosystem based initiatives are cost effective, even at the global level, in reducing carbon emissions mainly as a result of land use change.
8. Ecosystems are critical in REDD initiatives and climate mitigation strategies. The country needs to exploit more funding along the REDD lines.

The Challenges:

- The extent of our knowledge and database relating to past climate changes, current trends and carbon sequestration is severely limiting the amount of predictive analysis we can conduct on the MWS;
- The extent of degradation in the area is not known, yet some level of detail on hydrology and ecology is available. Thus the likely impacts of climate change cannot be quantified. However, the current hotspot zones may be given priority in rehabilitative measures;
- The eco-regions have been classified differently by various experts thus the impacts of climate change based on eco-regions poses comparison challenges;
- There is lack of quantitative data on the anticipated changes in the MWS, due to complexity of interactions and general climate change uncertainties. The tree-grassland composition under climate change, is quite complex to ascertain. This is because trees dominate under high CO_2 and are more competitive in water use in savannas, thus are likely to blossom in a drier climate change conditions. However, the grasslands blossom under increased

temperatures, and are more competitive in nitrogen use than trees. Thus the composition of savannas under a climate change is difficult to establish – the composition of the system may stay the same, or at least similar to the current;

- There is lack of data on costs of adaptation (quantifiable) due to a reduction in ecosystem services. However, this information would help in climate mitigation strategies, especially under REDD. However, it is also noted that, REDD itself does not have any standardised methodologies;
- There is lack of basic data on the science of wetlands e.g. soil (TOC, bulk density, sedimentation rates, CO_2 sequestration); on vegetation (long term monitoring results; impacts of droughts, the most sensitive species, biodiversity monitoring framework and below/above ground CO_2 sequestration by trees/grasses). As such there is limited information on hydrology-ecology interactions;
- There is need for data on vulnerability indices for the ecology, the water resources and people and their livelihoods. The interdependencies need to be modelled and tested against field data.

3.6.4 Suggested follow on work

1. Improved daily rainfall data collection and use in prediction models;
2. More research is needed in groundwater volumes; age and isotopic fingerprinting i.e. to determine the source (hydrothermal vs. rainwater); water accounts; ecology of the MFMP are;.
3. There is need for detailed ecology of the MWS - for conditions of normal, below normal and above normal rainfall. How the ecology responds to rainfall or moisture events;
4. The ecological droughts need to be documented e.g. which trees, grass and other vegetative parameters/functions are most affected. How the ecological declines affect ecosystem services;
5. More data is needed on carbon sequestration for wetlands i.e. the soils and vegetation (below and aboveground soil C stocks).
6. Indicators of vulnerability need to be identified for livelihoods and ecosystems in the area.

4 Linkages with and findings for other components

4.1 Wildlife

(a) Site inventory
Considerable synergy occurred between the Site Inventory and the wildlife component, with species lists provided by the site inventory and detailed population, distribution and trends of the large mammals and birds provided by the wildlife component. The site inventory also provided species data for the vegetation map, helping to identify the species lists per vegetation type.

(b) Biodiversity Hotspots
Considerable input from the wildlife component was fed into the MCA analysis to identify biodiversity hotspots, including the large mammal threatened species, distribution and range kernel analysis hotspot analysis, and the birdlife distribution range, species diversity distribution and details of the numbers and distribution of threatened species and those of conservation concern conservation. In addition, the Vegetation Map analysis fed into the MCA biodiversity hotspot analysis.

(c) Indicator species
The Wildlife component also contributed much detail on the species of birds and mammals most suitable for use as indicators, e.g. flamingos and zebras, and their population, distribution and trends, which provides the baseline reference data on which their monitoring will be based.

(d) Ecosystem functioning
Mammal and bird distribution ranges highlighted areas important for connectivity and function within the MWS and between the MWS and other systems, and also the areas providing the most resources within the system.

(e) Rangeland Ecology
The vegetation map provided data on the vegetation component of the hotspot analysis and for the site inventory. A vegetation table with species per vegetation type was also compiled for the site inventory.

(f) Climate Change
Examples of key indicators that can be used in monitoring the impact of climate change on the MWS and its biodiversity were taken from the analysis in the wildlife report. Species like Zebra, Wildebeest, Elephant, and Flamingo were identified from the wildlife component as particularly dependent upon rainfall patterns and resulting surface water hydrology within the boundaries of the MFMP.

(g) Hydro(geo)logy
The importance of surface water and its seasonal variability and dynamics is crucial in the understanding of wildlife population and trends, and really controls the amount, number and migrations of animals in and out of the MWS on an annual and episodic basis.

4.2 Land use

(a) Site Inventory
The development of the land systems/habitat categories, based on physical and biological characteristics, and the hydrological characteristics provide an important component of the land use MCA, and spatial land use planning.

(b) Biodiversity Hotspots
Hotspots also are very important to consider in the land use MCA and will form an integral part of the land use component, in particular in highlighting land use zones, e.g. wilderness areas, and low impact use areas.

(c) Indicator species
Indicator species will contribute to the monitoring of recommended land use options and development zones, to ensure appropriate adaptive management of the option developments.

(d) Ecosystem functioning
The identification of important hydrological functions and where they occur, e.g. groundwater recharge points, and important migration routes, e.g. zebra and wildebeest migration routes, are important to consider during land use planning and in the MCA analysis.

(e) Rangeland ecology
The importance of rangeland in the MWS, balancing its use by wildlife, cattle and arable farming, and its current state of, and potential for degradation need careful consideration during the land use planning component. This will also play a big role in the potential for and mitigation of land use conflicts.

(f) Climate change
Climate change will potentially play an important role in resource availability, e.g. surface water availability and land use potential, e.g. grazing throughout the MWS, and considering where these changes are most likely to have the greatest impacts will be key in designing and recommending robust and adaptive land use options.

(g) Hydro(geo)logy
The main sources of hydrological input and off take are considerations that are essential to the land use option MCA analysis and planning. Addressing water use conflict is one of the high priority topics considered in analysing land use options on a spatial scale, and developing land use strategies.

4.3 Economic valuation

(a) Site Inventory
Quantitative and qualitative accounts of the physical and biological resources of the MWS contribute an important process in establishing the type and amount of resources provided by the MWS. Also, biological distribution and movement data provides essential input into the resource use potential through tourism related activities and consumptive use.

(b) Biodiversity Hotspots
Biodiversity hotspots have an important value in their own right, on a number of levels, and their identification can help highlighting sites of increased value.

(c) Indicator species
Indicator species have no real input into economic values, apart from their indirect importance, through monitoring resource use potential and maintaining sustainable development.

(d) Ecosystem functioning
Through the provision of ecosystem goods and services socio-economic benefits are inextricably linked to ecosystem functioning. Both direct and indirect benefits come from ecosystem functions

and processes that are crucial for maintaining resources and services provided and ensure sustainable development.

(e) Rangeland ecology
An important natural resource in the MWS is rangeland and this report provides vital evidence for the value and extent of the economic potential of the systems rangeland over varied land use scenarios. Changes that have occurred as a result of the livestock sector, such as bush encroachment and soil erosion, are effectively irreversible and have greatly reduced the economic value of the land towards the southern end of the Boteti River and around the margins of Makgadikgadi.

(f) Climate change
The potential for climate change highlighted the value of carbon sinks in the MWS, as an indirect use value.

(g) Hydro(geo)logy
Water is one of the most important direct use values in the system and understanding its quantity and quality contributes greatly to the economic valuation component. It also provides a number of indirect use values through its various processes and function within the system that are vital to maintaining ecosystem integrity and supporting livelihoods and economies.

4.4 Tourism

(a) Site Inventory
A good description of the background information and the physical and biological characteristics of the MWS contributed to the identification of the tourism hotspots in the system, and also highlighted the potential to diversify the industry through other activities apart from traditional game viewing.

(b) Biodiversity Hotspots
Tourism in Botswana is largely based on the safari industry and high tourism zones overlap with high biodiversity areas throughout the country. Identifying biodiversity hotspots here facilitated both the identification tourism potential and the activities on which it can potentially be based.

(c) Indicator species
Indicator species will form an essential component of appropriate management strategies within tourism areas to control impact on the systems biodiversity and functioning.

(d) Ecosystem functioning
Ecosystem functions identified in this report highlighted some unique wildlife movements and migrations, and attractive hydrological features, e.g. groundwater springs that feed directly into tourism option analysis.

(e) Rangeland ecology
There are strong linkages between the ecology and tourism potential of the project area. One of the objectives of this report is to emphasise that tourism should not be seen as being diametrically opposed to livestock-keeping, but as a valuable route to economic diversification and sustainability.

(f) Climate Change
No great input to the tourism component came from the climate change report, apart from the potential deleterious impacts to the industry it presents.

(g) Hydro(geo)logy
Much about the attraction of the MWS is the fact that it is a wetland of unique character and variability, giving rise to some unique and attractive features. These provide tourism potential and varied activity options. Also the provision of water is essential for tourism operations.

4.5 Scenario issues

(a) Site Inventory
A detailed background to the physical and biological components of the MWS provides a good base knowledge of the system on which to develop options and make recommendations on development options that includes their use and potential impact.

(b) Biodiversity Hotspots
Building in conservation planning into the scenario analysis has been possible with the identification of biodiversity hotspots, and these hotspots will form an integral part of incorporating biodiversity into management planning and development options/recommendations.

(c) Indicator species
Indicator species will, again, provide a tool for the effective monitoring of the potential outcomes, including impacts, of the development scenario options.

(d) Ecosystem functioning
Ecosystem functions and processes are essential to consider in the planning and analysis of development options, and ensure adoption of the ecosystem approach to scenario development and management planning. Some of these functions, indeed, comprise integral roles in wise use development potential.

(e) Rangeland ecology
The wise use of rangeland resources in the MWS and the mitigation of its use conflicts, undoubtedly posses one of the biggest challenges in the effective management of the system, and thus the rangeland report has contributed a great deal to the development of scenarios and development options and analysis.

(f) Climate change
Climate change formed one of the criteria under which development scenarios were assessed. It possesses an important controlling factor in the long term implications of development option decision making.

(g) Hydro(geo)logy
Water, its source, quantity, quality and use is another major component of the development option scenario analysis, and a great deal of consideration has been given to the hydro(geo)logy report in this component.

4.6 Livelihoods

(a) Site Inventory
Knowledge of the MWS's physical, chemical and biological components taken from the literature and from expert opinion in the site inventory can be compared and combined with local indigenous knowledge to help develop integrated management strategies that will follow the ecosystem

approach. The inventory also provides information on the potential for resource use, including those not necessarily already known.

(b) Biodiversity Hotspots
Indigenous knowledge is important when considering the historical state and trends of biodiversity and their habitat at these hotspots, if they are to be monitored and managed effectively.

(c) Indicator species
In order to participate in monitoring their own natural resources and contribute to their effective management and sustainable use, it is essential that the community and other local users are involved in the identification and adoption of key indicators to monitor, so that they share their local knowledge in the decision making and monitoring on the ground is more likely to happen.

(d) Ecosystem functions
Ecosystem functions are integral to the maintenance of livelihoods in the MFMP area and as such need careful consideration in terms of the potential for livelihood improvement through the services they provide and the maintenance of their ecosystem on which they depend.

(e) Rangeland Ecology
The importance of rangelands to the livelihoods of the people in the MFMP area is unquestionable. There is, therefore, a great deal of synergy between this report and the livelihood component, the report providing the resource use potential and extent of impact and conflict, and the livelihood component providing data on the current and historical situation.

(f) Climate Change
The potential for a reduction in rainfall and increased evaporation rates with increased temperatures has huge implications on the rural community in the MFMP area when one considers the importance of subsistence rain-fed arable farming and livestock to their livelihoods. Considerable consideration to this was, therefore, given in the climate change report.

(g) Hydro(geo)logy
Water is, again, without doubt one of the most important resources controlling the potential of the system to support and improve livelihoods in the MFMP area. In particular the amount of surface and ground freshwater is a precious commodity and the need to maintain its supply and quality is one of the major challenges to livelihood improvement in the system.

4.7 Policy

(a) Species Inventory
A comprehensive descriptive account of the MWS is an essential component of meeting the Ramsar Convention requirement for wetland listing and appropriate management of the system. This inventory, therefore, comprises important baseline knowledge on which to build on, through continued inventory, which needs to be identified in national related policies and translated on the ground.

(b) Biodiversity Hotspots
Under the CBD convention, Botswana has a responsibility to protect and maintain biodiversity through effective conservation planning and management of protected areas. Identification of priority biodiversity hotspots are a significant step towards meeting this responsibility, which now calls for further action and policy driven monitoring and effective conservation of these sites through wise use and ecosystem approach based management.

(c) Indicator species
Indicator species are essential in the effective implementation of adaptive management, which is integral to the Ramsar Convention management framework and CBD guidelines on adoption of the ecosystem approach. National policy requires the adoption of these indicators in appropriate and improved monitoring programmes by various Central and Local government departments, e.g. Water Affairs and their surface water monitoring and conservation programme.

(d) Ecosystem functions
Similarly, adoption of the ecosystem approach, in line with the Ramsar and CBD convention guidelines and responsibilities requires careful consideration and inclusion of these ecosystem functions in policy making and for effective monitoring of their ‘condition’ to be translated through management activities and interventions on the ground.

(e) Rangeland ecology
A critical policy to the land use changes and improvements envisaged within the ecology component is that of CBNRM. The component has deliberately sought not to create new legislation but identifies critical areas where the existing legislation is challenged, such as that of ‘dual grazing rights’ and communal rangeland management. The equity issue lies at the heart of natural resource management in the MFMP area and remains a key policy goal of Vision 2016 and District Development Plans.

(f) Climate Change
Climate change cuts across many sectors and levels in light of the impacts that are likely to occur. It is one that requires considerable attention and careful representation in respective natural resource, socio-economic as well as governance related policies applicable to the MFMP area.

5 References

Abel, N.O.J., Flint, M.E.S., Hunter, N.D., Chandler, D. and Maka.G., (1987). Cattle- Keeping Ecological Change and Communal Management in Ngwaketse. ILCA/IFPP/ODG. Norwich. East Anglia.

Abel, N.O.J. and Blaikie, P.M., (1989). Land degradation, stocking rates and conservation policies in the communal rangelands of Botswana and Zimbabwe. Land Degradation and Rehabilitation. 1: 101-123.

Acocks, J.P.H., (1975). Veld types of South Africa. In: Killick, D.J.B. Memoirs of the Botanical Society of South Africa. 40. 1-128

African Wildlife Foundation. (2005). AWF website: http://www.awf.org.

Alexander, K., G. Signorelli, D. Mompoloki and van der Post, (2002). Site Survey for the Development of an Integrated Wetland Management Plan for the Makgadikgadi Palustrine Wetland System. Prepared for NCSA, Botswana Government and IUCN.

Andrew, M.H., (1988). Grazing impact in relation to livestock watering points. Trends in Ecology and Evolution. 3 (12): 336-339.

Anonymous, (1999). Wetland risk assessment framework. People and Wetlands: The Vital Link. 7th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971), San José, Costa Rica, 10-18 May 1999

Anonymous, (2009). Botswana Fourth National Report to the Convention on Biological Diversity. Department of Environmental Affairs, Botswana Government.

Anonymous, (2001). Botswana Wetlands Policy and Strategy. Department of Environmental Affairs, Botswana Government.

Anonymous, (2004). Botswana's National Water Conservation Policy, A Policy for Achieving a Water-Wise and Water-Efficient Botswana: A Draft for consultation. Government of Botswana.

Anonymous, (2005). The Precautionary Principle in Biodiversity Conservation and Natural Resource Management: an issues paper for policy-makers, researchers and practitioners. IUCN Policy and Global Change series. IUCN Publications Services Unit, Switzerland. (www.iucn.org).

Anonymous, (2007a). Revised Botswana Biodiversity Strategy and Action Plan. Ministry of Environment, Wildlife and Tourism, Government of Botswana.

Anonymous, (2007b). Follow-up to the Joint Inspection Unit report and strategy development to foster the implementation of the Convention to Combat Desertification (UNCCD): Addendum; Draft ten-year strategic plan and framework to enhance the implementation of the Convention (2008–2018). MEWT, Botswana Government.

Anonymous, (2009). Botswana’s Fourth National Report to the Convention of Biological Diversity (CBD). MEWT, Botswana Government.

ASCE (American Society of Civil Engineers), (1998). Sustainability Criteria for Water Resource Systems. Task Committee on Sustainability Criteria, Water Resources Planning and Management Division American Society of Civil Engineers and the Working Group of UNESCO/IHP IV Project M-4.3.

Arntzen, J. and E.M., Veenendaal, (1986).A Profile of Environment and Development in Botswana. IES/NIR. Gaborone. 172pp.

Barnes, D.L., (1979). Cattle ranching in the semi-arid savannas of east and southern Africa. In: Walker, B.H. (Ed). Management of Semi-Arid Ecosystems. Elsevier, Amsterdam. 9-54.

Bennun, L., (2002). Monitoring Important Bird Areas in Africa: a regional framework. Unpublished report to GEF/UNDP on behalf of African NGO-Government Partnerships for Sustainable Biodiversity Action Project (RAF/97/G31/A/1G/31).

BirdLife International, (2000). Threatened Birds of the World. BirdLife International. Barcelona, Spain; Cambridge, UK.

BirdLife International, (2004). State of the World's Birds 2004: Indicators for Our Changing World. BirdLife International. Cambridge, UK.

BirdLife International, (2006). Monitoring Important Bird Areas: a global framework. Cambridge, UK. BirdLife International. Version 0.

BirdLife Botswana, (2007). Important Bird Areas of Botswana Monitoring Report. BirdLife Botswana. Gaborone.

Blair Rains, A. and A.M., McKay, (1968). The Northern state lands, Botswana. Land Resources Study. No.5. D.O.S. Tolworth.

Bonifica, (1992). Aerial Surveys of Botswana 1989-1991. Final Report. Technical Assistance to the Department of Wildlife and National Parks. Gaborone. 145pp.

Botswana National Atlas, (2001). The Department of Surveys and Mapping. Gaborone, Botswana

Botswana Society, (1971). Proceedings of the Conference on Sustained Production from Semi-Arid Areas with particular reference to Botswana. Special Edition No.1. Gaborone. 304pp.

Bryant R.G., G. Bigg, N. Mahowald, F.D. Eckardt and S. Ross S., (2007). Climate controls on dust emissions from S African sources. Journal of Geophysical Research - Atmospheres. Volume 23, Issue 6, June 2008, Pages 1563-1580.

BSAP-SR, (2003). Biodiversity Strategy Action Plan Stocktaking Report. Prepared by IUCN and Ecosurv. Department of Environmental Affairs, Botswana Government.

Burgess, N.D., J.D., Amico Hales, T.H. Ricketts, and E. Dinerstein, (in press) Factoring species, non-species values and threats into biodiversity prioritisation across the eco-regions of Africa and its islands. Biological Conservation.

Butterworth, M.H., (1985). Beef Cattle Nutrition and Tropical Pastures. Longman. London.

Campbell, A.C., (1978). The 1960s drought in Botswana. In: Hinchley, M.T. (Ed) Proc. of a Symposium on drought in Botswana. The Botswana Society. Gaborone. 98-109.

Campbell, A.C., 1981. A comment on Kalahari wildlife and the Kuke fence. Botswana Notes and Records.13. 111-118.

Campbell, A.C. (1995). Utilisation of Wildlife in Botswana From Earliest Times to AD 1900. In: The Present Status of Wildlife and Its Future in Botswana. Proc. of a Symposium/Workshop. Kalahari Conservation Society/Chobe Wildlife Trust. 45-68.

Campbell, A.C. and Child, G. (1971). The impact of man on the environment of Botswana. Botswana Notes and Records.3. 91-110

Campbell,A., Kapos, V., Scharlemann, J. P.W., Bubb, P., Chenery, A., Coad, L., Dickson, B., Doswald, N., Khan, M. S. I., Kershaw, F. and Rashid, M. (2009). Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation.
Secretariat of the Convention on Biological Diversity, Montreal. Technical Series No. 42, 124 pages.

Carl Bro, (1982). An Evaluation of Livestock Management and Production in Botswana with Special Reference to the Communal Areas. Vols. I, II and III. Evaluation Unit.Ministry of Agriculture and the Commission of the European Communities European Development Fund. Malervangen.

CBD. (2003). Monitoring and Indicators: Designing National-Level Monitoring Programmes and Indicators. Ninth meeting. Montreal, November 10–14. Item 5.3 of the provisional agenda. Subsidiary Body on Scientific, Technical and Technological Advice, Secretariat of the Convention on Biological Diversity, Montreal, Québec, Canada. UNEP/CBD/SBSTTA/9/10. http://www.cbd.int/doc/meetings/sbstta/sbstta-09/official/sbstta-09-10-en.pdf.

Christopher R. P. and D. T. Fischer, (2005). Selection of bioclimatically representative biological reserve systems under climate change. Biological Conservation 121; 429–441

Coe, M., Cumming, D.H.M. and Phillipson, J., (1976). Biomass and production of large Arfrican herbivores in relation to rainfall and primary production. Oecologia.22., 341-354.

Collyer, C. (2007). The Impact of the Makgadikgadi Fence on Problem Animal Control Activities along the Boteti. BSc Undergraduate dissertation, Department of Environmental Science, University of Botswana.

Cooke, H.J. (1978). Botswana’s present climate and the evidence for past change . In Hinchley, M.T. (Ed) Proc. of a Symposium on Drought in Botswana. The Botswana Society. Gaborone . 53-59.

Cooke, H.J. (1983). The struggle against environmental degradation - Botswana’s experience. Desertification Control Bulletin, No.8. UNEP. Nairobi.

Cooke, H.J. (1985). The Kalahari today: a case of conflict over resource use. Geogr.J. 151: 75-85.

Cooke, H.J. and Silitishena, R.M.K. (1986). Botswana - An Environmental Profile. Report Prepared for UNEP Desertification Control Activity Centre. February. 1986. UNEP. Gaborone. Botswana.

Conservation International, (2004). Conservation International website www.conservation.org.

Cullen, R., Hughey, K.F.D., Fairburn, G. and Moran, E., (2005). Economic analyses to aid nature conservation decision making. Oryx, 39: 327-334.

Creel, S., G.Spong and N.Creel, (2001). Interspecific competition and the population biology of extinction –prone carnivores. Pp35-61. In Carnivore Conservation, Conservation Biology 5. CUP. UK

Curtin, C.G., Sayre, N.F. and B.D. Lane, (2002). Transformations of the Chihuahuan Borderlands: grazing, fragmentation, and biodiversity conservation in desert grasslands. Environmental Science and Policy; 5 ,p55–68

Dangerfield, J.M.D. (1997). The What, How and Why of Biodiversity for Botswana. Botswana Notes and records. 27., 271-280.

Darwall, W.R.T. and J-C Vié (2003). Identifying Important Sites for Conservation of Freshwater Biodiversity: Extending the Species based Approach. Unpublished Report. IUCN.

Debenham, F. (1952). The Kalahari today. Geogr.J. 118: 12-24.

Deloitte and Touche (1992). Chobe Management Plan. DWNP/KCS/USAID. Gaborone.

de Ridder, N. and Wagenaar, K.T. (1986). Energy and protein balances in traditional livestock systems and ranching in eastern Botswana. Agricultural Systems.20(1).1-16.

DHV (1980). Countrywide Animal and Range Assessment Project., 7 vols., European Development Fund and Ministry of Commerce and Industry, Gaborone.

Dudley, N. (Editor) (2008). Guidelines for Applying Protected Area Management Categories. Gland, Switzerland: IUCN. x + 86pp.

Dufrêne, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach Ecological Monographs 67: 345–366.

DWNP (1993a). People's Assessment of Livestock Predation by Wild Animals in Western Central District. Department of Wildlife and National Parks. Serowe.

DWNP (1993b). Evaluation of Livestock Losses to Predation in Western Central District. Department of Wildlife and National Parks. Serowe.

DWNP (1995). Makgadikgadi/ Nxai Pan Management Plan: Options Document. Draft Final. May 1995. Department of Wildlife and National Parks (NRMP- US-AID). Gaborone.

DWNP (2003). Dry Season Aerial Survey Botswana, 2003. Department of Wildlife and National Parks, Gaborone.

East, R. (1984). Rainfall, soil nutrient status and biomass of large African savanna mammals. Afr.J.Ecol.22 (4). 245-270

Eckardt FD, Bryant RG, McCulloch G , Spiro B and Wood WW (2008), The hydrogeochemistry of a semi-arid pan basin case study: Makgadikgadi, Botswana Applied Geochemistry, Volume 23, Issue 6, Pages 1563-1580.

EcoSurv (1994). EIA for the Rakops – Mopipi Road. Department of Roads. Gaborone

Eken, G., L. Bennun, T. M. Brooks,W. Darwall, L.D.C. Fishpool, M. Foster, D. Knox, P. Langhammer, P. Matiku, E. Radford, P. Salaman, W. Sechrest, M. L. Smith, S. Spector, A Tordoff. (2004). Key Biodiversity Areas as site conservation targets. BioScience 54(12): 1110–1118.

Ervin, J., K. J. Mulongoy, K. Lawrence, E. Game, D. Sheppard, P. Bridgewater, G. Bennett, S.B. Gidda and P. Bos. (2010). Making Protected Areas Relevant: A guide to integrating protected areas into wider landscapes, seascapes and sectoral plans and strategies. CBD Technical Series No. 44. Montreal, Canada: Convention on Biological Diversity, 94pp.

Fenton, M. B., Cumming, D. H. M., Rautenbach, I. L., Cumming, G. S., Cumming, M. S., Ford, G., Taylor, R. D., Dunlop, J., Hovorka, M. D., Johnson, D. S., Portfors, C. V., Kalcounis, M. C. and Mahlanga, Z (1998). Bats and the loss of tree canopy in African woodlands. Conservation Biology 12:399-407.

Ferrar, T. (1995). Makgadikgadi/Nxai Pan Management Plan. Final Draft. Prepared on behalf of the Department of Wildlife and National Parks as part of the NRMP USAID project no: 690-0251.33. Under the auspices of the IUCN. Gaborone

Field, D. (1977). Potential Carrying Capacity of Rangeland in Botswana. Gaborone: Land Utilisation Division, Ministry of Agriculture.

Field, D. (1978). Range Ecology Handbook for Botswana. Ministry of Agriculture. Gaborone.

Finlayson, C.M. (2003). The challenge of integrated wetland inventory, assessment and monitoring. Aquatic Conservation: Marine and Freshwater Ecosystems, 13: 281-286.

Frank, L.G. (1998). Living with lions: carnivore conservation and livestock in Laikipia District, Kenya. US Agency for International development, Conservation of Biodiverse Resource Areas Project, 623-0247-C-00-3002-00, pp. 1–63.

Gaston, K.J. & Spicer, J.I. (2004). Biodiversity: an introduction. Blackwell Science, Oxford.
Gould D (1986), Brines of Sowa Pan and adjacent areas, Botswana, Mineral Deposits of Southern Africa, I and II, pp. 2289–2299.

Georgiadis, N.J. (1987). Responses of savanna grasslands to extreme use by pastoralist livestock. PhD. Dissertation. Syracuse University. New York. 142pp.

Georgiadis, N., Hack, M., Turpin, K., (2003). The influence of rainfall on zebra population dynamics: implications for management. Journal of Applied Ecology 40, 125–136.

Groves, C. R., M.W. Beck, J.V.Higgins, and E. C. Saxon (2003). Drafting a Conservation Blueprint: A Practitioner’s Guide to Planning for Biodiversity. Island Press.

Fleishman, E., R.F.Noss and B.R. Noon (2006). Utility and limitations of species richness metrics for conservation planning Ecological Indicators 6, 543–553

Hannah, L. Wetterberg, G. and L.Duvall (1988). Botswana Biological Diversity Assessment. Natural Resources Management Support Project. USAID

Hay, E.R and. Hartnady, C.J.H. (2001). Towards “map-centric” simulation modelling of TMG recharge. In: Pietersen, K. and Parsons, R. (eds). A Synthesis of the Hydrogeology of the Table

Mountain Group – Formation of a Research Strategy. Water Research Commission Report TT158/01, 103-107.

Harrington,R.,Owen-Smith,N.,Viljoen,P.C.,Biggs, H. C.,Mason,D.R.,&Funston,P.(1999). Establishing the causes of the roan antelope decline in the Kruger National Park,South Africa. Biological Conservation, 90, 69–78.

Hartnady, C.J.H., and Hay, E.R. (2002). The use of structural geology and remote sensing in hydrogeological exploration of the Olifants and Doring River Catchments. In: Pietersen, K. and Parsons, R. (eds). A Synthesis of the Hydrogeology of the Table Mountain Group – Formation of a Research Strategy. Water Research Commission Report TT158/01, 19-30.

Hemson, G., Maclennan S., Mills, G., Johnson, P. and D. Macdonald (2009). Community, lions, livestock and money: A spatial and social analysis of attitudes to wildlife and the conservation value of tourism in a human–carnivore conflict in Botswana. Biological Conservation 142 , 2718–2725

Hoole, A. and F. Berkes (2009). Breaking down fences: Recoupling social–ecological systems for biodiversity conservation in Namibia. Geoforum.

Infield, M. and A. Namara, (2001). Community attitudes and behaviour towards conservation: an assessment of a community conservation programme around Lake Mburo National Park, Uganda. Oryx, 35: 48-60.

IUCN (1992). The IUCN Review of the Southern Okavango Integrated Water Development Project. Final Report. IUCN.

IUCN, (2003). 2003 IUCN Red List of Threatened Species. Gland [Switzerland] and Cambridge [UK]: IUCN – The World Conservation Union. Online. Available: http://www.redlist.org.

IUCN, (1994). Guidelines for protected area management categories. IUCN Commission on National Parks and Protected Areas with the assistance of the World Conservation Monitoring Centre. IUCN, Gland.

James, C.D.,Landsberg,J.,and Morton,S.R.(1999). Provision of watering points in the Australian arid zone: Are view of effects on biota. Journal of Arid Environments, 41, 87–121.

Johnson, N. C. (1995). Biodiversity in the Balance: Approaches to Setting Geographic Conservation Priorities. Page 115. Biodiversity Support Program,Washington,DC.

KCS (1983). Which Way Botswana's Wildlife? Proc.of a Symposium., National Museum. Gaborone.

KCS (1988). Makgadikgadi Region Land Use Plan, 1988. Prepared by the Kalahari Conservation Society. 108pp + Aps.

KCS (1995). The Present and Future Status of Wildlife and Its Future in Botswana. Procs.of a Symposium/Workshop organised by the Kalahari Conservation Society and Chobe Wildlife Trust. 7-8th November 1995.

Lange, R.T. (1969). The piosphere: Sheep track and dung patterns. Journal of Range Management.22. 396-400.

Lindsay, W.K. (1992). Technical Assistance to the Project 'Initial Measures for the Conservation of the Kalahari Ecosystem. Final report. Commission of the EuropeanCommunities. Bonifica S.p.a.

Marata, D. (2000). Area4B Ranch Survey. Ministry of Agriculture.

McCulloch, G.P.(2003). The Ecology of Sua Pan and its flamingo populations. PhD thesis, University of Dublin Trinity College Dublin and Ministry of Environment, Wildlife and Tourism.

McFarlane MJ and Eckardt FD (2008). Lake Deception : A New Makgadikgadi Palaeolake Botswana Notes and Records, vol 38 Pages 195-201.

McGowan International and Coopers Lybrand, (1988). National Land Management and Livestock Project: Incentives/Disincentives Study. Vols I,II and III. Gaborone. Botswana.

McNaughton, S.J. (1985). Ecology of a grazing system: the Serengeti. Ecol. Monogr.55. 259-294

McLoughlin, C.A., and Owen-Smith,N.(2003).Viability of a diminishing roan antelope population:Predationis the threat. Animal Conservation, 6, 231–236.

Mills, M.G.L., Freitag, S. and van Jaarsveld, A.S. (2001). Geographic priorities for carnivore conservation in Africa. P467-484. In Carnivore Conservation Biology 5.Eds. Gittleman, J.L., Funk, S.M., Macdonald, D. and R.K.Wayne. The Zoological Society of London. Cambridge University Press.

Mills, M.G.L.,and Funston,P.J.(2003).Large carnivores and savanna heterogeneity.In J.T.duToit,K.H. Rogers, and H.C.Biggs (Eds.), The Kruger experience: Ecology and management of savanna heterogeneity (pp. 370–388). Washington:Island Press.

Mlisa, A., and Hartnady, C.J.H. (2003). Geo-informatics for groundwater exploration in the Western Cape Province, South Africa. 21st International Cartographic Conference (Abstracts of Papers, 10-16 August), Durban, South Africa, p. 33.

MOA, (1995). Desertification and Possible Solutions in the mid-Boteti River Area: A Case Study for the InterGovernmental Convention to Combat Desertification (INCD). Final Report. Volume I - The Desertification Process and Its Impacts. A Consultancy Report prepared by a Team from the Department of Environmental Science. University of Botswana.

Mosienyane, M. (1992). Livestock Production Impact on the Environment: Botswana's Experience. Report of the Workshop on Environmental Impact Assessment Legislation. 2-4th December.1992. Gaborone.

Murray, M. (1988). Management Plan for Central Kalahari and Khutse Game Reserves. Kalahari Conservation Society. Gaborone.

Murray, M. (1979). Wildlife Utilisation Investigations and Planning in Western Botswana. Department of Wildlife and National Parks. Government Printer. Gaborone.
Nash DJ and Eckardt FD (in press), Neotectonics, base level change and drainage evolution in the Kalahari Desert

Molwalefhe LN (2004). Geochemical evidence and origin of salinity in the shallow basinal brine from the Makgadikgadi Pans Complexes, northeastern Botswana, in Water Resources of Arid Areas Proceedings of the International Conference on Water Resources of Arid and Semi-Arid Regions of

Africa, Garborone, Botswana, 3-6 August 2004, Edited by T. R. Chaoka , D. Stephenson , and E. M. Shemang , Taylor & Francis.

Myers, N., R. A. Mittermeier, and C. G. Mittermeier. (2000). Biodiversity hotspots for conservation priorities. Nature 403:853-838.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington, D.C., 245 pp.

Mitsch, W.J. and Gosselink, J.G. (2007). Wetlands - fourth edition. John Wiley and Sons, New Jersey.

Nicholson, M.J. (1987a). The effect of drinking frequency on some aspects of the productivity of zebu cattle. J.Agric.Sci., Camb.108. 111-120

Nicholson, M.J. (1987b). Effects of night enclosure and extensive walking on the productivity of zebu cattle. J.Agric.Sci., Camb.109. 445-452

NRP (2000). Woody Biomass/Fuelwood Inventory and Monitoring around Bobonong and Mochudi, Botswana. Consultancy report for the Department of Energy, Government of Botswana. 100pp.

O'Connell, T.J., Jackson, L.E., and Brooks, R.P. (2000). Bird guilds as indicators of ecological condition in the central Appalachians. Ecological Applications 10: 1706-1721.

Olson, D. M., and E. Dinerstein. (1998). The Global 200: A representation approach to conserving the earth's most biologically valuable eco-regions. Conservation Biology 12:502-515.

Owen-Smith, N. (1996).Ecological guidelines for water- points in extensive protected areas. South African Journal of Wildlife Research, 26, 107–112.

Owen-Smith, N.,and Mills, M.G.L. (2006).Manifold interactive influences on the population dynamics of a multispecies ungulate assemblage. Ecological Monographs, 76, 73–92.

Owino, A.O. (2001). Patterns of variation in waterbird numbers on four Rift Valley lakes in Kenya, 1991-1999, Hydrobiologia, 458:45-53.

Parry, D.C. (1987a). Wildebeest (Connochaetes taurinus) mortalities at Lake Xau, Botswana. Botswana Notes and Records. 19: 95-101

Parry, D. (1987b). Zebra die in the Makgadikgadi. Kalahari Conservation Society Newsletter. 18: 4.

Parry, D. (1989). The Wildlife Management Areas of Botswana. MSc Thesis. University of Witwatersrand, South Africa.

Patterson, B.D., Kasiki, S.M.., Selempo, E. and R. W.. Kays (2004). Livestock predation by lions (Panthera leo) and other carnivores on ranches neighbouring Tsavo National Parks, Kenya. Biological Conservation 119 (2004) 507–516.

Perkins, J.S., Ringrose, S., (1996). Development Cooperation Objectives and the Beef Protocol: The Case of Botswana. A Study of Livestock/Wildlife/Tourism Development Linkages. Metroeconomia Ltd. Consultancy Report; B-7- 5040/94. Gaborone, Department of Environmental Science, University of Botswana.

Perkins, J.S. and Thomas, D.S.G. (1993a). Environmental responses and sensitivity of permanent cattle ranching, semi-arid western central Botswana. pp.273-286 in D.S.G.Thomas and R.J.Allinson (Eds.) Landscape Sensitivity. Wiley. Chichester.

Perkins, J.S. and Thomas, D.S.G. (1993b). Spreading deserts or spatially confined environmental impacts? Land degradation and cattle ranching in the Kalahari Desert of Botswana. Land Degradation and Rehabilitation. 4: 179-194.

Reed M. S., A. J. Dougill And M. J. Taylor, (2006). 'Integrating Local and Scientific Knowledge For Adaptation to Land Degradation: Kalahari Rangeland Management Options'. Land Degradation & Development (www.interscience.wiley.com).

Ramsar Convention Secretariat, (2007). Inventory, assessment, and monitoring: An Integrated Framework for wetland inventory, assessment, and monitoring. Ramsar handbooks for the wise use of wetlands, 3rd edition, vol. 11. Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat, (2007). Wetland inventory: A Ramsar framework for wetland inventory. Ramsar handbooks for the wise use of wetlands, 3rd edition, vol. 12. Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat, (2007). Designating Ramsar sites: The Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance.
Ramsar handbooks for the wise use of wetlands, 3rd edition, vol. 14. Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat, (2007). Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites. Ramsar handbooks for the wise use of wetlands, 3rd edition, vol. 16. Ramsar Convention Secretariat, Gland, Switzerland.

Redford, K. H., P. Coppolillo, and E. Sanderson. (2003). Mapping the conservation landscape. Conservation Biology 17:116-131.

Revenga, C. and Y. Kura. (2003). Status and Trends of Biodiversity of Inland Water Ecosystems. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 11.

Richardson, D.M., Bond, W.J., Dean, W.R.J., Higgins, S.I., Midgley, G.F., Milton, S.J., Powrie, L.W., Rutherforord, M.C., Samways, M.J. and Schulze, R.E. (2000). Invasive alien species and global change: A South African perspective. In: Invasive Species in a Changing World, Ed: Mooney, H.A. and R.J.Hobbs., Island Press, California., US.303-347.

Ringrose, S., Matheson, W., Tempest, F., and Boyle, T., (1990a). The Development and Causes of Range Degradation Features in South-east Botswana Using Multi-temporal Landsat MSS Imagery, Photogrammetric Engineering and Remote Sensing, 56:(9)1253-1262.

Ringrose, S., Matheson, W., Tempest, F., and Boyle, T., (1990b). An Attempt to Separate out Climatic and Man-induced Causes of Range Degradation Features in Botswana using Landsat MSS, Geocarto International, 4:41-56.

Ringrose, S., Vanderpost, C and Matheson, W.,(1996a). The use of integrated remotely sensed and GIS data to determine causes of vegetation cover change in southern Botswana, Applied Geography, 35pp.

Sandford, S. (1977). Dealing with Drought and Livestock in Botswana. ODI. London.

Sandford, S. (1980). Keeping An Eye on TGLP. National Institute of Development and Cultural Research. Working Paper. No.40. University College of Botswana. Gaborone.

Sandford, S. (1983). Management of Pastoral Development in the Third World. John Wiley, Chichester. UK.

Sawdon, G (1995). The Elders Speak to Tomorrow's Children. Permaculture Trust of Botswana. Serowe Printer Cooperative. Serowe. Botswana.

Sawdon, G (1995). The Elders Speak to Tomorrow's Children. Permaculture Trust of Botswana. Serowe Printer Cooperative. Serowe. Botswana.

SBSTTA (Subsidiary Body on Scientific, Technical and Technological Advice) (1999). Development of indicators of biodiversity. UNEP/CBD/SBSTTA/5/12. Montreal: Secretariat of the Convention on Biological Diversity (downloadable at http://www.biodiv.org/sbstta5).

Schwarz, E.H.L (1926). The Boteti River. The Geographical Journal, Vol. 67, No. 6. pp. 528-535.

Sefe, F., Ringrose, S. and Matheson, W., (1995). Desertification in north-central Botswana, Causes, Processes and Impacts, Journal of Soil and Water Conservation, 20:397-408.

Sefe, F., Perkins, J.S. and E. Toteng, (1997). Boteti River Resource Assessment. Prepared for District Office of Lands, Serowe.

Semeniuk, C.A. and Semniuk, V. (1995). A geomorphic approach to global classification for inland waters. Vegetatio 118, 103-124

Shepherd, G. (2004). The Ecosystem Approach: Five Steps to Implementation. IUCN Gland, Switzerland and Cambridge, UK. vi + 30 pp.

Sinclair, A.R.E., (1977). The African Buffalo: A Study of Resource Limitations of Populations. Chicago University Press, Chicago.

Skarpe, C. (1983). Cattle grazing and the ecology of the western Kalahari, Botswana. In: Which Way Botswana's Wildlife? Proc. of a Symposium., National Museum. Gaborone., 21-24.

Skarpe, C. (1986a). Dynamics of vegetation structure and production in ungrazed and grazed savanna in western Kalahari, Botswana. In: Vegetation Ecology in the western Kalahari in Relation to Large Herbivore Grazing., Acta Univ. Ups., Uppsala. 1-46

Skarpe, C. (1986b). Plant community structure in relation to grazing and environmental changes along a north-south transec in the western Kalahari. Vegetatio.68. 3-18.

Skarpe, C. (1986c) Monitoring vegetation change and rangeland degradation. Report for Seminar on Monitoring Systems for Environmental Control. Nov. Gaborone.

Skarpe, C. (1990a). Structure of the woody vegetation in disturbed and undisturbed arid savanna, Botswana. Vegetation. 87. 11-18.

Skarpe, C. (1990b). Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana. J.Appl.Ecol.27. 873-885

SMEC (1987). Southern Okavango Integrated Water Development Phase I. Final Report Technical Study. Vol.I: Main Report. Snowy Mountains Engineering Corporation, Cooma, NSW. Australia.

Smit, I.P.J and C.C.Grant (2009). Managing surface-water in a large semi-arid savanna park:Effects on grazer distribution Patterns. Journal forNatureConservation 17, 61—71

Smith, R.D. and Maltby, E. (2003). Using the Ecosystem Approach to Implement the Convention on Biological Diversity: Key Issues & Studies. IUCN Publications Services Unit, Switzerland. (www.iucn.org).

Smith, J., Samways, M. J. and Taylor, S. (2007). Assessing riparian quality using two complementary sets of bioindicators. Biodiversity and Conservation 16: 2695-2713.

Springate-Baginski, O., Allen, D. and Darwall, W.R.T. (eds.) (2009). An Integrated Wetland Assessment Toolkit: A guide to good practice. Gland, Switzerland: IUCN and Cambridge, UK: IUCN Species Programme. xv+144p.

Stoddart, L.A., Smith, A.D. and Box, T.W. (1975). Range Management. McGraw-Hill, New York.

Stuart-Hill, G., Grossman, D., (1993). Parks, profits and professionalism: lion return to Pilanesberg. African Wildlife 47, 267.

Stuart-Hill. G., Diggle, R., Munali, B., Tagg, J. and D.Ward (2005). The Event Book System: a community-based natural resource monitoring system from Namibia. Biodiversity and Conservation; 14:2611–2631.

Stuart-Hill, G.C. and Perkins, J.S. (1997). Wildlife and Rangeland Management in the Proposed Nyae Nyae Conservancy. World Wide Fund for Nature- LIFE Project/ Nyae Nyae Farmer's Co-operative. 34pp.

Stuart-Hill, G., Diggle R., Munali, B, Tagg, J., and D. Ward, (2005). The Event Book System: A Community-based Natural Resource Monitoring System from Namibia Natural Resource Working Group, Namibian Association of Conservancy Support Organisations.

Strand, H., Höft, R., Strittholt, J., Miles, L., Horning, N., Fosnight, E., and Turner, W., eds. (2007). Sourcebook on Remote Sensing and Biodiversity Indicators. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 32, 203 pages. (www.cbd.int).

Suhling, F., M. Samways, J. Simaika and J. Kipping (in prep.): Dragonflies (Odonata). In: IUCN freshwater species assessment – regional report for southern Africa.

Sweet, R.J. (1986). Boreholes in the Kalahari: the pros and cons. Kalahari Conservation Society Newsletter. 11: 10-11.

Taylor, F.W. (1985). The potential for the commercial utilisation of indigenous plants in Botswana. In: Plants for Arid Lands. Eds: G.E. Wickens, J.R. Goodin and D.V. Field. Proceedings of the Kew International Conference on Economic Plants for Arid Lands, Royal Botanic Gardens, Kew, England, 23-27 July 1984, George Allen and Unwin. London. p231-242.

Taylor, F.W. and Moss, H, (1982). Final report on the Potential for Commercial Utilisation of Veld Products. Vols I and II. Veld Product Research. Gabane.

Teague, W.R , Dowhower, S.L. and J.A. Waggoner, (2004). Drought and grazing patch dynamics under different grazing management Journal of Arid Environments 58; p97–117.

The Nature Conservancy. (2005). The Nature Conservancy Website: www.nature.org. The Nature Conservancy.

The Nature Conservancy, World Wildlife Fund, Wildlife Conservation Society, Conservation International, and BirdLife International. (2003). A Resource Guide to Terrestrial Conservation Planning at the Regional Scale. Arlington, Virginia, USA.

Thomas, Lee and Middleton, Julie, (2003). Guidelines for Management Planning of Protected Areas. IUCN Gland, Switzerland and Cambridge, UK. ix + 79pp.

Thuiller, W., G. F. Midgley, M. Rougeti and R. M. Cowling, (2006). Predicting patterns of plant species richness in mega diverse South Africa. Ecography, Vol. 29 Issue 5, Pp 733 – 744.

Tolsma, D.J., Ernst, W.H. and Verwey, R.A. (1987). Seasonal variation of nutrient concentrations in a semi-arid savanna ecosystem in Botswana. J.Ecol. 24. 991-1000.

Trollope, W. S. W., Potgieter, A. L. F. and Zimbatis,N. (1989). Assessing veld condition in the Kruger national park using key grass species. Koedoe 32 (1): 67 – 93.

Tyler, S. (2001). A review of waterbird counts in Botswana, 1991-2000. Babbler Special Supplement No. 1. BirdLife Botswana. Gaborone.

UNEP (2005). One Planet Many People: Atlas of Our Changing Environment. Division of Early Warning and Assessment (DEWA) United Nations Environment Programme UNEP. Nairobi, Kenya.

Van der Maas H.A, E. Kooyman, T. Rampha, and A. de Wit (1995). North West Boteti baseline survey; socio-economic and bio-physical baseline survey of the communal area between and including the villages of Rakops and Makalamabedi in the Boteti sub-district. University of Utrecht, Netherlands.

Van Oudtshoorn, F. (1999). Guide to grasses of southern Africa. Briza Publications.
Pretoria.Vogel H (2004) Map, Groundwater Salinity, Central District, Dept. of Geological Survey (DGS) and Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

Van Rensburg, H.J. (1971). Range Ecology in Botswana. FAO Technical Document. No.2, UNDP/SF/359 (BOT.1) Rome

Van Vegten, J.A. (1981). Man-Made Vegetation Changes: An Example from Botswana's savanna. National Institute of Development and Cultural Research Working Paper. No.40. University College of Botswana. Gaborone.

Van Vegten, J.A. (1983). Thornbush invasion in a savanna ecosystem in eastern Botswana. Vegetatio.56., 3-7.WMC, Water Management Consultants Report (2008), Botswana Ash Brine Wellfield Model Audit 1-121/R1 Shrewsbury Shropshire, UK.

Veenendaal, E.M. and Opschoor, J.B., (1985). Botswana's Beef Exports to the EEC: Economic Development at the Expense of a Deteriorating Environment? Institute for Environmental Studies. Free University. The Netherlands.

Verlinden, A. (1994). An Action Plan for the Management of Wildebeest Populations in the Kalahari. Department of Wildlife and National Parks. Reserach Division. Gaborone

Walker, B.H.,Emslie,R.H.,Owen-Smith,N.,and Scholes, R. J.(1987).To cull or not to cull: Lessons from a southern African drought. Journal of Applied Ecology, 24, 381–401.

Walker, B.H., Ludwig, D., Holling, C.S. and Peterman, R.M. (1981). Stability of semi-arid savanna grazing ecosystems. Journal of Ecology, 69: 473-498.

Walker, B.H. and Noy-Meir, I. (1982). Aspects of stability and resilience of savanna ecosystems. In Huntley, B.J. and Walker, B.H. (Eds.). Ecology of Tropical Savannas, 556-590. Springer-Verlag, Berlin.

Weare, P.R. and Yalala, A., (1971). Provisional vegetation of Botswana. Botswana Notes and Records. 3. 131-152.

Western, D (1975). Water availability and its influence on the structure and dynamics of a savannah large mammal community. E.Afr.Wildl.J. 265-286.

Western, D (1982). The environment and ecology of pastoralists in arid savannas. Development and Change.13. 183-211

Western, D. (1986). Cattle and pastoralism: survival and production in arid lands. Human Ecology.14(1), 77-94

Westoby, M., Walker, B.H. and Noy-Meir, I. (1989). Range management on the basis of a model, which does not seek to establish equilibrium. J. Arid Environments 17, 235-239.

White, D. (1983). Vegetation map of Africa. FAO.

White, R. (1994) Report on the Kgalagadi District Wildlife Management Areas. Draft Version. USAID.

White, R. (1995). Kgalagadi District Wildlife Management Areas. Draft Final. Produced as part of the USAID Natural Resources Management Project. 106pp.

Wildlife Conservation Society. WCS Homepage http://www.wcs.org Wildlife Conservation Society.

Wood WW, Eckardt FD, Kraemer TF and Eng K. (2010). Quantitative eolian transport of evaporate salts from the Makgadikgadi Depression (Ntwetwe and Sua Pans) in northeastern Botswana. Implications for regional ground-water quality. In Sabka Ecosystems Volume 3, Africa, Barth H-J, Böer B (eds) Kluwer: Dordrecht.

WWF, Zoological Society of London, Global Footprint Network. (2006). Living Planet Report. Gland, Switzerland, 40 pp. http://assets.panda.org/downloads/living_planet_report.pdf