OKACOM

Review of
Water Chemistry
and
Water Quality
in the Okavango Delta

Specialist Report prepared by Paul Warmeant for :

PERMANENT OKAVANGO RIVER BASIN COMMISSION

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1. INTRODUCTION

The Okavango as a water resource has received considerable attention as water resources elsewhere in Southern Africa diminish. A distinct effort has been made to analyse the hydrology and geomorphology of the Delta to assess the surface water outflows and general resource potential.(UNDP/FAO 1997, SMEC 1987, 89, Shaw and Thomas 1992, Cronberg et al 1995, 96, McCarthy et al 1992, 93,94,95,96).

Considerably less is known of the overall ecology, hydrochemistry and hydrobiology of the Okavango and less still of the Delta's adjoining Kwando/ Linyanti and Chobe river systems. Since the late 1980's, the Botswana Department of Water Affairs (DWA), the University of Botswana and Lund University Sweden has carried out a detailed monitoring programme in the Okavango on surface water quality. The monitoring has so far been based mainly on the Jao/Boro river (Fig 1 & 2).

This report reviews the existing information available on water chemistry and comments on water quality in the Okavango. However, there is an overlap between the chemical, biological and physical processes that interact to determine water quality and affect water chemistry. This review includes a brief look into the overlapping processes as a precursor for more in-depth studies.

1.1 Nomenclature

Due to the large diversity in habitat encountered in the Okavango, (e.g. permanent and seasonal rivers and floodplains) and the temporal and spatial variability of study areas, chemical analyses of water quality have been difficult to compare.

To avoid confusion and better assimilation of all available data, this review adopts the terminology and definitions used by the South African Department of Water Affairs and Forestry (South African Water Quality Guidelines, Volume 7 Aquatic Ecosystems 1st Edition 1996).

Botswana has chemical analysis guidelines for drinking water quality, (Appendix A) but as yet has not developed a broad base set of guidelines to cover other aspects of water quality. Other adopted guidelines are also included in Appendix A.

Figure 1 :
(2a) Flood zonation map of the Jaco/Boro River system (after DWA, SMEC, 1989)
(2b) Sampling Locations from Cronberg et al (1996)

Figure 2 : Okavango Delta and Linyanti Swamp Location map (after UNDP/FAO, 1997)

Water Quality Definition

As stated above, water chemistry is only one portion of the criteria that governs water quality. The definition as described by the South African DWA states that the term water quality is used to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses. Three types of criteria used in assessing water quality have been suggested by the South African DWA:

1) Constituent Specific- where a value or range of each constituent represents a level of ecological risk associated with the presence of that constituent in the water.

2) Complex Mixtures- in which an approach based on whole effluent toxicity is used to evaluate complex chemical mixtures.

3) Biological- where qualitative and quantitative data is used to help describe the biological status of the aquatic systems.

Use in Botswana

The biological and complex mixture criteria are currently being developed in South Africa. The constituent specific criteria, however, are directly applicable to the Okavango delta as the waters are of a good quality and complex mixtures are as yet unlikely to exist in this essentially undeveloped wetland (SMEC 1989). Most work done on the Okavango falls into the constituent specific criteria but an increased focus is being placed on biological criteria. (e.g. Cronberg et al 1992, 1995, 1996).

Constituent Specific Criteria (CSC)

CSC are categorised into four parts;

1) Non toxic constituents:- which are generally system characteristic, in that their natural concentrations depend on localised geo-chemical, physical and hydrological processes and are non toxic except at extreme concentrations. Such constituents include the total dissolved solid (TDS) content of water. The need to determine the level at which the constituents become toxic is of great importance in water quality studies.

2) System variables:- are regulators of processes such as fish spawning and migration. The biota of aquatic systems are usually adapted to the natural seasonal changes in water quality, however changes in duration and frequency of these cycles may cause severe disruption to the ecological and physiological function of aquatic organisms (South African Water Quality Guidelines, Volume 7 Aquatic Ecosystems 1st Edition 1996). Temperature, pH, dissolved oxygen, and water flow velocity's are important variables in the Okavango. Knowing the natural limits of these variables is essential in assessing the water quality variations expected with future development.

3) Nutrients:- which are generally not toxic but stimulate eutrophication if present in access. For example inorganic nitrogen (nitrate, nitrite, ammonium) and inorganic phosphorous (ortho-phosphates).

4) Toxic constituents:- Seldom occur in high concentrations in unimpacted regions such as the Okavango. Typical toxic constituents include: Inorganic- Al, As, Cd, Cu, Hg, Mn, NH_4^+ Organic- Phenol and atrazine.

2. WATER CHEMISTRY DESCRIPTION IN THE OKAVANGO USING THE ABOVE CRITERIA.

2.1 Systems Variables

pH

The pH of the Okavango surface water varies between 5.9 to 7.6 (SMEC 1987 and Cronberg et al 1995). Permanent and seasonal swamps associated with the Jao, Boro river (Fig 1) show little variation from 6.9 to7.O. The largest variation in pH is found in the groundwater and ranges from 6 to 9.8 (Maun Groundwater Project 1996). In the Boro river, pH was found to be slightly higher at lower discharges (Sawula and Martins 1991).

Water Temperature

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

Dissolved Oxygen (DO).

Dissolved Oxygen content throughout the flowing waters of the Okavango is generally high and near saturation conditions (UNDP 1997). From a small number of measurements in October 1975, the dissolved oxygen content appeared to be variable. Inflow measurements at Mohembo reach 7.8mg/1, in the Santandadibe (central delta) measurements averaged 2.4mg/1, and at the outflow (Matlapeneng Bridge) 6.2mg/1.

Cronberg et al in 1995 carried out more detailed studies of DO by taking over 250 samples, obtaining an overall average of 81.9% saturation. The Jao/Boro river averaged 78% saturation of its surrounding floodplains and swamps averaged 84%. Perennial swamps and seasonal swamps outside the immediate Jao/Boro system averaged 69% and 90% respectively (Appendix D).

The waters of the Okavango have variable DO content. Studies by Cronberg et al 1996 stated that the DO content of water was below, or substantially below, saturation and reflected stagnant conditions throughout the wetland. Such variations in results possibly reflect the relative stages of flood progression in study areas. Future work should focus on monitoring these changes.

DO measurements were found to give a high standard deviation up to 30% saturation, thus caution should be taken in interpretation.

2.2 Non-toxic Inorganics

Total Dissolved Solids

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

Mean values of the total dissolved solids of the Boro river range from 30mg/1 to 120mg/1. General ionic concentrations are shown below, whilst other data on general physiochemical variables are compiled in Appendix B. More detail is given in Appendix D.

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

(After Sawula and Martins 1991)

Trends of TDS

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

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

Sources of TDS

Ternary diagrams of ionic signatures (Fig 3), show that surface waters of the Jao/Boro system are essentially of rainwater type with a small proportion attributed to rock dominated origins. (Sawula and Martins 1991) This is as expected, considering that rainfall in the Angolan highlands is the principle source of floodwater for the Okavango. Rainfall within the Okavango contributed up to 35% of the total water input into the system (SMEC 1989).

Figure 3 : Ionic Composition of the Boro River (After Sawula and Martins, 1991)

Figure 4 : Salinity range of the Okavango Delta and related waters (After UDP, 1997)

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

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

2.3 Mass Balance, Salininty And Carbonate Formation

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

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

The precipitates formed mainly consist of. calcite, silicon and carbonates. dominated by $NaHCO_3$. The term salinity used in the context of this review therefore reflects the increased concentration of these salts, which directly increase the overall salinity of the Okavango (McCarthy & Ellery 1994).

The sodium in the bicarbonate, $NaHCO_3$ remains soluble and can reach concentrations in the soil that are toxic (McCarthy et al 1986). However, the occurance of saline surface water is rare. It has been shown by McCarthy et al 1991, that through transpirational processes the sodium bicarbonates are confined to island centres. The precipitating salts are then flushed from the system during the rainy season which prevents the sustained accumulation of salts in surface water. Although this process occurs throughout the delta, the formation of carbonates does not fully explain mass deficiencies of TDS.

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

Figure 4 shows the general salinity range of the Okavango as a function of TDS. (After UNDP 1977). Further data is included in Appendix B.

2.4 Groundwater Salinity

Studies by the Maun Groundwater Project 1997 (MGP) have shown that groundwaters are of a similar composition to floodwaters in the distal portion of the Okavango. Oxygen and Deuterium isotopic signatures of groundwater suggest that most groundwater samples represent water recharged from infiltration of surface water (Fig 5).

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

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

The Boro prison well was shown to be intruded by saline water. However, no other evidence of groundwater pollution was discovered, but as salinities are increasing within the Okavango and that recharge of Maun's wellfields has been shown to be largely from infiltration of surface waters, the potential for intrusion is high.

2.5 Toxic Constituents

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

Tables 1 and 2 show transition metal concentrations of surface water in the Okavango (After Cronberg et al 1995). Water quality criteria are shown in Appendix A.

Inorganic and organic toxic constituents of water in the Okavango delta are present in low values and represent mostly natural background accumulations. It is important, however, to establish a baseline of present concentrations, should the concentrations change through later development. It should be noted that measuring trace amounts of metals and nutrients at the microgram per litre level are difficult and results should be viewed with caution (UNDP 1977).

2.5.1 Inorganics (Trace elements)

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

Figure 5 : Stable Isotope Content of the Okavango Delta and Related Waters

The Aluminium ion can be extremely toxic. Within the Okavango, concentrations were generally low 2.5 g/1, and well below recommended concentrations for protecting aquatic biota or human consumption. Certain analytical techniques have been shown by McFarlane 1991 to underestimate true filterable Aluminum concentrations, but as values are low the data shown in Tables 1 and 2 would still be within the quality guidelines regardless of analytical technique. Aluminium in the Okavango mainly exists as an aluminate ion $Al(OH)_4$ but it may also occur as colloidal $Al(OH)_4$ and as stable complexes with various ligands (Cronberg et al 1995).

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

2.5.2 Organotoxins

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

2.5.3 Biotoxins

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

2.6 Nutrients

Nitrogen and total Phosphorous

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

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

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

Table 1 : Estimated surface water mean concentrations of transition metals in Duba Island and Boro junction in the Jao/Boro River. (After Cronberg et al, 1995)

Table 2 : Trace Elements in Okavango Waters in May 1975 (SWECO)

Trends in Nutrients

1) Inflow

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

2) Intra Delta

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

3) Isolated Pools

These environments were found to have different chemical and biological characteristics compared to the rest of the delta (Table 4, Appendix D).

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

4) Outflow

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

5) Nutrient Export Comparisons

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

Compared to Zimbabwean catchments, the Okavango has similar total P exports, but 5 times more total Nitrogen export (Thornton 1986).

6) Nutrient Summary

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

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

2.7 Plankton, Bacteria And Dissolved Organic Carbon

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

Phytoplankton

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

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

Zooplankton

Available data is presented in Appendix E. Identification of zooplankton was based on 35 samples by Cronberg et al 1996.

River channels with low N and P levels were essentially devoid of zooplankton (282 numbers/l) whereas distal regions with higher N and P levels contained large numbers, (up to 2800 numbers/l). Very few species differences was found across the surveys (Fig 1). Rotifera and Navplius larvae were the dominant taxa found.

Bacteria

Environmental factors and water chemistry variables that affect bacterial abundance are presently unknown (Cronberg et al 1996). Thus, variation in bacterial counts at this time has unknown use in providing insight into water chemistry or water quality changes. However, should a better understanding be determined, basic data is presented in Appendix E.

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

Dissolved Organic Carbon (DOC)

The concentrations of DOC within the Okavango are high to extremely high in some isolated pools and lagoons, 16 to 285 mgC/1. (Cronberg et al 1996). The increase in DOC is proposed to occur via "flushing" of the swamps and floodplains with flood cycles. DOC concentrations also increase downstream via evaporational process similar to those described in Section 2.3.

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

Average concentrations of DOC throughout the delta are:

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

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

DOC Mass Balance.

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

3. CONCLUSION

The major processes affecting water chemistry and quality appear to be hydrological and climatic. The dominance of these processes overprint the biological processes also at work. The large temporal and spatial heterogeneity of habitats in the Okavango also make determination of specific processes affecting water chemistry and quality, difficult.

Precipitation of solutes (Calcite, Silica and Carbonates) caused by high evapotranspiration rates assist in maintaining the freshness of waters. Islands act as sinks or kidneys filtering salts (Na^{+2}, Mg^{+2}, Ca^{+2}, K^{+} and silica) from the waters by increasing island salinity to toxic levels.

The concentration of solutes via the above processes and in conjunction with flow regimes control the trends observed in solutes. These trends are well defined at inflow and outflow but become obscure within the permanent and seasonal swamps. Dissolved organic carbon recycling indicate that chemical processes are more complex within the seasonal swamps than permanent swamps and rivers.

In general, inflow waters are characterised as calcium-sodium-bicarbonate with moderate levels of silica. Intra delta waters undergo the chemical processes described resulting in outflow waters characterised as sodium-calcium-bicarbonate with high levels of silica.

Inflow Nitrogen and Phosphorous levels experienced similar increases in concentration largely due to evapotranspiration processes. This trend was also lost on progression into the delta. Total N and Nitrate-N exhibited high levels of variability in both permanent and seasonal swamps, whereas P exhibited its highest variability in seasonal swamps. Rivers can be classified as oligiotrophic, swamps and floodplaines vary between oligiotrophic and mesotrophic with isolated pools and lagoons clearly mesotrophic to eutrophic.

Phytoplankton biomass was low in rivers but increased in swamp areas relative to water flow and nutrient levels. Zooplankton were essentially non-existent in rivers but occurred in large numbers at distal regions with high phytoplankton and nutrient contents.

3.1 Future Work

3.1.1 Uncertainties in Chemical Processes

The high evapotranspiration rates causing subsequent precipitation of solutes appears to be the Okavango's main chemical process. There is no doubt that this process is very active, but there are still large mass balance deficiencies which cannot be totally explained by precipitation reactions.

Certain islands show salt accumulation at their centers. However, neighbouring islands of similar size, age, vegetation pattern, geology and location can show no salt effect. (Warmeant 1997, unfinished Masters thesis). The Maun Groundwater Project 1996 has shown that the distal reaches of the deltas groundwater supply are rapidly becoming more saline in places.

Isotopic signatures of some well points indicate that groundwater recharge is primarily from floodwater in origin. Certainly subsurface conduits are active for distribution of TDS, but what remains to be determined is, how much TDS are infiltrating through from the distal portions of the delta, and the longer term effects on Maun's water supply.

Other questions to be considered regarding salinization include:

1) Is the process of salt build-up detrimental, and if so, over what time scale?
2) Is salt accumulation likely to increase or decrease due to further development in the catchment area?
3) Are there any visible effects of adjustment in the water system such as frog, fish or muscle distributions changing?. Fishing species of birds depend on water clarity for survival. Distributions of Pels fishing Owl's could be useful baseline data on general water chemistry changes.
4) Does rainfall add any significant amount of salts to the system given average rainfall and distribution over the delta?

As yet, no one has recorded the chemical changes that should occur when relatively oxygenated and oligiotrophic surface waters of a new flood inundate seasonal floodplaines with underlying deoxygenated, solute rich groundwater. The resulting processes that could occur may provide an insight into the more complex water chemistry that exists in seasonal floodplaines. This phenomenon should be monitored both spatially and temporally to assess variation in the composition of both waters.

To assist the understanding of chemical reactions in seasonal swamps, the decomposition reactions and products of plants in the seasonal swamp should also be studied.

3.1.2 Methodologies and Analytical Procedures

Cronberg et al 1995, 1996 carried out detailed chemical analysis over a large area of the delta Fig 1. Similar field practices should be adopted for future monitoring with sizes of sample and study grids adjusted accordingly to maintain continuity.

Ideally, analytical procedures used should also be consistent with work previously done. Methods used in Cronberg et al 1996 are shown in Appendix F. However, if possible, methodologies and analytical procedures used for chemical analysis should be available and consistent with corresponding Namibian and Angolan studies.

3.1.3 Monitoring Chemical Constituents and Baseline Determinations.

Constituents described in this review should be included in any future study. Some constituents, such as toxics, have received minor attention. However, as development increases in the Okavango catchment the concentration of present natural levels of toxic constituents will be useful in assessing future major impacts.

3.1.4 Area Selection Criteria

Suggested areas are given based on the following four criteria:

1) Suitable coverage of varying habitat types.
2) Logistical suitability such as:
    i) Proximity to airstrip
    ii) Accessibility by vehicle, boat or foot during flood periods
3) Time constraints on study.
4) Availability of previous information.

3.1.5 Suggested Study Areas.

Area 1 (The Jao/Boro River. Fig 1 and 2)

This area should be used to continue monitoring of previous work for comparisons with seasonal variations. This area was initially chosen because of its importance for Maun's water supply.

Area 2 :

The Xudum system Fig 2 is suggested because of its purely seasonal nature. The previous work on the Jao/Boro system has been limited in the lateral extent of study regarding seasonal floodplaines.

Recent work on hydrogeology of islands is being carried our in the Xudum region to determine if similar transpirational processes cause precipitation of solutes in a similar manner to that observed in permanent swamps (Warmeant 1997 unfinished Masters thesis). Correlations can also be made with work being done by Ambrose Gieske in the same region. Significant additional monitoring of chemical constituents will need to be done in the Xudum region to compare it to the results from the Jao/Boro area.

Area 3

The Maunachira River has been studied by McCarthy and the Okavango Research Group as the University of Witwatersrand. Although water chemistry has not been the focus of their studies, valuable information on hydrology and vegetation control have been recorded which will greatly assist in long term monitoring plans.

Area 4

The Mburoka/Santantadibe Fig 1 has received little attention. A comparative study with the Jao/Boro system would give a greater insight into the chemical processes active over larger areas of permanent and seasonal rivers and floodplaines.

3.1.6 Work Programme

Immediate Goals

1. Establishment of water chemistry / quality guidelines should be agreed upon and adopted by Botswana, Namibia and Angola to maintain continuity. Such as the guidelines and nomenclature outlined in this review.

2. Establishment of monitoring and analytical techniques that are reproducible by Botswana, Namibia and Angola.

3. Establishment of sample and monitoring sites applicable to water chemistry / quality and other disciplines, time constraints, logistics and budget.

NB The use of satellite imagery available at Tsetse Fly control in Maun would be invaluable in pinpointing exact areas of interest to all scientific disciplines. Local knowledge of the Department of Water Affairs (Jane Nengu, Maun) and independent Pete Smith would enable relatively exact re-sampling of previous studies and an additional insight into other potentially important study areas.

Short term monitoring

General recording of systems variables such as temperature, pH, Dissolved Oxygen, Total Dissolved Solids, toxics, nutrients, salts, dissolved organic carbon and plankton should regularly be monitored. Particular interest should be given to the fluctuations of dissolved oxygen, TDS and nutrient loads in seasonal floodplaines.

Historical chemical information on pollen in peat has been previously attempted by McCarthy with little success due to oxidation (Pers comms). Isotope work on microfauna could be an alternative method of determination.

Long term monitoring (3 - 5 years)

Monitoring of approaching floods and the effects on water chemistry, although a relatively quick event, the effect of chemical interaction will need to be monitored throughout the season to assess full chemical interaction. Several such events will need to be monitored to complete a significant data base. Also, the approaching flood water will need to be monitored over the various study areas to asses the effects on similar habitats in different areas and effects on different habitats in all areas. This will be constrained by logistics.

A similar continuation of monitoring will be needed for the process of evapotranspiration chemistry. Rainfall additions of TDS will also need to be monitored to assess the effects.

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Appendix A

Drinking Water Quality Guidelines and Ranges for Toxic Constituents

1) DWA Maun
2) DWA and Forestry RSA
3) After Cronberg et al 1996

Appendix B

1) Major Physiochemical Variables in the Jao/Boro System. (After Cronberg et al, 1995)

2) Average Chemical Constituents in the Jao/Boro System, Swamps and Floodplains. (After Cronberg et al, 1995)

Appendix C

Rainwater Chemical and Isotope Composition. (After MGP, 1996)

Appendix D

1) Physiochemical Variability of the Jao/Boro System from November 1991 to October 1992. (After Cronberg et al, 1996)

2) Physiochemical Data of Isolated Pools. (After Cronberg et al, 1996)

Appendix E

Phytoplankton, Zooplankton and Bacterial Data for the Jao/Boro System. (After Cronberg et al, 1996).