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GTZ

MOLAPO DEVELOPMENT PROJECT

MDP

REPORT ON HYDROLOGICAL CONDITIONS IN BORO-SHOROBE FLOODPLAINS
- Flood Seasons 1987/88 and 1988/89 -

by

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Water Management Section
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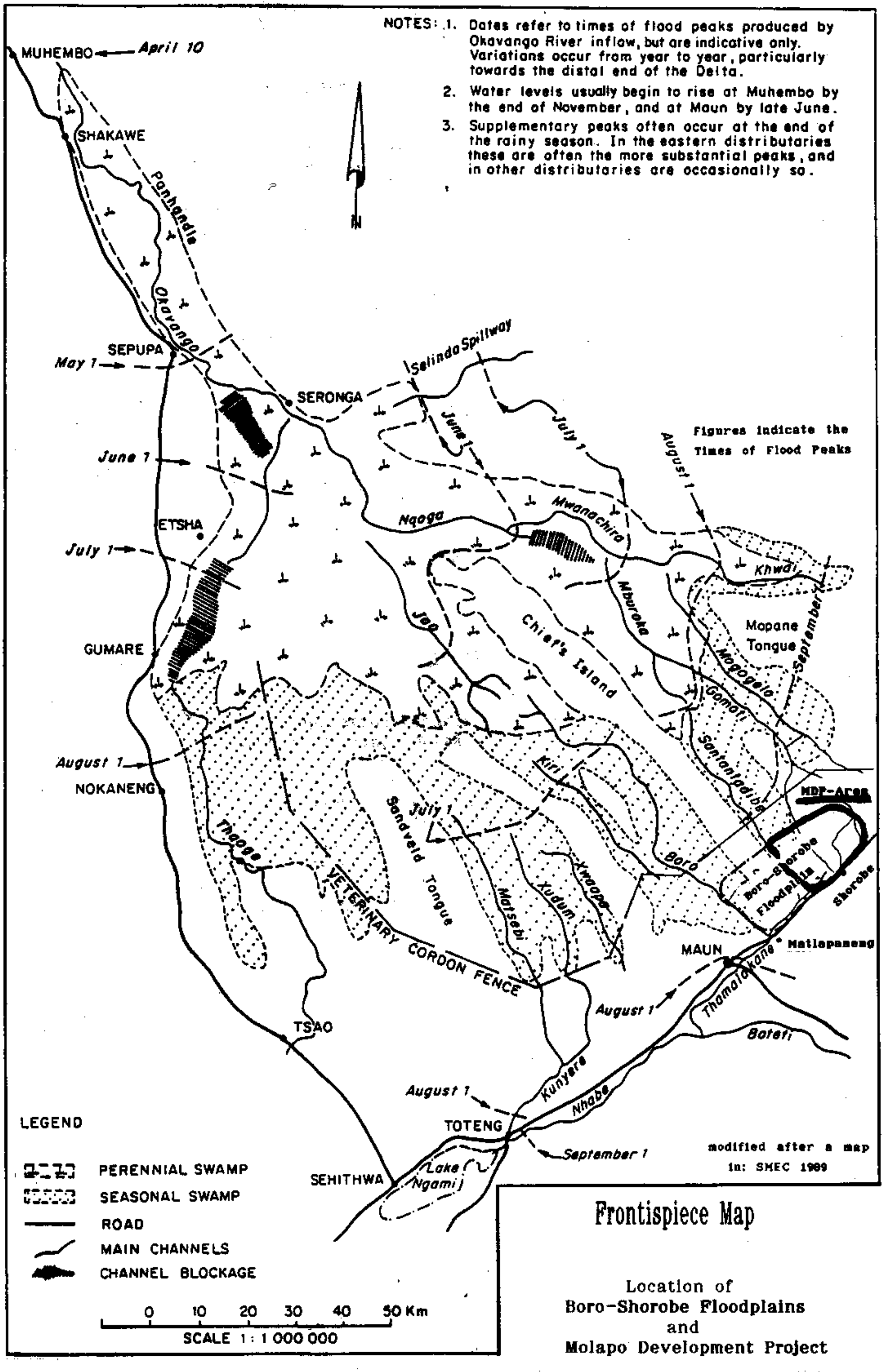

Frontispiece Map

Location of
Boro-Shorobe Floodplains
and
Molapo Development Project

HYDROLOGICAL CONDITIONS IN BORO-SHOROBE FLOODPLAIN

Technical Report on Hydrological Investigations in Flood Seasons 1987/88 and 1988/89

CONTENTS

SUMMARY

1. INTRODUCTION 1

2. MATERIALS AND METHODS 3

2.1 Discharge Measurements by MDP 3
2.2 Staff Gauge Readings by MDP 3
2.3 Hydrological Data from DWA-Maun 4
2.4 Flood Monitoring 5
2.5 Groundwater Observations by MDP 5
2.6 Meteorological Data 6
2.7 Water Analyses 6
2.8 Analyses of Topographical Maps 6

3. RESULTS OF HYDROLOGICAL SURVEYS IN 1987/88 AND 1988/89 SEASONS 8

3.1 Rainfall and Evaporation Records 8
3.2 Water Balance of Okavango Delta 10
3.2.1 Water Balance Components 10
3.2.2 Water Balance of Okavango Delta -Season 1988/89 14
3.2.3 Water Balance of Thamalakane Basins 1988/89 15
3.3 Extent of Flood in Molapo Areas 1988/89 17
3.4 Impact of Flood on Groundwater 18
3.5 Quality of Groundwater and Surface Water 19

4. EXTENT OF FLOODS WITHIN MOLAPO AREAS IN PREVIOUS SEASONS 21

5. IMPACT OF FLOOD PATTERN ON CURRENT LAND USE 26

6. IMPLICATIONS OF REGIONAL WATER DEVELOPMENT PLANS FOR MDP 29

6.1 Regional Water Rescources Planning 29
6.2 Needs of Improved Molapo Farming in Relation to SOIWD Works 30

7. REFERENCES 32

Abbreviations, Units 33

ANNEXES and APPENDICES

List of Tables and Maps

TABLES

Table 1	Staff Gauges of MDP
Table 2	Piezometers in MDP Area
Table 3	Annual Rainfall Summary
Table 4	Annual Rainfall in Okavango Delta Region
Table 5	Regional Evaporation (EO') of Okavango Delta
Table 6	Seasonal Precipitation Okavango Delta 1986-1989
Table 7	Outflows of Okavango Delta from Various Distributary Systems
Table 8	Hydrological Characteristics of Lower Boro Outflow 1981-1989
Table 9	Water Balance of an Experimental Swamp Area
Table 10	Summarizing Seasonal Water Balance for 1988/89
Table 11	Comparison of Evaporation versus Infiltration Relations
Table 12	Salinity of Surface- and Groundwater
Table 13	Peak Water Levels in Boro 1969-1989
Table 14	Assessment of Farming Conditions in MDP Area since 1969
Table 15	Yield Estimates for Seasons 1984/85 and 1987/88

Maps

Frontispieces Southern Okavango Delta - Location of MDP

Map 1	Hydrological Investigation Sites in Boro-Shorobe Floodplains
Map 2	Station Locations for Climatic Data
Map 3	Flood Extent in 1988/89 Season
Map 4	Flood Extent 1986 in Xasanare area
Map 5	Flood Extent in 1984/85 Season
Map 6	Floodable Areas in Boro-Shorobe Floodplain
Map 7	Lower Boro Dredging Scheme

(Note: not all maps are attached to this report)
maps 3-5 are compiled to a reduced scale of 1:50 000
from 1:15 000 original maps

ANNEX

TABLES

Table A.1	Monthly Rainfall Data Season 1988/89
Table A.2	Station Xhwaa: Annual and Monthly Rainfall 1984-89
Table A.3	Station Xhwaa: Totals for 5-Day Periods for Season 1988/89
Table A.4	Station Mazanga: Annual and Monthly Rainfall 1984-89
Table A.5	Station Mazanga: Totals for 5-Day Periods for Season 1988/89
Table A.6	Station Maun: Monthly and Annual Values of Rainfall 1922-87
Table A.7	Monthly Rainfall Data - Okavango Delta 1987/88 and 1988/89
Table A.8	Mean Evaporation at Maun
Table A.9	Regional Open Water Evaporation of Okavango Delta
Table A.10	Monthly and Annual Discharge at Mohembo 1969/70 to 1988/89
Table A.11	Hydrological Data Mohembo - Daily Records 1987/88
Table A.12	Precipitation of Okavango Delta Region 1986/87 to 1988/89
Table A.13	Monthly Flow Volumes of Boro 1981/82 to 1988/89
Table A.14	Annual Discharge of Boro 1970/71 to 1988/89
Table A.15	Basic Hydrological Data Flood Season 1988/89
Table A.16	Water Balance Relation between Delta Inflow and Delta Outflow
Table A.17	Boro - Thamalakane Discharge Relations
Table A.18	Volume Calculations of Thamalakane East of Boro T-junction Thamalakane T1 Basin
Table A.19	Volume Calculations of Thamalakane upstream Boro T-junction Thamalakane T2 Basin
Table A.20	Volume Calculations of Thamalakane downstream Boro T-junction Boro-Matlapaneng Basin
Table A.21	Volume Calculations of Thamalakane downstream Boro T-junction Matlapaneng-Maun Bridge Basin
Table A.22	Summarizing Hydrological Balance of Thamalakane Basins
Table A.23	Staff Gauge Records Flood Season 1988/89: Stations: Matlapaneng Bridge, Maun Bridge, Boro KB4, Boro at Xasanare, T1, T2, T3
Table A.24	Hypsometric Data (Area - Stage - Volume Relations) 1. Matlapaneng Reservoir 2. Maun Reservoir 3. Thamalakane Reservoir (Santandadibe-Gomoti) 4. Thamalakane Basin (Boro-Gomoti) 5. Xhwaa Molapo 6. Tchonxomo Molapo 7. Dikabole Molapo 8. Sakapane Molapo 9. Totoga Molapo
Table A.25	Discharge Measurements MDP 1. Matsaudi Bridge 4/7/88 2. T 3; Date 15/8/88 3. T 3; Date 27/8/88 4. T 3; Date 2/9/88 5. Xasanare off-take; Date 6/9/88 6. Xasanare off-take; Date 16/9/88
Table A.26	Dipstick Discharge Measurements 1988
Table A.27	Total Flow Volumes According to Water Balance Calculations
Table A.28	Water Sample Analyses MDP
Table A.29	Chemical Water Analyses DWA
Table A.30	Floodable, Suitable and Flood Protected Molapo Areas
Table A.31	Hypsometric Data for Xhwaa + Tchonxomo + Dikabole Melapo
Table A.32	Water Levels and Flooded Areas in MDP-Areas 1969 to 1988

ANNEX

FIGURES

Figure 1 Annual Rainfall Xhwaa 1984-1989
Figure 2 Rainfall for 5-Day Periods Xhwaa 1988/89
Figure 3 Annual Rainfall Mazanga 1984-1989
Figure 4 Rainfall for 5-Day periods Mazanga 1988/89
Figure 5 Annual Rainfall Maun and MDP Areas 1988/89
Figure 6 Evaporation (mm/d) at Maun -long term averages
Figure 7 Evaporation (mm/mo) at Maun - long term averages
Figure 8 Water Balance Distributary Systems - Okavango Delta
Figure 9 Okavango at Mohembo - Annual Discharge 1970-1989
Figure 10 Okavango at Mohembo - Monthly Discharge 1988/89, 1986/87
Figure 11 Okavango at Mohembo - Monthly Discharge 1987/88, 1983/84
Figure 12 Flow Volume (10-day AVG) at Mohembo OCT 87 - SEP 88
Figure 13 Regional Precipitation - Okavango Delta 1986-1989
Figure 14 Boro Outflow - Annual Discharge 1970-1989
Figure 15 Boro Outflow - Monthly Discharge 1981-1983
Figure 16 Boro Outflow - Monthly Discharge 1987-1989
Figure 17 Boro Outflow - Monthly Discharge 1984-1987
Figure 18 Water Balance Okavango Delta 1988/89 - Inflow plus Rainfall
Figure 19 Water Balance 1988/89 - Delta Outflow
Figure 20 Water Balance 1988/89 - Boro Outflow as % Delta Inflow
Figure 21 Water Balance 1988/89 - Outflow at Maun as % Boro Outflow
Figure 22 Water Balance - Thamalakane System Components
Figure 23 Water Balance 1988/89 - Storage Volume of Thamalakane Basins
Figure 24 Water Balance 1988/89 - Evaporation and Infiltration Losses
Figure 25 Water Balance 1988/89 - Thamalakane Losses in % Boro Outflow
Figure 26 Water Balance 1988/89 - Thamalakane Losses as SV,Inf.ETow
Figure 27 Water Balance 1988/89 - Water Losses in % of Boro Outflow
Figure 28 Water Balance 1988/89 - Water Losses in Mat plus Maun Basins
Figure 29 Water Balance 1988/89 - Water Losses in T1 plus T2 Basins
Figure 30 Water Balance 1988/89 - Schematic of Delta Flow Distribution
Figure 31 Water Balance 1988/89 - Schematic of Thamalakane Flow Distr.
Figure 32 Reservoir Capacity Matlapaneng, Area vs. Stage
Figure 33 Reservoir Capacity Matlapaneng, Volume vs. Stage
Figure 34 Reservoir Capacity Matlapaneng, AVG Depth vs. Stage
Figure 35 Reservoir Capacity Maun, Area vs. Stage
Figure 36 Reservoir Capacity Maun, Volume vs. Stage
Figure 37 Reservoir Capacity Maun, AVG Depth vs. Stage
Figure 38 Reservoir Capacity Thamalakane (Sant.-Gomoti),Area vs. Stage
Figure 39 Reservoir Capacity Thamalakane, Volume vs.Stage
Figure 40 Reservoir Capacity Thamalakane, AVG Depth vs. Stage
Figure 41 Reservoir Capacity Xhwaa Molapo, Area vs. Stage
Figure 42 Reservoir Capacity Xhwaa Molapo; Volume vs. Stage
Figure 43 Hydraulic Gradient Boro - Gomoti and Thamalakane at Maun
Figure 44 Flow Pattern in Boro-Shorobe Floodplain
Figure 45 Annual Hydrograph - Boro XB4 (7412)
Figure 46 Annual Hydrograph - Matlapaneng Bridge
Figure 47 Annual Hydrograph - T 1
Figure 48 Annual Hydrograph - T 2
Figure 49 Annual Hydrograph - T 3
Figure 50 Flood Extent 1987, Date Jul 87
Figure 51 Flood Extent 1988, Date Aug 88
Figure 52 Flood Extent 1985, Date Aug 85
Figure 53 Flood Extent 1985, Date Sep 85
Figure 54 Flood Extent 1984, Date Sep 84
Figure 55 Discharge Matsaudi Bridge 4/8/88
Figure 56 Discharge T2-station 15/8/88
Figure 57 Discharge T3-station 27/8/88

Figure 58 Piezometer Records station P1
Figure 59 Piezometer Records station P2
Figure 60 Piezometer Records station P4
Figure 61 Piezometer Records station P6
Figure 62 Piezometer Records station P7a
Figure 63 Piezometer Records station P11
Figure 64 Hydrograph of Flood Levels of Boro River 1969-1989
Figure 65 Hydrograph of Estimated Flood Level in MDP area 1969-1989
Figure 66 Reservoir Capacity Xhwaa + Tchonxomo - Area vs. Stage
Figure 67 Reservoir Capacity Xhwaa + Tchonxomo - AVG Depth vs. Stage
Figure 68 Reservoir Capacity Xhwaa + Tchonxomo - Volume vs. Stage
Figure 69 Seasonal Variation of Rainfall and Flood Level
Figure 70 Farming Calendar for Molapo Areas
Figure 71 Proposed Reservoirs and Dam Sites for SOIWD plans
1. Low Outflow Scenario
2. Above Average Outflow Scenario

HYDROLOGICAL CONDITIONS IN BORO-SHOROBE FLOODPLAINS

Flood Seasons 1987/88 and 1988/89

S U M M A R Y

Objectives

Hydrological data form the basis for planning and execution of all works related to control floods and to improve flood conditions for molapo farmers. Due to a high variability of both flood duration and level as well as to erratic rainfall the proper collection filing and evaluation of the data is essential for any assessment regarding the potential of the area and to establish plans for its future development.

Methods

Field work of MDP staff comprised readings of staff gauges, measuring of discharges and groundwater depths, collecting of meteorological records, monitoring of flood, and carrying out water analyses. In addition data from DWA and DMS were collected, filed and evaluated. Relationships between the area inundated and stage, flood volume and average depths were computed from topographical maps.

Results

* The rainfall in seasons 1987/88 and 1988/89 (JUL-JUN) was 26-47% higher than long term average (Xhwaa). Dry spells occured during the growing season.

* The seasonal (OCT-SEP) inflow into the Okavango Delta was 'very low' in 1986/87 (79% of AVG; i.e. some 10 000 MCM) and 'low' in 1987/88 (86% of AVG).

* The rainfall over the Delta was about average in 1987/88 and some 30% above AVG in season 1988/89. Rainfall contributed to some 30% of the total water volume within the delta (1988/89 season [APR-MAR]).

* Okavango outflow occurred only in the Lower Boro distributary system. Seasonal outflow (APR-MAR) during the period 1985-1988 was the lowest ever recorded since 1972-1974 (worst period since start of records 1933). Outflow in season 1987/88 only amounted to 19% and 1988/89 to 36% of average (some 264 MCM/season).

* Delta outflow amounted to about 0.8% of the inflow and to about 1.1% of inflow plus rainfall (1988/89 season). The remaining water volume was lost to evaporation (77%) and groundwater (22%).

* A water balance (1988/89 APR-MAR season) was established for Thamalakane Basins (Gomoti confluence to Maun bridge). This yielded that some 17% of 96 MCM Boro outflow was diverted as backflow to Shorobe floodplain (T1 + T2 basins), 12% was lost within Thamalakane Matlapaneng and Maun basins, leaving 71% for downstream sections and the

Boteti River. Within T1 + T2 basins some 13% were used for storage filling, 24% for evaporation and some 64% for infiltration. The ratio of Boro outflow, which was diverted to Shorobe, changed during the course of season from 33% during commencement, 9% during peak, 16-23% during recession phase and 35-42% during '2nd flood peak', induced by heavy local rainfall.

* There were no significant changes of groundwater depths and no influence of flood on groundwater recorded in 1988/89 season. Groundwater levels are currently very deep, i.e. usually below 6.5 m b.g.l. or 926.5 MSL. Groundwater is normally slightly saline (0.4-1.0 mS/cm), whereas surface water is very low saline (<0.15 mS/cm).

* Extent of floods in previous years (1969-89) was evaluated by staff gauge records and aerial photos. No floods occurred in 8 out of 20 years, prolonged floods in 4, and conditions were favourable in 8 years only. Under controlled conditions (FCI exists since 1986) in 10 out of 20 years at least 50% of the floodable melapo area could have been inundated and used for farming. Flood conditions were favourable in 1980/81, 1981/82, 1982/83 and 1984/85 seasons. No melapo areas were flooded in 1983/84 and during the period 1985-1989. Rainfall which is also important to assess the production potential, was below average since 1980, except for last two years. Farming conditions, therefore, were favourable only in 8 out of 20 years, considering rainfall and floods.

* Implementation of S.O.I.W.D. related works can improve flood conditions in the MDP area. Requirements of molapo farming are to (i) increase availability of water, (ii) increase water level temporarily in Thamalakane basins, and (iii) release water for about 2-3 months during the period July to end of September. In order to avoid conveyance losses to adjacent - mainly unused - melapo it is necessary to construct bunds along the northern sections of the Thamalakane River upstream of the 'molapobund'. Dredging of the Lower Boro within 25 km distance north of the cordon fence as proposed in the SOIWD plan would not be necessary to cover the demands of traditional molapo farmers in Boro-Shorobe floodplain only. Outflow supplementation schemes, however, are required if other users also should benefit from the Delta's outflow with regard to quantitiy and reliability of water supply.

1. INTRODUCTION

Activities of MDP's water management section are aimed at increasing the availability of floodwater and the reliability of its supply to melapo in the eastern Boro-Shorobe floodplain, and to assure that flooding periods match as far as possible with the molapo farming calendar. Thereby:

- high and prolonged floods are avoided by sluice operations in order to allow farmers to conduct timely soil preparations before the rainy season starts
- a '2nd flood', induced by high rainfall, is avoided and standing crops are protected until they are harvested
- usable flood levels can be achieved in more years in comparison with natural (uncontrolled) conditions.

For adequate planning and operation of flood control infrastructures (bunds, sluices, channels) and to provide information for controlling any possible hazard of floods, eg. salinity, drainage, erosion, it is necessary to collect hydrological and hydro-pedological data.

This report summarizes all relevant hydrological data which were collected between May 1988 and June 1989 -including some data from previous unpublished records- in order to obtain information on

- extent and pattern of flood in the area
- general water balance of the Okavango Delta (inflow-rainfall-outflow)
- water balance of the Thamalakane Basins (especially Boro backflow)
- impact of flood on groundwater in the area
- quality of groundwater and surface water in the area
- identification of needs to develop Matlapaneng Reservoir.

There exists no compiled data collection on hydrological conditions in the Boro-Shorobe area up to date. Single records were either distributed in several technical reports or they exist on draft sheets only, without compilation in hydrological data files. Some valuable information was collected up to 1987 in the following reports:

- R.Roostee (1983): Flood Control for Improved Farming in the Molapo
- FAO (1984): Assistance to the Molapo Development Project
- H.Bendsen (1987): Topographical Surveys in the Boro-Shorobe Floodplains
- R.Roostee (1987): On Water Management in the Boro-Shorobe Floodplains

This report WM-H1 summarizes the data records for the Lower Boro flood seasons 1987/88 and 1988/89. In order to avoid confusion about different periods of flood- and meteorological seasons the following time periods were used in this report:

- hydrological year
  - Lower Boro River (Delta outflow): April to March
  - Okavango River (Botswana standard): October to September
- meteorological year(Botswana standard): July to June.

Due to the different timings of flood peaks it was necessary to use different periods for hydrological Lower Boro and Okavango years (seasons). Usually floods in the Lower Boro commence in April-June and terminate in December-January, whereas Okavango floods starts in December-January and terminates in August-September. The latter flood season fits quite well to the standard hydrological year. The Lower Boro flood, however, is shifted for several months and the period of the 'flood season' should be shifted accordingly. Otherwise useless annual figures would be calculated by the partition of records of one flood season. The same would apply to annual rainfall data which are based on statistical analyses of calendar years.

This report also might serve the WM-staff as a first guideline for future data filing and compilation in order to facilitate adequate data quality checks and data evaluation.

The bulk of information in this report is presented in the form of tables and graphics. In most cases the text only refers to the relevant tables and graphics and hence it was avoided to repeat in prose what is already clear from their cursory examination. Due to the large number of tables and graphics they are presented altogether as Annex.

In the course of data compilation it proved to be necessary to check and modify some of the records which where collected from other departments, and to file and evaluate these data independently from these departments. The availability in due time of data which have been checked on quality and which are properly filed is a problem which remains to be solved in future.

This report is a complement to WM-Technical Reports of the MDP:

- WM-F1 Distribution of Molapo Farming Areas - Season 1987/88
- WM-M1 Climatological Summaries for Boro-Shorobe Floodplain - Season 1988/89 (in preparation)
- WM-P1 Hydro-Pedological Surveys in Molapo Areas - Season 1988/89 (in preparation).

7

2. MATERIAL AND METHODS

2.1 Discharge Measurements by MDP

MDP conducted 8 discharge measurements during the flood season 88/89 along the Thamalakane River (upstream Boro T-junction) and at the Xasanare offtake. The location of investigation sites are shown on Map 1.

A dipstick gauge (acc. to Jens; Supplier: Hydro-Bios, Kiel/W.-Germany) for measuring flow velocity was used. The dipstick bar was developed especially for shallow waters (10-80 cm depth) and flow velocities in the range of 5-150 cm/s. The single-axis instrument is conically-round shaped and measures the -integrated- vertical average torque for the total applied dipping depth. A single measurement yields, therefore, the mean vertical current speed of a given section. A deviation of less than 5% from standard measurements with propeller current meter is reported.

Apart from obtaining actual discharge data the dipstick measurements were undertaken in order to prove that the method is applicable under various local conditions and to train the local staff for its proper use.

Standard observation forms (field data sheet) were developed. The calculation of total discharge was performed on a spreadsheet form (Atari ST, VIP-Professional/Lotus 1-2-3 V.1 compatible). For training purposes and to obtain a comparison between the (interpolating) stepwise calculation procedure and the more accurate graphical method, the discharge was determined also graphically for three measurements.

2.2 Staff Gauge Readings by MDP

Several staff gauges were installed by MDP during June-August 88 along the Thamalakane River and within the Xhwaa molapo to record the water levels continuously during the flood. The installation of additional staff gauges within other melapo was stopped due to the lack of floods within any molapo. The installation will be continued during June-August 1989 in order to take readings for the total Boro-Shorobe floodplain during flood season 1989/90.

The staff gauges consists of enamelled plates (1 m long, graduated in cm; Supplier: Enamel, Durban/ RSA) which were mounted on iron channel profiles. Some of the gauges were protected by a concrete slab at the surface. In future the posts, on which the plates are mounted, will be completely embedded in conrete. Along the Upper Thamalakane River banks of gauges were installed to cover the expected range of levels. The settlement of staff gauges might be a problem in clayey soils and will be investigated in future. The gauges were surveyed to obtain the levels of gauge-zero (MSL), using the nearest benchmarks.

The locations of staff gauges and relevant benchmarks are shown in Map 1 and Table 1 summarizes all data on MDP-staff gauges, inclusive gauges which had been installed 1983-88. For temporary water level readings three gauges were installed within rain-ponds in Xhwaa and Nxamathama melapo and Xasanare channel.

Table 1: Staff Gauges of MDP

Location	Staff No.	Topographic Elevation	current no. of plates
Thamalakane	T 1	931.27	3
Thamalakane	T 2	931.75	2
Thamalakane	T 3	932.34	2
Charichamba	M 1*	930.5	1
Santandadibe	M 2	933.82	3
Sakapane	M 3*	930.5	1
Totoga	M 4*	931.5	1
Nxamathama	M 6	931.15	1
Xere bund	M 5	932.88	2 + 2
Xhwaa bund	M 7	932.48	2 + 1
Xhwaa	M 8*	933.0	1
Xhwaa	M 9*	933.0	1
SC-bund	M 12	932.16	2
SC-channel	M 13*	931.5	1
Xasanare	X 1	935.57	4
Boro KB4	KB4	931.30	4

up-date 14/7/88 * MSL-levels actually under surveying

Readings were taken weekly or twice a week during the flood season, recorded in HY.9 DWA-forms, and plotted on DWA standard graph paper.

2.3 Hydrological Data from DWA-Maun

Data from staff gauge readings and discharge measurements for stations

Mohembo (Okavango River inflow)	station K 7
Boro River Pantoon Site	station 7412
Matlapaneng Bridge	station (only staff gauge)
Maun Bridge	station 7654

were collected continuously from DWA, Hydrology Section Maun, and filed in HY.5 standard forms. The calculation of monthly and annual values were conducted on spreadsheet forms by MDP. The monthly figures (1981 cont.) for Lower Boro River were determined graphically by MDP, since the irregular course of discharge (large variations within short time periods) and the large time lags between single measurements makes any calculation without daily interpolation of (missing) figures less accurate. It proved to be necessary for MDP to file and interprete the original DWA-field data independently from DWA-Gaborone because the computerized files were not available in due time, and some of the records showed inconsistencies. In some cases the original field sheets had to be consulted.

2.4 Flood Monitoring

Ground observations and staff gauge readings were employed to record the spread of the flood and its peak from the first occurrence of floodwater (mid June 88) in the Upper Thamalakane River. Informations was collected on aerial photo mosaics and transferred to the MDP base map, scale 1:50 000 (Map 3). Due to the limited extent of flood, which was confined to the Lower Thamalakane river bed, a scheduled survey photo flight was cancelled.

Extent of floods in previous years was assessed and compiled with use of aerial photographs (1985), draft maps of MDP (1984) and field observations (1987). The flood pattern was compiled from field observations of MDP staff during 1984-1988 and from information provided by farmers.

2.5 Groundwater Observations by MDP

MDP installed in 1988 in total 13 piezometers within the molapo areas to observe the groundwater table continuously. Borehole drillings were made with a 5'' hotline auger, borrowed from Ove Arup & Partners International, Gaborone, and with the assistance of DWA and SMEC. PVC observation pipes of 2.5'' diam. were installed up to depth of 8 m. The pipes were perforated with 4 mm holes within the lower 1.5 m section and protected from clogging by plastic screens. The surrounding open space of filters was filled by clean gravel filter (pack with 2.4 - 4.2 mm gravel) and sealed with bentonite slurry at the top of the porous section to prevent water entering from the upper strata. The surface layers sealed by bentonite, too and a 35 kg concrete slab and a lockable iron shield protect the upper part of the observation pipes. The materials were partly delivered by DWA.

Table 2: Piezometers in MDP-area

Location	Piezometer No.	Depth (m)	Topographic Elevation (MSL)
Nxamathama	P 1a	2.50	933.5
Nxamathama	P 1b	5.00	933.5
Xhwaa west	P 2	7.00	933.0
Met station	P 3	3.43	936.5
Totoga	P 4	8.27	933.5
Xhwaa camp	P 5	6.00	933.5
Thamalakane	P 6	5.05	933.5
Sakapane	P 7a	7.56	933.0
	P 7b	3.25	933.0
Mazanga	P 8	7.80	933.5
Shorobe	P 9	6.11	932.5
Xhwaa east	P 10	7.00	933.0
Sakapane River	P 11	7.17	933.5

up-date 30/08/88 all MSL-levles actually under surveying

The existing 9 piezometers in the Xasanare area, installed by SMEC and monitored by MDP from 1986 up to date, were continously monitored as far as access to the remote areas was possible. Unfortunately most of the piezometer collapsed meanwhile, or they had been destroyed, either by straying cattle or by people, so that water tables in the Xasanare area cannot be recorded since October 1988.

2.6. Meteorological Data

Daily rainfall in Xhwaa and Mazanga melapo (weekly recording charts) is recorded by MDP staff since 1984. Other climatic elements are observed at the Agro-Meteorological Station- Xhwaa since October 1988 (see WM-M1 Report).

Additional daily rainfall records are available from the Department of Water Affairs, DWA-Maun, for the Okavango Delta stations at:

Etsha, Gaenga, Txaba, Xakue, and Kwihum.

Some of the files and records were unsuitable for analytical purposes due to poor observation methods or instrument failures.

From the Department of Meteorological Services, DMS-Gaborone, rainfall data were collected for the Okavango Delta stations at:

Maun, Gumare, Shakawe, Sehitwa, and Seronga.

Evaporation figures for Maun Meteorological station (at airport) were collected at DMS, most data, however, are apparently not suitable for further calculations (see WM-M1 Report).

2.7 Water Analyses

The electrical conductivity (EC) and pH-values of surface- and groundwater samples were measured with portable EC- and pH-meters throughout the entire season. Groundwater samples were taken from the piezometer pipes, surface water samples from various sites of the Thamalakane and Boro Rivers and within the Okavango Delta.

One sample from the water supply well at the Service Center was analysed in more detail by the Laboratory at Hydrology Section of DWA, Maun. Additional data on river water quality were collected from DWA-Maun.

2.8 Analyses of Topographical Maps

Information on stage-inundation relationships (hypsometric data) for various subbasins of the Boro-Shorobe floodplain were derived from topographical maps, 1:5000 and 1:2500 scales. The photogrammetric maps 1:5000 scale had been prepared by the Department of Surveys and Lands in 1985-96 on request of MDP. The maps were delivered to MDP in mid 1987. In addition, topographical maps 1:2500 scale were prepared (terrestrical survey) by MDP in 1986/87 for the melapo of Xhwaa and Shorobe. On 1:5000 maps the surface areas (in ha) for 0.5 m contours and on 1:2500 maps the areas for 0.25 m contours were computed by planimetering to establish stage-inundation relationships. Some of these data already had been summarized in WM-Reports W4 (Roostee 1987) and W7 (Bendsen 1987).

Hypsometric data showing the relationship between stage (water level) and (i) inundated surface area, (ii) storage volume, and (iii) average depth are now available for the areas of

Matlapaneng Reservoir	(data from SMEC,1989)
Maun Reservoir	(data from SMEC,1989)
Thamalakane Basin	(Santandadibe-Gomoti bund)
Thamalakane Reservoir	(Boro-Santandadibe bund)
Xhwaa molapo	(Xhwaa, Nxokudi areas)
Toroga molapo	
Tshonxomo (former:Shorobe)	(Tshonxomo, Mochaba, Bura areas)
Nxabe molapo	(Shorobe, Dikabole areas)
Mazanga molapo	
Sakapane molapo	
Totoga molapo	
Charichamba South	
Gabamachao I	

(all data and analyses from MDP 1987-1989 if not otherwise mentioned).
(see Table A.24 and Figures 32-42)

3. RESULTS OF HYDROLOGICAL SURVEYS IN 1988/89 SEASON

3.1 Rainfall and Evaporations Records

The rainfall during the seasons 1987/88 and 1988/89 was considerably higher (some 120%) than the long term average and especially higher (>140% of AVG 84-89) than rainfall of the previous years of drought (Table 3):

Table 3: Annual Rainfall Summary

	Maun	Xhwaa	Mazanga	
Season 1987/88	352	678	482	mm
Season 1988/89	653	584	552	mm
AVG (1922-1987)	464	-	-	mm
AVG (1984-1988)	338	389	297	mm

meteorological season JUL to JUN

Monthly rainfall figures from 1984 to 1989 for the MDP-stations at Xhwaa and Mazanga are shown in Tables A.2 and A.4. The totals for 5-day intervals for the season 88/89 are shown in Tables A.3 and A.5. The results are summarized in Figures 1-4.

Monthly rainfall data for Maun, some 30 km southwest of MDP areas, and the Molapo stations are summarized in Table A.1 and Figure A.5. Table A.6 summarizes the monthly rainfall data for Maun for the total record period from 1921 to 1987. Additional information is given in Report WM-M1.

Despite favourable total rainfall conditions some dry spells occurred during the growing season, of which four weeks in March are especially remarkable. Early season rainfall (SEP-DEC) yielded some 80 mm only, compared to 150 mm on average. Main rainfall season started exceptionally late on 31st December. Total rainfall in Maun in 1988/89 was slightly higher compared to molapo areas, whereas it was considerably lower in Maun in the previous season 1987/88 (refer to WM-M1 Report).

Most of the rainfall was falling in localized thunderstorms. A 10-day period of mist (fog) with intermittend drizzle, however, occurred in mid February. Daily maximum rainfall was 97 mm (April at Xhwaa) and 6 days were encountered with rainfall >25 mm. About 60% of the total seasonal rainfall occurred during these 6 days. Total number of rain days was 50 in Xhwaa and 54 in Mazanga. Rainfall intensity was often in excess of 20 mm/hr, causing severe run-off on inclined, bare or compacted surfaces.

The rainfall for several stations in the Okavango Delta and its fringes is summarized in Table A.7. Data from DMS (Met Services) indicate that the rainfall in the northern Delta varied from 500 to 870 mm. The figures for several stations, however, are not of adequate standard or they are incomplete, and this applies especially for the DWA stations within the perennial swamps. The records for Khiwum station with 626 mm for 1988/89 season can be regarded as fairly reliable only. The available records, however, are not yet complete and records from Safari Camps in the eastern Delta reported rainfall as high as some 1300 mm.

The total seasonal rainfall 1988/89 for the entire Okavango Delta was calculated to some 640 mm which is about 20% above normal rainfall and about 30% above rainfall of previous season 1987/88 (Table 4):

Table 4: Annual Rainfall in Okavango Delta Region

	Southern	Central Delta	Northern	Okavango AVG	Area* Rainfall
season 87/88	504	435	553	497	2982
season 88/89	575	544	801	640	3840
AVG	464	?	531	539	3234
	mm	mm	mm	mm	MCM

* Perennial and seasonal Okavango swamps cover on average 6000 km^2 (variable from 3500 to 8000 km^2 surface area in normal years)

Due to the relatively high number of rainfall days in January, February and April, the cloudiness during these months was also high (AVG 5/8) and mean temperatures slightly lower than normal. Consequently the actual evaporation rates during the summer season were lower than the long term averages. Actual data on evaporation are not available or they are not of adequate standard for analytical purposes (see WM-M1 Report). The regional evaporation of the Okavango Delta, therefore, was calculated as the mean evaporation of the "free water surface, EO", based on figures for Shakawe and Maun. Mean monthly and annual averages for Maun are shown in Table A.8 and Figures 6 and 7 (see also WM-M1 Report). A reduction of -10% from the AVG values was employed for the months January to April 1989 to calculate the actual evaporation, EO', of the swamps (EO'swamps) for the season 1988/89 in Table A.9. The seasonal figures are summarized in Table 5.

Table 5: Regional Evaporation (EO') of Okavango Delta

period	EO'	EO'swamp	EO's (Okavango area)
APR 88 - MAR 89+	2070	2173	9908
JUL 88 - JUN 89*	2168	2277	10531
	mm	mm	MCM

\+ hydrological Boro year * meteorological year
(see explanations Table A.9)

3.2 Water Balance of Okavango Delta

3.2.1 Water Balance Components

Calculations of the water balance of the Okavango Delta are based upon the following variables (Figure 8):

i) inflow and precipitation
- Okavango River inflow at Mohembo
- regional rainfall over swamps
- surface run-off from adjacent areas (islands)

ii) ooutflows
- Boro River
- Thaoge River
- Kunyere River (e.g. Xudum)
- Shashe River
- Santandadibe River and Gomoti River

iii) groundwater losses

iv) evaporation losses.

Okavango River Inflow

Total seasonal inflows (OCT-SEP) in 1986/87, 1987/88, and 1988/89 were <u>considerably lower</u> than average inflows, even if the "low-flow regime" during 1980-89 is considered:

1985/86	8764 MCM	(i.e. 91% of AVG 69-89)
1986/87	7558 MCM	(i.e. 79% of AVG 69-89)
1987/88	8286 MCM	(i.e. 86% of AVG 69-89)

The average flow volume during the 3-year period Oct 1986 to SEP 88 amounted to 8202 MCM/a (i.e. 85% of AVG 1969-89), the lowest inflow since the worst 3-year period from OCT 1972 to SEP 1974 (records since 1933), when inflow amounted to 7732 MCM/a only. This period then was followed by a 5-year period of high floods until 1979 (Figure 9).

Complete records for monthly inflows at Mohembo from OCT 1969 until MAY 1989 are summarized in Table A.10. Variations of monthly discharges for hydrological years 1983/84, 1986/86, 1987/88, and 1988/89 are shown in Figures 10 and 11 and plotted against AVG discharges for period 1970-89.

The hydrological year 1986/87 (Figure 10) was characterized by a very low peak ($\approx$ 400 m^3/s) in April and an abrupt decline during May-June. The August-September records of some 150 m^3/s were the lowest since 1970.

Daily and 10-day discharge figures for season 1987/88 are summarized in Table A.11. Inflow during the beginning of the season was extremely low (<300 MCM/mo). The flood commenced late February, the discharge remained at a rather low level and peaked end of April. During May the discharge was constantly high ($\approx$ 500 m^3/s) until it rapidly declined since June. The discharge remained, however, during the late season above the previous years levels (Figure 12).

Regional Precipitation

Monthly precipitation values of the hydrological seasons 1986/87, 1987/88 and 1988/89 are shown in Table A.12 and Figure 13. The seasonal rainfall in 1986/86 amounted to 63% of the long-term average (≈ 500 mm) only, reached 1987/88 the average and was 1988/89 about 30% higher than on average (Table A.6). Monthly figures can extremely deviate from the average values, too, since most of the rainfall occurred during localized thunderstorms.

Table 6: Seasonal Precipitation (Okavango Delta) 1986-89

year	AVG	1986/87	1987/88	1988/89	
Okavango	497	313	502	636	mm
Delta	-	63	101	128	% AVG
Area	2982	1878	3012	3816	MCM*
rainfall	2975	2504	4016	5088	MCM+

AVG = mean of (Maun + Shakawe) rainfall, 1922-1985, 1945-1985 resp.
MCM* rainfall over 6000 km² swamp area (realistic area figure for 1985 to 1989, SMEC pers.comm.)
MCM+ rainfall over 8000 km² swamp area; area figures for swamps differ considerably acc. to various authors; during the early eighties the swamps area was estimated to 8000 km³ (SMEC 1987,Vol.III)

Surface Run-off

The surface run-off from adjacent islands within the perennial and seasonal swamp areas is not considered in the calculations. These areas are extremely flat and the fringes of the islands are mostly covered by a dense vegetation of trees and grasses, providing efficient protection from run-off. The Delta area rainfall is calculated for an overall area of 6000 km² and covers all perennial swamps and most parts of the seasonal swamps. The rainfall which occurs over the larger Delta islands rapidly infiltrates, due to the predominantly sandy texture and the protecting natural vegetation cover.

There occurs, however, some run-off due to overgrazing, agricultural use and slope in the molapo areas at the southern Delta fringes and along the Thamalakane River. The surface run-off is estimated to some 20% of the total rainfall, i.e. the effective rainfall over the Thamalakane River, RFm and RFs, is calculated to 1.20 RF (see explanations Table A.15).

Okavango Delta Outflow

Any outflow from the seasonal swamps is collected either within the Thamalakane and Nqabe Rivers or the Lake Ngami. Other outflows can occur along the northeastern fringe towards the Linyanti-Zambesi River system or into Savuti swamps in years of exceptionally high floods. The years from 1984 up to date, however, are characterized by low inflows into the Delta system, and hence the outflow was restricted to the southern fringes.

In general there was no outflow or only very limited outflow recorded for most distributary systems (schematic configuration shown in Figure 8):

Table 7: Outflows (MCM) of Okavango Delta from Various Distributary Systems

distributary	Hydrological Season (APR-MAR) 1986/87	1987/88	1988/89	source
Thaoge	0	0	0	MDP#
Xudum/Kunyere	?	0	2	DWA-Maun
Shashe	0	0	0	DWA-Maun
Gomoti	0	0	0	MDP
Santandadibe	0	0	0	MDP
Boro (main channel)	129	50	96	MDP
Boro (Xasanare etc.)*	5	0	0	MDP

* estimates # Thaoge Mission Report to DWA

Detailed annual and monthly figures are summarized in Tables A.13 and A.14 for the Boro outflows since 1970 and 1981 up to date respectively. Figure 14 shows the high variation between the annual totals since 1970, with an average of 355 MCM (STD of 210 MCM). Four years of low outflow (1970-1973) were followed by 6 years of above average outflow and another 2 years with average outflow. Since 1982 the outflow was considerably less than average, except for years 1984/85 and the current flood in 1989/90. This results in an average outflow of 163 MCM (STD of 96 MCM) for the period 1980-1988.

The seasonal and annual variation for various hydrological years is shown in Figures 15 to 17. The flood seasons of the Lower Boro since 1981 up to date are characterized in Table 8.

Table 8: Hydrological Characteristics of Lower Boro Outflow 1981-89

year	start	peak	peak level	recession	cease	outflow
1981/82	JUN	JUL-AUG	v.high	OCT-DEC	JAN	average
1982/83	JUN-JUL	JUL-AUG	average	SEP-NOV	DEC	low
1983/84	JUN-JUL	JUL-AUG	v.low	SEP-OCT	NOV	ext.low
1984/85	MAY-JUN	JUL-AUG	v.high	SEP-DEC	JAN	average
1985/86	JUL	AUG	low	OCT-NOV	DEC	v.low
1986/87	JUL	JUL-AUG	low	OCT-NOV	DEC	low
1987/88	JUN-JUL	JUL-AUG	v.low	SEP-OCT	NOV	ext.low
1988/89	JUL-AUG	AUG-SEP	v.low	OCT-NOV	no	v.low

hydrological year of Lower Boro from APR to MAR
v. - very ext. - extremely

Groundwater Losses

The groundwater losses of the Delta area towards surrounding areas seem to be rather low when compared to other losses. Shallow, locally confined aquifers are seasonally recharged from the swamps, however, isotopic studies (cit.in: SMEC 1987,Vol.III) yielded that no significant groundwater flow exists towards the fringes and towards the surroundings of the Okavango Delta. It is likely that some groundwater losses occur from the swamps towards shallow aquifers beneath the adjacent islands where subsequently losses by evapotranspiration occur. In the seasonal swamps groundwater losses occur to replenish soil moisture and to restore the shallow water table.

It is estimated -for the Okavango swamps- that groundwater losses are approximately proportional to the volume of the surface water reservoir, or in the same order of magnitude as the surface water outflow (Dincer et al. 1987). The water balance of an experimental swamp area was calculated as follows (FAO 1976, cit. in: Dincer 1987,p.51):

Table 9: Water Balance of an Experimental Swamp Area

inflow	+ 19.6 TCM	100 %	
surface outflow	- 7.2 TCM	-39 %	of total losses
evaporation	- 2.4 TCM	-13 %	of total losses
volume change res.	+ 1.0 TCM		
groundwater losses	- 9.0 TCM	-48 %	of total losses

Note: Groundwater losses are calculated from the water balance

Evaporation Losses

The evaporation losses within the Okavango Delta area are roughly calculated to amount some 2200 mm or 10 000 MCM/season (Table A.9). Due to (i) seasonal changes of the extent of perennial and seasonal swamps and (ii) different vegetation types with various evaporation coefficients which vary from 0.3 to 1.5 (refer SMEC 1987,p.106) it is rather impossible to quantify the actual evaporation rates for the Okavango Delta region precisely. An uniform annual vegetation factor of 1.05 was employed for both annual and seasonal swamps. The surface area was estimated to 3500 km² from AUG-JAN and 6000 km² during the flood season from FEB-JUL. Mean values for the 'open water evaporation' were used (chapter 3.1).

3.2.2 Water Balance of Okavango Delta - Season 1988/89

The hydrological basic data and the water balance for the flood season 1988/89 (APR-MAR) are calculated for monthly periods in Tables A.15 and A.16. Annual totals are summarized in Table 10.

Table 10: Summarizing Seasonal Water Balance for 1988/89 (APR-MAR)

inflow at Mohembo	8384 MCM	70 %	(Qi)
rainfall	3539 MCM	30 %	(RFd)
total plus	11923 MCM	100 %	(Qt)
theoretical losses*			
evaporation	9911 MCM	83 % of Qt	(EO)
groundwater losses	1917 MCM	16 % of Qt	(GR)
adjusted losses*			
evaporation	8430 MCM	78 % of Qt	(EOadj)
groundwater losses	3397 MCM	22 % of Qt	(GRadj)
outflow at Boro	96 MCM	0.8 % of Qt	(Qb)

Mohembo records were shifted for 4 months; OCT record = APR

*Note: - theoretical losses consider potential evaporation
- adjusted losses consider the actual evaporation, derived from adjusted, i.e. positive, groundwater losses figures (in several months the potential EO's figures are higher than Qt values resulting in negative (theoretical) groundwater losses; these negative values were replaced by the groundwater losses in June)

Figure 18 shows the monthly variation of inflow and outflow. The inflow is shifted for 4 months due to the time lag between inflow at the northern Okavango and the outflow at the southern fringe. The flood (inflow) actually peaked in April (Figure 12) at Mohembo, the Lower Boro outflow, however, peaked in AUG-SEP (Figure 19). The monthly inflow figures were shifted in order to compare both figures.

Table A.15 shows that during the first part of the Lower Boro flood season the outflow amounted to 1.7% of the inflow and it decreased to less than 0.5 % at the end of the flood season in December. Due to high rainfall over the Delta in January and February the outflow increased again in mid January and still continued to increase at the end of the hydrological year (APR-MAR). Figure 20 shows the monthly variations of Boro outflow as percentage of the inflow at Mohembo (Qi) and the inflow plus rainfall (Qt) respectively.

The calculated figures for evaporation and groundwater losses (Table A.16) suggest that for extented perennial swamp areas the relation between evaporation and groundwater losses is considerably higher compared to smaller areas, e.g. experimental swamps (Table 9), floodplains or river channels (see Figures 28,29). The ratios for various areas are summarized in Table 11.

Table 11: Comparison of Evaporation versus Infiltration Relations

area	EO / Inf-ratio	remark
Okavango swamps	2.48	adjusted figures of EO
experimental swamp	0.27	
Thamalakane River		
total season	0.36	
beginning flood	0.16	moderate PET
peak flood	0.75	low PET
decreasing flood	0.58	high PET
end of flood	0.31	moderate PET

3.2.3 Water Balance of Thamalakane Basins - Season 1988/89

The Lower Boro outflow in relation to the outflow at Maun bridge is shown in Table A.17. About 70% of the outflow (without rainfall over the Thamalakane basins) flows downstream of Maun (at bridge) into the Lower Thamalakane and further downstream into the Boteti River. The outflow volumes for both Lower Boro and Thamalakane at Maun are compared in Figure 19. Figure 21 shows the monthly variation of the outflow at Maun as a percentage of Boro outflow. During the first month the outflow amounts to less than 50%, due to filling of the Upper and Middle Thamalakane basins and high infiltration rates within these basins. Subsequently the ratio increases to some 85% at the flood peak, until it decreases again to some 30-40 % at the end of the flood season. The high outflow ratio in March is caused by a second flood peak due to exceptionally high rainfall in JAN-MAR period.

The calculation of the water balance of the various Thamalakane basins is based on staff gauge readings (Table A.23) and hypsometric data (Table A.24 and Figures 32-42). The latter are presented in the relationship of:

elevation in MSL
versus
storage volume in MCM
surface area (ha)
average water depth (m).

It should be mentioned that the accuracy of the hypsometric data is not very high for both low water levels (below 933.0 MSL) and the river channels. Contour lines for these areas were available in 0.5 m intervals only and slight changes in elevation result in considerable increases in surface areas due to the saucer shaped basins (melapo and river beds).

Figures 45 to 49 show the gauge readings for the Boro and the Thamalakane River at various stations. Table A.23 summarizes daily or weekly staff gauge readings (plotted on Hydrographs), prepared by MDP. It is remarkable that the flood peaked twice during the flood season 1988/89, the "1st flood", due to Mohembo inflow, peaked end of August and the "2nd flood", due to high rainfall, started in February 1989 (still raising in June 1989). The water levels of the 1st peak occurred within 2 days at all staff gauge stations (29.08 until 2.09.1988). The water level gradient (during the peak) was very low in the Thamalakane:

Boro Xasanare	936.98 MSL	- 14.5 km	= 29 cm/km
Boro KB4	932.82 MSL	0.0 km	reference point
Matlapaneng bridge	932.41 MSL	+ 5.2 km	= 7.8 cm/km
Maun bridge	932.04 MSL	+ 16.6 km	= 4.7 cm/km
T2	932.62 MSL	+ 9.0 km	= 2.2 cm/km
T3	932.59 MSL	+ 15.5 km	= 1.5 cm/km

Tables A.18 to A.21 show monthly changes of storage volumes, evaporation and rainfall which are calculated for the following Thamalakane basins (see Figure 22):

Thamalakane upstream Boro T-junction (Lower Thamalakane):
'Boro backflow'
T 1 Thamalakane from Boro to Santandadibe
T 2 Thamalakane from Santandadibe to Gomoti

Thamalakane downstream of Boro T-junction (Middle Thamalakane):
T-Mat Thamalakane from Boro T-junction to Matlapaneng bridge
T-Mau Thamalakane from Matlapaneng bridge to Maun bridge.

The average depth of the basins, depending on average monthly water levels (Table A.23), was slightly increased (10 cm) to account for the irregular shape of the river channels. Example: an elevation of 932.48 MSL (e.g. OCT 88) would result in an average depth of 0.58 cm in the Thamalakane Basin (Boro-Gomoti); this depth was increased and set to 0.68 cm (Table A.24.4).

Figures for these four Thamalakane subbasin are included in Table A.22 which summarizes the following water balance calculations:

- changes in storage volume, SV'
- losses by evaporation of open water (river) surface, ETow
- supplement by rainfall over the River, RFt
- water balance, SV' + ETow
- infiltration losses, Inf, Qbr - Qm - SV' - ETow
- Thamalakane losses total, (Qbr - Qm) = (SV' + ETow + Inf)
- Thamalakane losses as percentage of Boro outflow,
  (SV' + ETow + Inf - RFt) * 100 / (Qb - Qm).

The results are presented in Figures 23-29, showing monthly storage volumes and evaporation plus infiltration losses for the sub-basins. Thamalakane losses are shown both in percentage of Boro outflow and in volumes (MCM). The subdivision of water losses into storage volume changes, evaporation and infiltration losses are shown in Figures 28 and 29 for T1 + T2 basins and T-Mat + T-Maun basins respectively. Annual totals are illustrated in Figures 30 and 31, and most important for MDP project is that

about 17% of the total annual Lower Boro outflow was lost as 'Boro backflow' into the Lower Thamalakane basins, i.e. 17.8 MCM.

This percentage is derived for a year of below average outflow and further investigations are required to verify this relation also for years of average or above average floods.

The water balance calculations (monthly flow volumes are summarized in Table A.27) can be roughly checked against spot measurements of the discharge within the Thamalakane River upstream of Boro T-junction. The discharge measurements are presented in Figures 55-57 and in Tables A.25.1 to A.25.6. Comparisons between calculated values and discharges are summarized in Tables A.26 and A.27. The figures for August-September (dates of discharge measurements) indicate that the calculated water balance values are some 25% lower compared to measured discharges:

season 1988	m^3/s	m^3/d	MCM m^3/mo	
water balance calculations	0.74	64267	1.93	SEP
water balance calculations	0.96	82871	2.57	OCT
discharge measurements (ø) at T 3 (15/8/88 - 2/9/88)	1.01	87264	2.62	AUG/SEP

It should be mentioned, however, that spot discharge measurements with a dipstick were conducted under difficult conditions, i.e. at a very low flow rate (AVG 7-10 cm/s) and a rather high relation width-depth of the river which can easily produce a deviation of some 10-30% compared to the accurate discharge. In general, therefore, the discharge measurements confirm the figures calculated from the water balance for the Thamalakane basins.

3.3 Extent of Flood in Molapo Areas in 1888/89

The flood peak level, peak discharge rates and total annual discharge volume were low in the Lower Boro River in 1988/89 (Table A.13). The flood conditions, however, improved compared to the extremely low flood in the previous year and the Thamalakane River was filled with floodwater until the end of the season (MAR). Nevertheless, molapo areas of the MDP were not inundated during the 1988/89 flood season. All floodwater in the Thamalakane River originated from the Lower Boro outflow at the Boro T-junction where the water is diverted downstream (via Maun-Boteti) and upstream ('backflow') towards the Gomoti confluence near Shorobe village.

There was only limited flow in the Santandadibe and Gomoti Rivers south of the Kunyere faultline (Vet Control Fences) and therefore these rivers did not reach the Thamalakane confluence. Larger blockages existed in the Santandadibe system which severely restricted the flow just south of the cordon fence. In August the flood reached the village of Cairo (5 km south) were it was diverted by farmers. It was recognized that the flow pattern changed as compared to previous (drought) years and several areas (floodplains) had been flooded which were dry even in 1984 during an average Boro-flood. In the Gomoti system the flood stopped at the cordon fence and did not reach Makoba village.

The Lower Boro flood commenced in July 1988 and inundation was confined to the Thamalakane channel where it covered a maximum area of some 257 ha within the T 1 and T 2 basins, calculated from Boro T-junction upstream to the Gomoti confluence (see Figure 44). The maximum water level in the

Thamalakane next to the Santandandibe confluence was 932.62 MSL.(Figures 47-49). The flood slowly receeded until January 1989. Subsequently the water level was continuously rising again, as a result of the high summer season rainfall over the Delta area. The maximum extent of the flood is shown in Map 2. In Figure 51 the extent of flooded areas on 31st August 1988 is presented for various sections (schematically shown as boxes) of the Thamalakane River downstream to Maun bridge.

Furthermore some 250 ha molapo areas were inundated within the Xasanare distributary for some 3 months, the front line did not reach, however, the Thamalakane confluence. The flood entered the Xasanare system through the main bund (Xasanare off-take) at km 4.2 (from vet fence). The (ungated) bund was opened by farmers on 10/08/88 and it was closed in December 1988. An average discharge of some 0.42 m^3/s or 1.1 MCM/mo was measured in September 1988 (Table A.26 and A.25.5-7). Assuming a total inflow period over 75 days (AUG-OCT) with 36 000 m^3/d and 55 days (NOV-DEC) with 15 500 m^3/d the discharge into the Xasanare channel totals some 3.6 MCM from AUG-DEC. Since March 1989 (up to date) the main Xasanare channel is flooded again, and since May 1989 adjacent molapo areas are flooded also, the floodwater entering the floodplains from various channels along the Kunyere faultline.

3.4 Impact of Flood on Groundwater

The piezometer records for P1, P2, P4, P6, P7a and P11 are presented in Figures 58-63 for the period August 1988 to April 1989. Measurements in various melapo (MDP-area) indicated that there was no significant influence of the flood on groundwater depth. A very slight rise of the GW-table in the range of 5-35 cm occurred in some piezometers during the rainy season, other piezometers, however, showed a slight continuous drop over the entire season, e.g. P7a.

In most melapo the groundwater table is deeper than 6.5 m b.g.l., i.e. below 926.5 MSL, and in some piezometers (P3, P5, P8, P9, P10, P13) the GW-level remained below the tube depth (mostly 6 to 9 m).

Piezometer P6, nearby the Thamalakane River at T3, showed an uprise of some 40 cm in water level one month after the sandy river bed at some 300 m distance was inundated. Three months later, before the rainy season started, the water level dropped again.

The existing alignment and the observation densitiy of piezometers does not allow the calculation of hydraulic gradients, derived from groundwater contours. It is suggested that the heterogeneous floodplain pattern and the stratification of the alluvial sediments in the Boro-Shorobe area requires a more sophisticated layout of piezometer lines. This remains beyond the scope of MDP works and the existing piezometers serve as spot observations only.

3.5 Quality of Surface- and Groundwater

Existing data on groundwater and surface water quality indicate that there are no restrictions on its domestic use and for agricultural purposes. The total salinity, expressed as EC_w, is 'very low' throughout the year in both groundwater and surface waters.

Table 12: Salinity of Surface and Groundwater

location	EC	TDS
Okavango Water		
Mohembo inflow	< 0.07 mS/cm	< 50 ppm
Okavango Delta channels	0.10 mS/cm	64 ppm
Lower Boro (Xasanare)	0.11 mS/cm	70 ppm
Santandadibe	0.11 mS/cm	70 ppm
Thamalakane T2		
beginning flood	0.17 mS/cm	109 ppm
peak flood	0.13 mS/cm	83 ppm
Thamalakane Matlap.bridge	0.10 mS/cm	64 ppm
Groundwater		
piezometers near river	0.40 mS/cm	256 ppm
piezometers in melapo (AVG range)	0.74- 1.00 mS/cm	474-640 ppm
deep well at S.C.	1.90 mS/cm	1216 ppm
traditional wells	0.5 - 1.2 mS/cm	320-768 ppm
Rainwater (DEC)	0.01 mS/cm	< 10 ppm
Surface Water (pools)		
after rainfall	0.07 - 0.55 mS/cm	44- 352 ppm
end of rainy season	0.1 - 2.0 mS/cm	64-1280 ppm

Details of water sample analyses are presented in Tables A.28.1-2. Seasonal changes in groundwater salinity are low. This might be the result of the lack of floods in melapo (since 1984) as they contribute to the replinshment of shallow aquifers.

Previous analyses yielded similar results indicating a very low total salinity (SMEC Vol.III,1987), the seasonal changes, however, were reported to be in a larger range:

Lower Boro 0.12 to 0.33 mS/cm 75 - 208 ppm

Various boreholes near Maun have generally a slightly higher salinity ranging from 0.1 to 0.6 mS/cm (DIWI 1989) with a predominance of calcium carbonate contents. Few wells had a EC up to 3.0 mS/cm (BRGM 1986) with a predominance of sodium chloride.

The well at the S.C. is, in contrast to water samples from neighbouring molapo (piezometer and traditional well records), medium saline and moderately hard. The total disolved solids are only slightly below the maximum permissible concentration (Table A.29). This well might tap deeper aquifers (>20 m) which are likely more saline than shallow aquifers. Due to the lack of borehole logs this remains, however, unproved.

It can be concluded from the data available that:

- surface water in channels is 'low salinity water'
- soil water in upper soil profiles (<0.5 m) is 'low to medium saline'
- soil water in deeper profiles (0.5-1.5 m) is 'low salinity water'
- shallow groundwater (4- 10 m) next to rivers is 'low salinity water'
- shallow groundwater (4- 10 m) in melapo is 'medium salinity water'
- deeper groundwater (> 15 m) is 'high salinity water'.

According to international standards water is considered as excellent for irrigation (agricultural) use if the EC is below 0.7 mS/cm (FAO, IDP 29). The maximum allowed TDS level for WHO and DWA drinking water standards are 1000 ppm and 1500 ppm respectively (DIWI 1989). The total hardness of most groundwaters, however, is often close to the maximum accepted level, especially in wells near Maun (BRGM 1986).

In general the water analyses for the MDP area suggest that there is nor a groundwater neither a soil salinization hazard to be expected in the near future. The actual soil salinity is reported to be low, the spot results, however, are not conclusive:

FAO-Soil Survey 1985		no data	
FAO Soil Lab 1985/86		< 0.1 mS/cm	
Agric Research Soil Lab (1987, 1988)		0.2 - 0.3 mS/cm^{+}	(1:2.5 extract)
USAID Survey 1987			
	topsoil	0.2 - 3.6 mS/cm (AVG 1.0)	(satur.paste)
	subsoil	0.1 - 1.0 mS/cm (AVG 0.2)	

(Note: $^{+}$conversion factor is (EC * 2.7) to get saturated paste value)

In future a soil salinity investigation programme should be conducted in cooperation with soil survey staff at Maun in order to verify the existing spot observations and to monitor the salinity level of arable soils under flooded and non-flooded conditions.

4. EXTENT OF FLOODS IN MOLAPO AREAS IN PREVIOUS YEARS

Due to the low inflow into the Okavango and the low rainfall over the delta the extent of floods within Boro-Shorobe floodplain had been limited in the previous years, too. Since 1982 the protected MDP-molapo areas were not flooded at all, except in 1984/85 season.

All floodwater in the eighties was derived from the Boro backflow only, due to the cease of any flow of the Gomoti and Santandadibe Rivers downstream of the buffalo fence. It is well recognized that flow within the Gomoti-Santandadibe distributary system which constitutes some 13% of the entire Okavango swamps, deteriorated considerably since the past 50 years. The deprive of its share of flow ic caused mainly by unfavourable -natural and artificial- developments upstream, e.g. the Ngokha blockage and Smith's channel (Kraatz, 1983). It lies in the nature of the Okavango system that variations of flow at the upper distributary system can cause pronounced changes of flow conditions at the far downstream ends, i.e. at the Kunyere and Thamalakane faultlines (Map 2).

Due to the lack of continuous records for Gomoti and Santandadibe Rivers only a tentative evaluation is possible of the distributaries contribution to the flood in Boro-Shorobe melapo for the previous 20 years. The prolonged and high floods during the period 1974-79 were almost exclusively caused by Boro backflow. The inflow from Santandadibe and Gomoti was most likely <15% of total inflow into the lower Thamalakane basins. In 1982 and 1983 flood seasons the Santandadibe flow did not reach the Thamalakane confluence and Mazanga molapo was not flooded. In 1984 -an average Boro flood year- there was only a small flow towards the confluence and once again, Mazanga molapo was not flooded. Since 1985 up to 1989 there was no flood at all which reached as far as Malalakgaka gauge some 3 km upstream Thamalakane confluence. Santandadibe flow into Xuxao lagoon was restricted to the floods in 1984 and 1986. In 1984 the lagoon was also fed by Boro backflow.

The conditions of flow in the Gomoti River south of the cordon fence were even worse. The was no flow within the lower channels of Shemeshemega and Qaaba (eastern branches of the Gomoti) for the past 25 years. The Gomoti main channel passes Makoba and Gabamachao melapo to reach the Thamalakane confluence next to Xhwaa molapo. There was no flow since 1979 south of Makoba village, except for 1984 when the flood passed several km southwards. It is evident that in years of low flow the flood does not reach the Thamalakane confluence at all. In years of high flood the discharge is very limited during the past 30 years.

Summarizing, the discharge in Gomoti-Santandadibe distributaries downstream of cordon fences did not contribute to flood MDP molapo areas and a water development scheme can not rely on Gomoti-Santandadibe discharge also in future. Only major river improvements can bring any change and may increase the flood reliability. Flood conditions in the MDP area are, therefore, caused by Boro backflow solely. Future changes should be, however, carefully observed and a hydrological monitoring system should be implemented.

Characteristics of floods during the period 1981-1987

The flood in 1987/88 (APR-MAR) was one of the lowest and shortest ever recorded. The Boro outflow amounted to 50 MCM only. The flood was confined to the Thamalakane River bed where some 257 ha were inundated (see Figure 50). The inundation commenced in June and lasted for several weeks only. The peak was recorded during mid to end July with following staff readings:

Xasanare	1.10 m	936.67 MSL		(MDP)
Boro	1.39 m	933.69 MSL		(DWA)
Matlapaneng	1.74 m	932.31 MSL		(DWA)
Maun bridge	1.34 m	931.55 MSL	AUG	(DWA)

The flood in 1986/87 (APR-MAR) can be characterized by a high but very short peak (Figure 45). The floodwater reached Nxamathama pool, none of the MDP melapo areas, however, had been flooded. The water stopped some 400 m in front of the Xhwaa sluice (implemented since 1986). The inundation of Nxamathama lasted for six weeks from July until end of August only. The following peak water levels were recorded:

Xasanare	1.60 m	937.17 MSL		(MDP)
Boro KB4	1.94 m	933.24 MSL		(DWA)
Nxamathama		933.10 MSL		(estimate MDP)
Matlapaneng	2.20 m	932.77 MSL		(DWA)
Maun bridge	1.90 m	932.11 MSL	OCT	(DWA)

Some 566 ha along the Xasanare channel had been flooded from the Boro River for several months (Bendsen 1987). The limited discharge capacity of the breached bund (Anglo-American), which was opened by the farmers, restricted the inundation of the area considerably, and a drop in water level of about 1 m was observed within few km distance from the Xasanare off-take. Map 5 shows the extent of the flood in 1986 in the Xasanare channel.

The extent of flood in 1985/86 (APR-MAR) was similar to the flood 1988/89 during the first part of the season (APR-NOV). Due to the low rainfall in 1985/86 summer season, however, no 2nd peak was recorded and the flood receeded continuously from October until December. The following peak water levels were recorded:

Xasanare	1.84 m	937.41 MSL	(MDP)
Boro KB4	1.73 m	933.03 MSL	(DWA)
Matlapaneng	2.07 m	932.64 MSL	(MDP)
Maun bridge	1.88 m	932.09 MSL	(DWA)

The inundated area was restricted to the Thamalakane River where an area of some 310 ha were covered at peak in September (Figures 52,53). Neither any MDP molapo areas nor Nxamathama pool were flooded.

The <u>flood in 1984/85</u> (APR-MAR) was the highest over the period 1981-89. The Boro outflow amounted to 290 MCM and the highest discharge of 28 m^3/s recorded since 1981 was measured in August 84. The following peak water levels were recorded:

Boro KB4	2.52 m	934.82 MSL		(DWA)
Maun bridge	2.49 m	932.70 MSL	OCT	(DWA)

The max flood levels in the project area (at Xhwaa sluice) were reported on 24th Sep 1984:

933.47	MSL	Xhwaa sluice,	933.30 at MS 8A	(MDP)
933.55	MSL	Xere sluice,	933.16 Bura melapo	(MDP)
933.15	MSL	Nxabe (Shorobe)		(MDP)
933.55	MSL	Sakapane		(MDP)
933.76	MSL	Boro T-junction (for reference)		(DWA)

The flood commenced in July and receeded from September onwards. Some pools in Xhwaa and Tshonxomo, however, were inundated as long as April 85. In total some 782 ha melapo (see Figure 54) had been flooded in addition to some 575 ha within the Thamalakane and Gomoti Rivers:

528 ha	in Xhwaa, Shorobe (Tshonxomo) and Nxabe melapo (MDP-areas)
254 ha	in Sakapane and Totoga
40 ha	in Mazanga
90 ha	in Charichambe

There are only very limited data available on floods and flooded areas prior to 1984. Estimations on the extent of floods can be derived from satellite images, aerial photos and staff gauge records in the Boro and Thamalakane. Some data are, in addition, not consistent with recent records.

The <u>flood in 1983/84</u> (APR-MAR) was very low and can be compared to 1987/88. No molapo areas were flooded and the following peak water levels were recorded:

Boro KB4	1.38 m		932.68 MSL		(DWA)
	1.60 m	?	932.90 MSL		(MDP)
Matlapaneng	1.70 m		932.27 MSL		(DWA)
Maun bridge	1.39 m		931.60 MSL	AUG	(DWA)

The <u>flood in 1982/83</u> (APR-MAR) was still below average with regard to the Boro outflow. The peak discharge (some 20 m^3/s) was similar to flood season 1986/86, the flood, however, lasted longer until September when it started to decline rapidly (Figure 15). The water level records indicated a rather high peak in:

Boro KB4	2.67 m	933.97 MSL		(DWA)
Maun bridge	2.08 m	932.29 MSL	AUG	(DWA)

The flood in 1981/82 (APR-MAR) was above average and the highest discharge record is as high as 30 m³/s in July 81. The peak water level were recorded:

Boro KB4	3.05 m	934.35 MSL		(DWA)
Matlapaneng	3.25 m	933.82 MSL		(DWA)
Maun bridge	3.10 m	933.31 MSL	JUL	(DWA)

The extent of flood in molapo areas is not exactly known, it is expected, however, that from August 1981 until April 82 most of the Boro-Shorobe melapo were prolonged flooded.

The flood in 1980/81 (APR-MAR) was above average and the peak water level in the project area had been - most likely - similar to 1981/82 season.

Boro KB4	2.86 m	934.16 MSL		(DWA)
Maun bridge	2.84 m	933.05 MSL	AUG	(DWA)

The flood levels (hygrographs) of the Lower Boro (hydrographs) from 1970 up to date are summarized in Figure 64. The peak water levels and flooded areas are calculated in Table A.32 with the use of hypsometric data of Table A.24. Table 13 presents a summary of seasonal figures.

Table 13: Peak Water Levels in Lower Boro

hydrological year (APR-MAR)	staff reading	topographic level	peak month	flooded molapo (ha)
1969/70	1.90 m	933.20 MSL	AUG	0
1970/71	1.46 m	932.76 MSL	AUG	0
1971/72	2.23 m	933.53 MSL	AUG	320
1972/73	2.49 m	933.79 MSL	SEP	512
1973/74	1.34 m	932.64 MSL	AUG	0
1974/75	3.16 m	934.46 MSL	APR	980
	3.02 m	934.32 MSL	SEP	1111*
1975/76	3.53 m	934.83 MSL	JUL/AUG	1111
1976/77	3.37 m	934.67 MSL	AUG/SEP	1111
1977/78	3.40 m	934.70 MSL	AUG/SEP	1111
1978/79	3.77 m	935.07 MSL	AUG	1111
1979/80	3.25 m	934.55 MSL	JUL	1111
1980/81	2.86 m	934.16 MSL	AUG	850
1981/82	3.05 m	934.35 MSL	JUL	1050
1982/83	2.23 m	933.53 MSL	AUG	320
1983/84	1.38 m	932.68 MSL	AUG	0
1984/85	2.52 m	933.82 MSL	AUG	520
1985/86	1.73 m	933.03 MSL	SEP	0
1986/87	1.94 m	933.24 MSL	JUL	0
1987/88	1.39 m	932.69 MSL	JUL	0
1988/89	1.52 m	932.82 MSL	AUG	0

* in years of flood level >934.0 MSL the maximum floodable area was estimated uniformly to 1111 ha

Flooded molapo areas were calculated only for Tshonxomo/Mochaba (former designation 'Shorobe') + Xhwaa + Dikabole (former designation 'Nxabe' melapo. Other melapo in the Boro-Shorobe floodplain (e.g. Sakapane) were not considered due to the (current) lack of flood control infrastructure in these areas. The (theoretical) water level for every year is calculated, assuming a hydraulic head loss of 0.50 m between Boro River and the peak water level inside the molapo, attainable after two months inundation period. The estimated hydrographs for the molapo areas are shown in Figure 65 from 1970 up to date, using the available flood data for 1984 and 1986 for calibration.

Floodable areas at 934.0 MSL level are listed in Table A.30 and floodable areas at 933.5 MSL level are shown in Map 6. Derived from 'surface area' versus 'water level' relationships for Xhwaa and Tshonxomo melapo (Table A.31 and Figures 66-68) the theoretically flooded areas were calculated. These figures do not, however, consider the actually cultivatable areas which might be less due to prolonged flooding in unprotected melapo. Furthermore the surface flow within the molapo basins is restricted by narrow channels and crestlines between various subbasins which also reduce the actually flooded areas as compared to the theoretically floodable areas, derived from water level versus surface areas relations. Field observations since 1984 indicate that:

- at WL below 932.80 MSL no flooding at all occurs in MDP melapo
- at WL between 932.80 and 933.50 MSL about 80% of the (theoretically) floodable areas only will be actually inundated
- at WL higher than 933.50 MSL the theoretically floodable melapo will be totally (100%) flooded, because flow restrictions are not important anymore.

The estimated flooded molapo areas are listed in Table A.32, assuming a loss of hydraulic head of 0.5 m, i.e. 2.2 cm/km equivalent to the gradient of 1:45 000. The estimated WL' at the entrance of the melapo (at sluice gates) is calculated in column 4 of Table A.32.

As conclusion it can be stated for the core area of the MDP:

- in 8 out of 20 years (40%) no flood occurred
- in 3 out of 8 'dry' years (i.e. 15% of 20 years) channeling in the Thamalakane would have allowed to flood some melapo
- in 4 out of 20 years (20%) a high and prolonged flood occurred which restricted the cultivatable areas under non-controlled conditions (since 1986 floods are controllable)
- in 8 out of 20 years (40%) at least parts (<30%) of the melapo had been flooded (without years of prolonged flooding)
- in 10 out of 20 years (50%) at least 50% of the floodable areas (550 ha) would have been flooded under controlled conditions
- in 12 out of 20 years (60%) at least 30% of the floodable areas (300 ha) would have been flooded under controlled conditions.

These conclusions are based on the assumption that only Boro backflow contributes to the flooding of Xhwaa, Tshonxomo and Dikabole melapo. The restoration of flow in the Gomoti system might increase the probability of flood occurences, which cannot be quantified due to lack of hydrological data.

5. IMPACT OF FLOOD PATTERN AND RAINFALL CONDITIONS ON CURRENT LAND USE

The flooding period has a strong influence on cultivation pattern in the Boro-Shorobe floodplain with regard to its duration, commencement and end of inundation. The advantage of the traditional molapo farming system is the inundation of the floodplains by Okavango floodwater for several weeks or months prior to the rainy season (Figure 69).

Molapo farming, therefore, is a flood recession practice which support rainfed cultivation on comparatively fertile floodplain soils. The inundation replenishes the soil moisture and due to the medium to heavy texture of the subsoils the profiles can store a considerable quantity of water which can be used by plants especially during the dry spells which occur often within the rainy season.

The lack of any flood restricts the possibility of cultivation to rainfed farming when plants depend on rainfall solely. Without previous flooding farming, therefore, is more risky because of the erratic start of the rainy season, the high variability of total seasonal rainfall and the occurence of extended dry spells within the rainy season.

Very high and prolonged floods likewise are adverse, as they do not allow timely soil preparation or farming at all under non-controlled conditions, i.e. without bunds and sluices. It is one aim of the MDP to avoid these high and prolonged floods (see Figure 70 for timely farming operations).

Table 13 indicates that adverse flood conditions occurred in 12 out of 20 years since 1969. During the period 1975 to 1979 floods were too high and prolonged, whereas the during the periods 1969-1970 and 1985 to 1988 no floods at all occurred. Favourable flood conditions -without flood control- existed during 1971 to 1974 and 1979 to 1984 (2 dry years included) only. Favourable farming conditions, however, require sufficient rainfall, too.

Table 14 summarizes the farming condition as depending on pre-flooding and rainfall for Xhwaa + Tshonxomo + Dikabole melapo since 1969. It is evident that natural conditions for non-flood controlled molapo farming are rather risky with regard to flood and rainfall:

- in 5 out of 20 years (25%) the molapo areas were non-flooded and rainfall was very low, i.e. in 1969/70, 1983/84, 1985/86, 1986/87, and 1987/88 (Remark: rainfall in 1987/88 was higher in Xhwaa compared to Maun, see Table A.1; cropping conditions, therefore, were more favourable in Xhwaa area).

- total rainfall was sufficient (>420 mm/a) for rainfed farming in 9 out of 20 years (45%). It is evident, however, that even in years of high rainfall dry spells (months with less than 40 mm) occurred which reduced yields especially under non-preflooded conditions, e.g. in 1970/71. Reasonable yields, on the other hand, can be produced on melapo soils under non-preflooded conditions with sufficient rainfall, e.g. 1973/74 and 1988/89.

- in 5 out of 20 years (25%) at least 30% of the molapo soils were flooded, rainfall, however, was very low, i.e. in 1972/73, 1978/79, 1981/82, 1982/83, and 1984/85. Yields most likely were reduced.

- in 2 out of 20 years (10%) rainfall was sufficient, the molapo areas, however, had been flooded for prolonged periods, i.e. in 1976/77 and 1977/78; it is most likely that in these years the cultivatable areas were considerably reduced.

- in 2 out of 20 years (10%) rainfall was low and the melapo had been flooded for prolonged periods, i.e. in 1975/76 and 1978/79; the cultivatable areas and yields were most likely reduced.

Table 14: Assessment of Farming Conditions in MDP Area since 1969

year	flood: flooded area (ha)	flood: prolong.	rainfall: annual mm	rainfall: start	rainfall: dry spells
1969/70	0	no	277	NOV	DEC,FEB-APR
1970/71	0	no	427	NOV	FEB-MAR
1971/72	320	no	697	NOV	(FEB),APR
1972/73	512	no	243	DEC	MAR-APR
1973/74	0	no	1188	OCT	MAR
1974/75	980	no	632	NOV	DEC
1975/76	1111	yes	379	DEC	APR
1976/77	1111	yes	512	NOV	DEC,APR
1977/78	1111	yes	734	NOV	MAR-APR
1978/79	1111	yes	292	DEC	FEB-APR
1979/80	1111	no	509	JAN	(MAR),APR
1980/81	850	no	496	NOV	DEC,APR
1981/82	1050	no	209	NOV	JAN-APR
1982/83	320	no	391	OCT	DEC,FEB-APR
1983/84	0	no	356	NOV	JAN-FEB,APR
1984/85	520	no	302	NOV	DEC,(FEB),APR
1985/86	0	no	386	DEC	MAR
1986/87	0	no	295	OCT	JAN,MAR-APR
1987/88	0	no	352*	DEC	JAN,APR
1988/89	0	no	653	DEC	(MAR)
1989/90	500 ?	?			

year - hydrological year APR 69 to MAR 70
meteorological year JUN 69 to JUL 70
rainfall data from Maun Met-station
rain season - start = first months >40 mm/mo
- dry spell = if any months from NOV to APR <40 mm/mo
months with some 40-60 mm in brackets
* rainfall in Xhwaa was 678 mm/a, no dry spells occurred until APR
prolonged - flood extends into the cropping season (DEC-APR)

The current distribution of cultivated lands and the development since 1951 is shown in detail in Report WM-N1, Tables 2, 4 and 5. There was a remarkable decrease of molapo farming ranging from some 3000 ha in the sixties to some 600 ha in 1988 observed (MDP-areas only). It is recognized, however, that the reference years in the sixties and seventies (1967, 1973, 1951) had average or above average rainfall and most likely more favourable flood conditions than it was the case especially in the eighties, when low floods and low rainfall coincided.

On the other hand it is remarkable that the distribution of farmland pattern changed during the last decades: the bulk areas of molapo farming are nowadays confined to Xhwaa and Tshonxomo melapo, whereas in former periods also Sakapane, Gabamachao, Totoga, Toroga and other melapo were cultivated more intensively. As a result of the absence of any flood in traditional molapo there was also a tendency in the eighties to utilize the seasonally flooded banks of the Boro and Thamalakane Rivers and parts of Xasanare areas. Furthermore, since 1951 there is a tendency that the remote molapo are deserted and cultivation is practiced near the larger settlements (along the Thamalakane Faultline: Shorobe, Mochaba, Matsaudi, Matlapaneng).

An exact comparison between two seasons with different flood conditions is possible for 1984/85 and 1987/88. In 1984/85 some 800 ha were flooded in MDP areas and despite unfavourable rainfall (<400 mm) some 800 ha had been cultivated. In 1987/88 rainfall was high (>600 mm), however, no melapo areas were flooded. The total cropped area comprised some 530 ha in MDP areas. The decrease of molapo farmland under unfavourable flood conditions amounted some 40-50%. The favourable flood conditions in 1989/90 season might prove whether the process of decline can be reverted under more favourable natural conditions.

The production potential under various conditions of pre-flooding and rainfall can be assessed by the comparison of yield estimates on (advanced) farmers fields for seasons 1984/85 and 1987/88 in Table 15.

Table 15: Yield Estimates for Seasons 1884/85 and 1987/88

flood conditions	1984/85 maize yields	1987/88 maize yields
pre-flooded	3.1 t/ha	no flood
non-flooded	crop failure	3.1 t/ha

figures provided by MDP-Agronomist 1989

The figures indicate that pre-flooding of fields is important especially in years of low rainfall. Sufficient yields, however, can be obtained from molapo soils also without pre-flooding provided that rainfall conditions are favourable.

6. IMPLICATIONS ON WATER DEVELOPMENT PLANS FOR MDP

6.1 Regional Water Resources Planning

Within the framework of the Water Resources Planning for National Development it was recognized that the outflow of water at the southern distal end of the Okavango Delta can be considered as one of Botswana's most valuable water resources. At present it is an underutilized resource which is under natural flow conditions a very unreliable resource, due to erratic rainfall and variable flood conditions. Present main users are

- molapo farmers of the Boro-Shorobe floodplain, in 1988/89 some 800 ha (floodplains and floodable areas are listed in Table A.30)
- riparian farmers (incl. small scale irrigation) along Thamalakane, and Boteti
- riparian commercial medium/large scale farmers (irrigation)
- cattle farmers along the Lower Boro, Thamalakane, Nhabe and Boteti
- in years of high floods also users along the Nhabe and Lake Ngami
- Orapa diamond mines which withdraw water from Mopipi pan in addition to the supply from deep groundwater wellfields.

Future demands are increasing (e.g.Orapa) and the increase in reliability of water supply is a precondition to any commercialized agricultural development in the area and for the improvement of traditional farming (e.g. molapo farming). In addition, the increasing water demand for Maun village requires the extraction of surface water from the Delta's outflow. The present water supply system is barely sufficient to meet future demands; the demand is covered by boreholes which tap shallow, locally slightly saline, aquifers with limited yields from the Shashe River and along the Thamalakane River.

Therefore, the need for a regional water development scheme was felt by Botswana government which entrusted DWA with the Southern Okavango Integrated Water Development Plan (SOIWD, executed by SMEC,1987,1988). After consideration of a large number of technical components and alternatives the proposals of SOIWD plans are as follows:

- outflow supplementation schemes:
  Lower Boro River Improvement Scheme (Boro-dredging);
  this should increase the annual outflow by some 50 MCM also in 'dry years'

- outflow regulation schemes:
  Matlapaneng Reservoir to meet Maun domestic use and to supply molapo
  Maun Reservoir to supply agricultural users along Thamalakane, allow fisheries and allow regulation of Boteti outflow
  Sukwane Reservoir to supply Orapa mines by means of pumping reservoir water through a pipeline to Mopipi reservoir.

Several river control structures are necessary. The most important are:

- Matlapaneng Dam
- Thamalakane Bund and Weir ('Molapo bund')
- Samedupi Dam
- Toteng Dam
- Shashe River Bund
- Sukwane Dam.

The results of the proposed systems configurations and the reservoir operation are in brief:

- increase reliability of Maun water supply to 99% of all years
- increase water reliability for Orapo mines to 91% of all years
- allow commercial agriculture on 1100 ha
- benefits for fishery and livestock by creating reservoirs
- allocate 51 MCM of floodwater for molapo farming in 66% of all years.

The dam sites and various scenarios of years with 'low outflow' and years with 'high outflow' are shown schematically in Figures A.71-72.

6.2 Needs of Improved Molapo Farming in Relation to SOIWD Works

DWA ensured the involvement of MDP in planning from the very beginning of the SOIWD works and the MDP expressed its opinions on various planning aspects. Moreover MDP specified the particular requirements to improve molapo farming in the Boro-Shorobe floodplain. These can be summarized as follows:

- first traditional water users of Boro outflow are the Boro-Shorobe molapo farmers. It is calculated that the natural backflow of the Boro (upstream towards Gomoti confluence at Shorobe village) amounts to some 15-20% (AVG 17%) of the annual discharge. This relation can be as high as 30% during the first month of the flood season. Any water development plan should consider these traditional water rights of molapo farmers.
- a high FSL level of 934.50 MSL of Matlapaneng Reservoir would facilitate MDP to flood molapo areas within 2.5 months, thus reducing the total water demand per unit area from some 40 000 m^3/ha to some 15-25 000 m^3/ha (see Roostee 1987).
- a gated bund across the Thamalakane, upstream of the Boro T-junction, is required for molapo farming to control upstream flow (masterbund of Kraatz' proposals, hereafter referred to as 'molapo bund').
- in order to flood some 1500 ha molapo areas (mainly Xhwaa,Tshonxomo, totage, Dikabole,Sakapane) within 2.5 months it is necessary to construct a gate of 4-5 m^3/s flow capacity at the molapo bund.
- the total water demand to flood some 1200 ha (WL 934.00 MSL) amounts to some 55 MCM/season, inclusive storage volume for Thamalakane River basin from Santandadibe to Gomoti confluence; if other melapo should be flooded the total water demand totals some 80-100 MCM/a.
- a timely release of floodwater from the Matlapaneng Reservoir should start latest in July and end in mid to end September. This allows for recession of flood during October-November to meet with the timely farming operations (see farming calendar).
- under the present hydrological regime (1969-1989) the probability of flood for Xhwaa and Tshonxomo melapo (1200 ha) is assessed at:
  40% of 20 years: no flood occurs
  20% of 20 years: some 30% of molapo areas are flooded
  40% of 20 years: at least 850 ha (i.e. 70%) are flooded.
- the SOIWD plans should increase the reliability and availablity of floodwater in Shorobe floodplains; the current plans of gate operations schedules the probability of flooding to about 66% which is not very satisfactory compared to benefits for other users.

Further operational rules and hydrological data must be evaluated for final comments.

- it is necessary to construct bunds along the northern fringe of the planned Matlapaneng Reservoir and the Thamalakane River, upstream of Santandadibe to Gomoti confluences (at Xhwaa sluice) to avoid huge water losses to adjacent melapo (e.g. Sakapane, Totoga, Charichamba).
- bunds along the Thamalakane upstream of 'molapo bund' should be in the (financial) responsibility of MDP, planning and construction, however, should be executed by the same contractor responsible for Matlapaneng works.
- dredging of the Lower Boro (see map 8) as proposed by the SOIWD plan is not necessary to cover the demands of traditional molapo farmers only.

Further details are discussed in attached minutes of meetings with DWA and SMEC consultants (Annexes 1-3).

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Unpublished field data were provided by:
Department of Water Affairs, Hydrology Section, Maun
Department of Meteorological Services, Gaborone

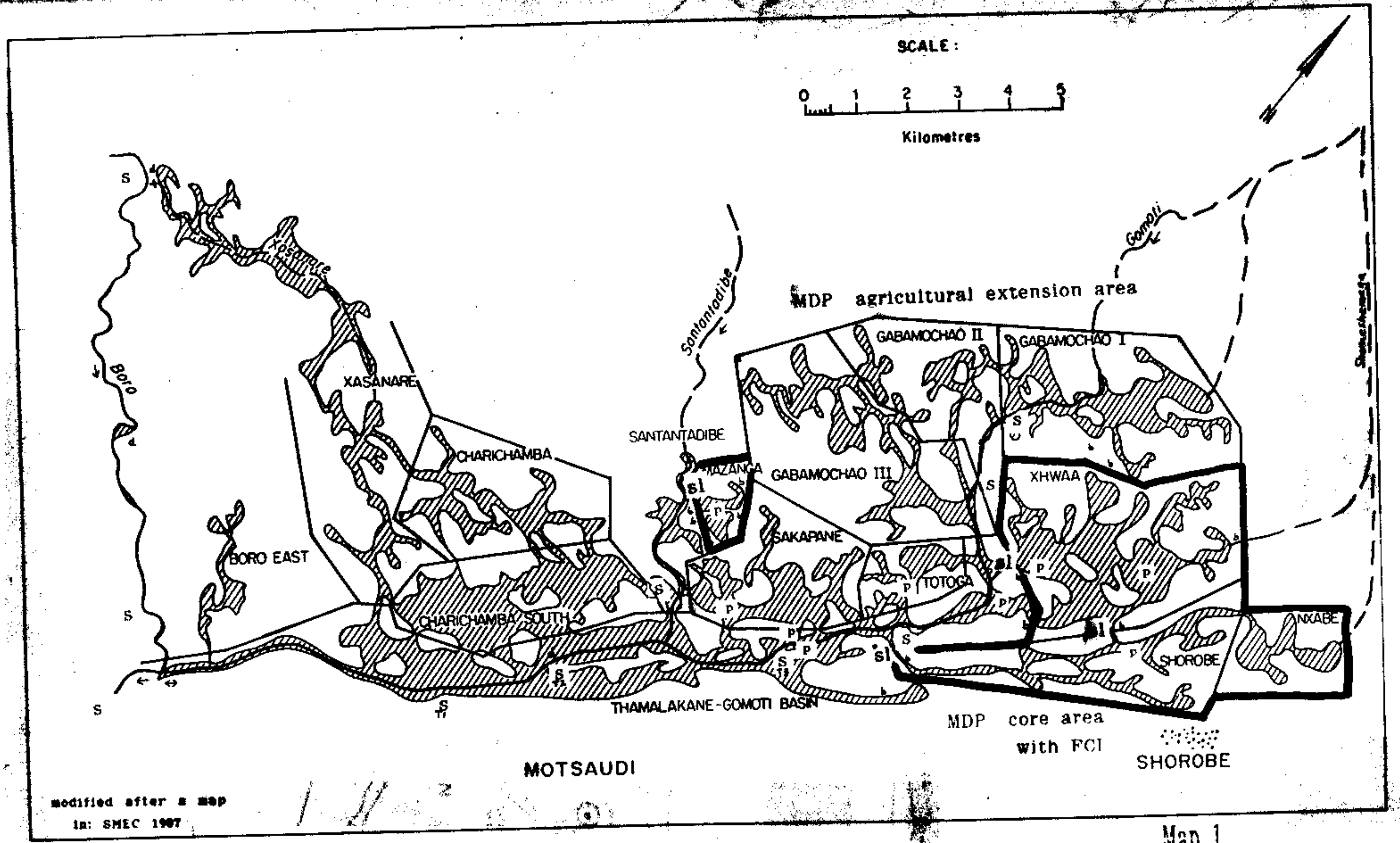
Abbreviations

adj.	adjusted value
AVG	average, mean
b.g.l.	below ground level
C.V.	coefficient of variation
DMS	Department of Meteorological Services, Gaborone
DWA	Department of Water Affairs, Gaborone or Maun
DAFS	Department of Agricultural Field Services, Gaborone
EC	electrical conductivity, measure of the water (or soil) salinity
EO	evaporation open water surface
EO'	adjusted (corrected) EO
GR	groundwater
Inf	infiltration (-rate)
MAX	maximum value
MDP	Molapo Development Project
MIN	minimum value
MSL	meter above sea level, topographic height
PET	potential evapotranspiration according to Penman
Q	discharge
Qb	Lower Boro outflow
Qi	Okavango Delta inflow at Mohembo
Qt	total Delta inflow incl. rainfall
RF	rainfall in mm
S.C.	Service Center of MDP
SMEC	Snowy Mountains Engineering Corporation (consultants)
STD	standard deviation
TDS	total dissolved solids, reported in ppm or mg/l
T1, T2	Upper Thamalakane River subbasins
Tmat,Tm	Middle Thamalakane subbasins
WL	water level, units in m or MSL
WM	Water Management Section (MDP)

Abbreviations of months are used in three digits with capital letters

Units

a	annum (year)
d	day
ha	hectar
hr	hour
MCM	million cubic meter
m; mm	meter; millimeter
mo	month
mS/cm	milliSiemens per centimeter, equivalent to dS/m and mmhos/cm
ppm	parts per million, equivalent to mg/l
TCM	thousand cubic meter



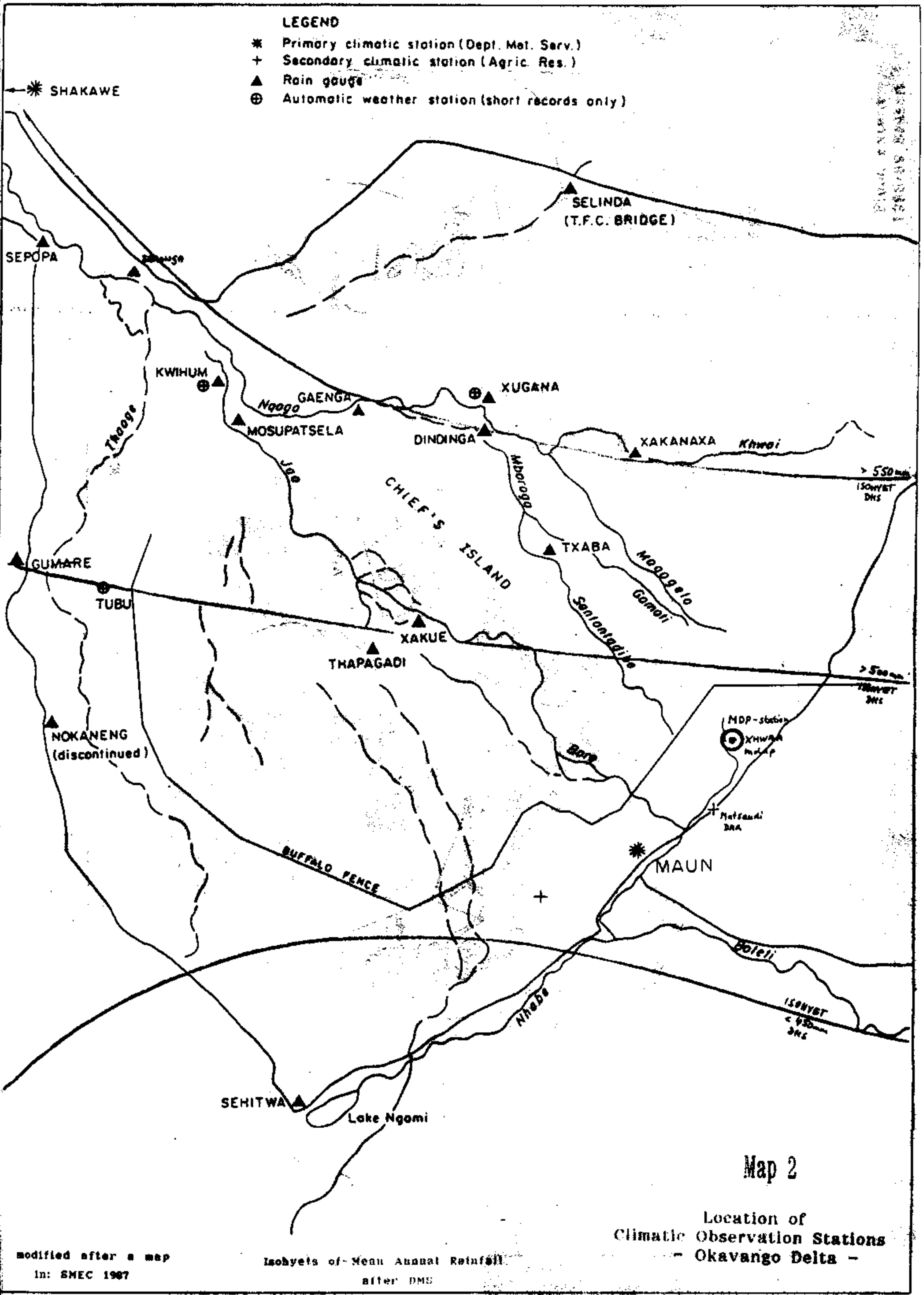
Map 1

p Piezometers
s Staff Gauges
d Discharge Measurement stations

sl sluice
b bund

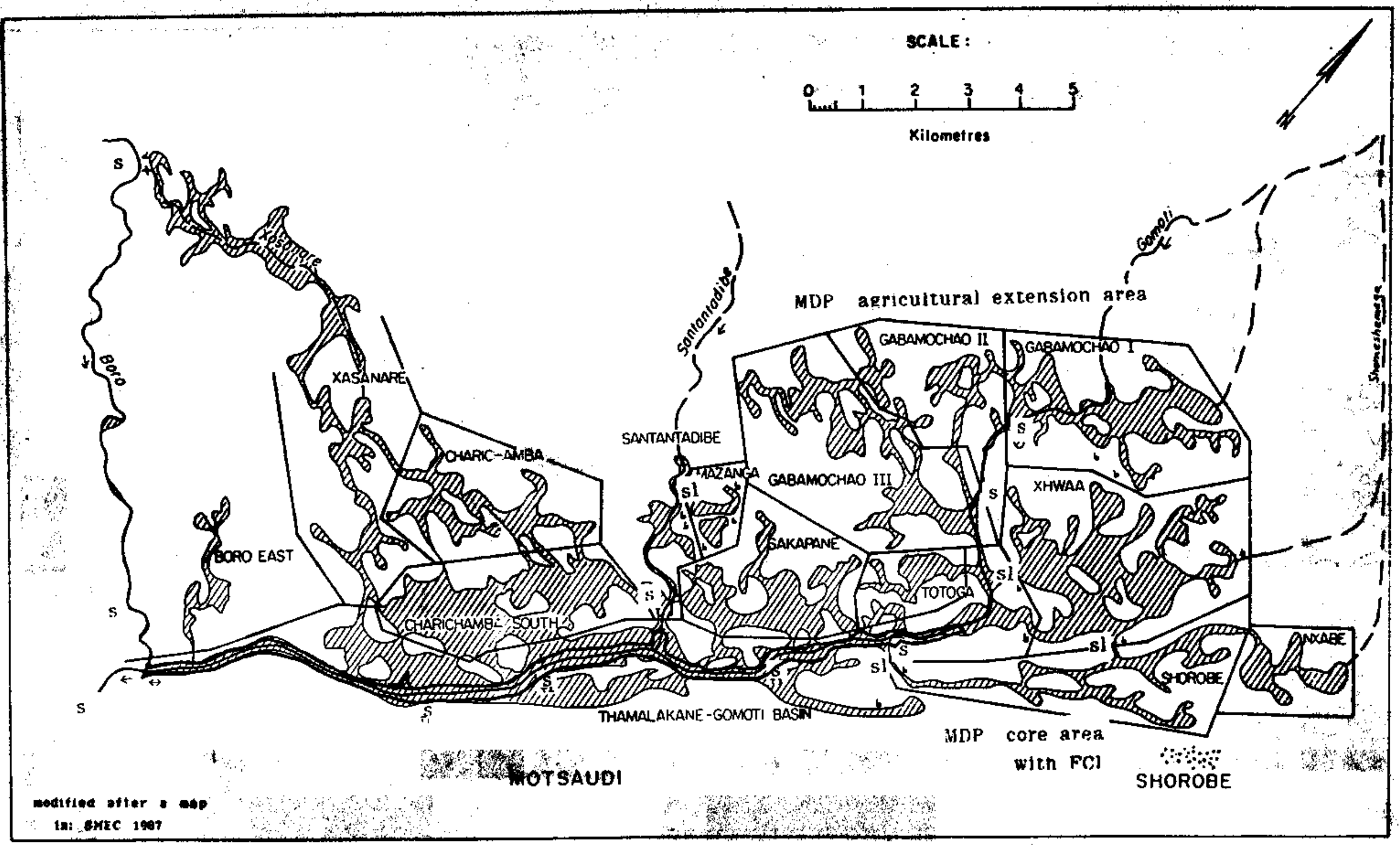
Hydrological Investigation Sites
in Boro-Shorobe Floodplains

Map shows the floodable areas
at 934.00 MSL level



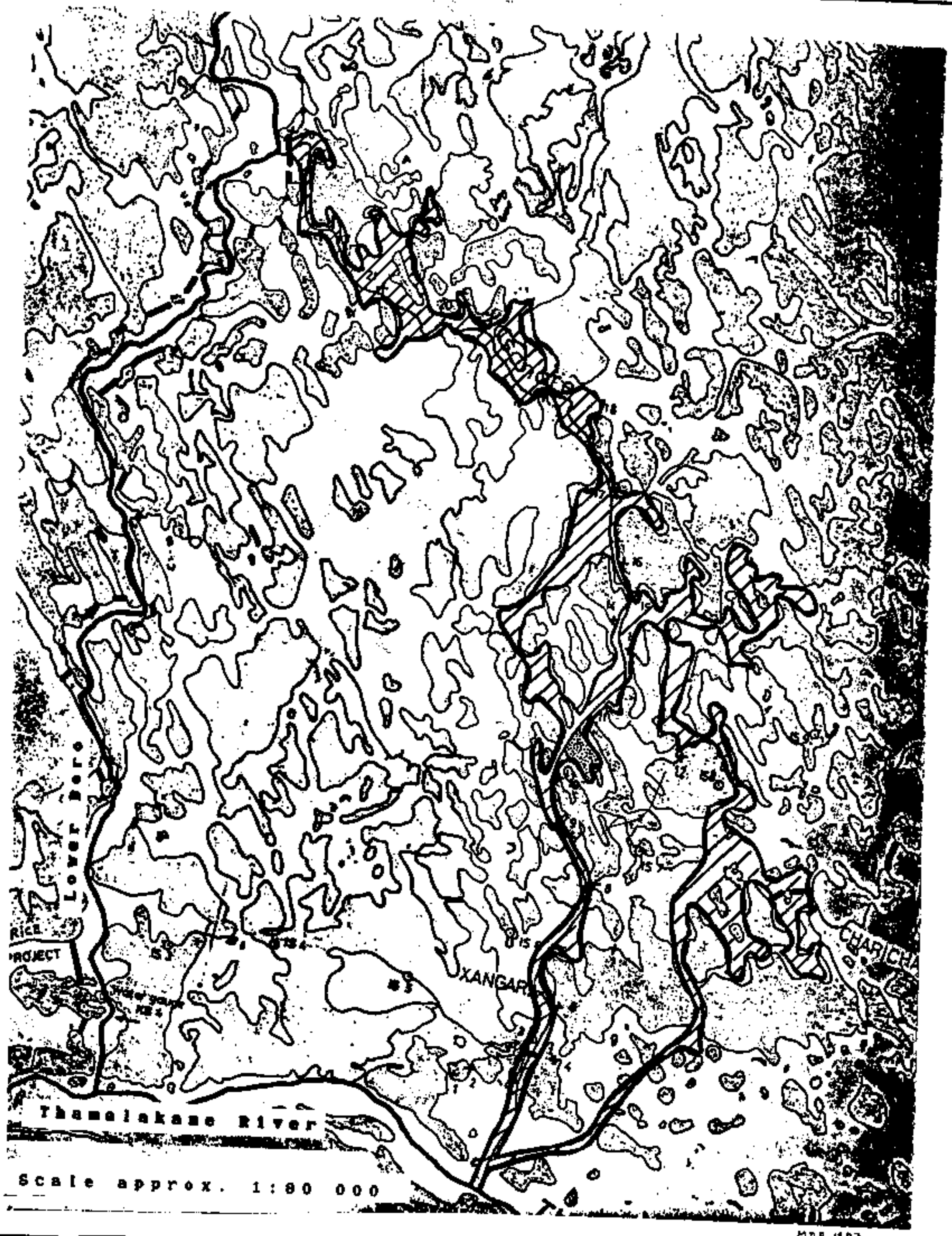
Map 2

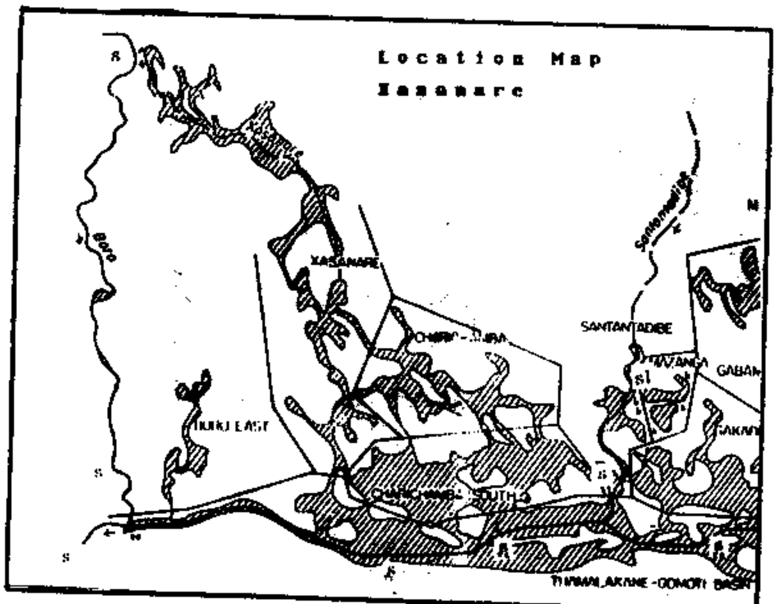
Location of
Climatic Observation Stations
– Okavango Delta –



Map 3

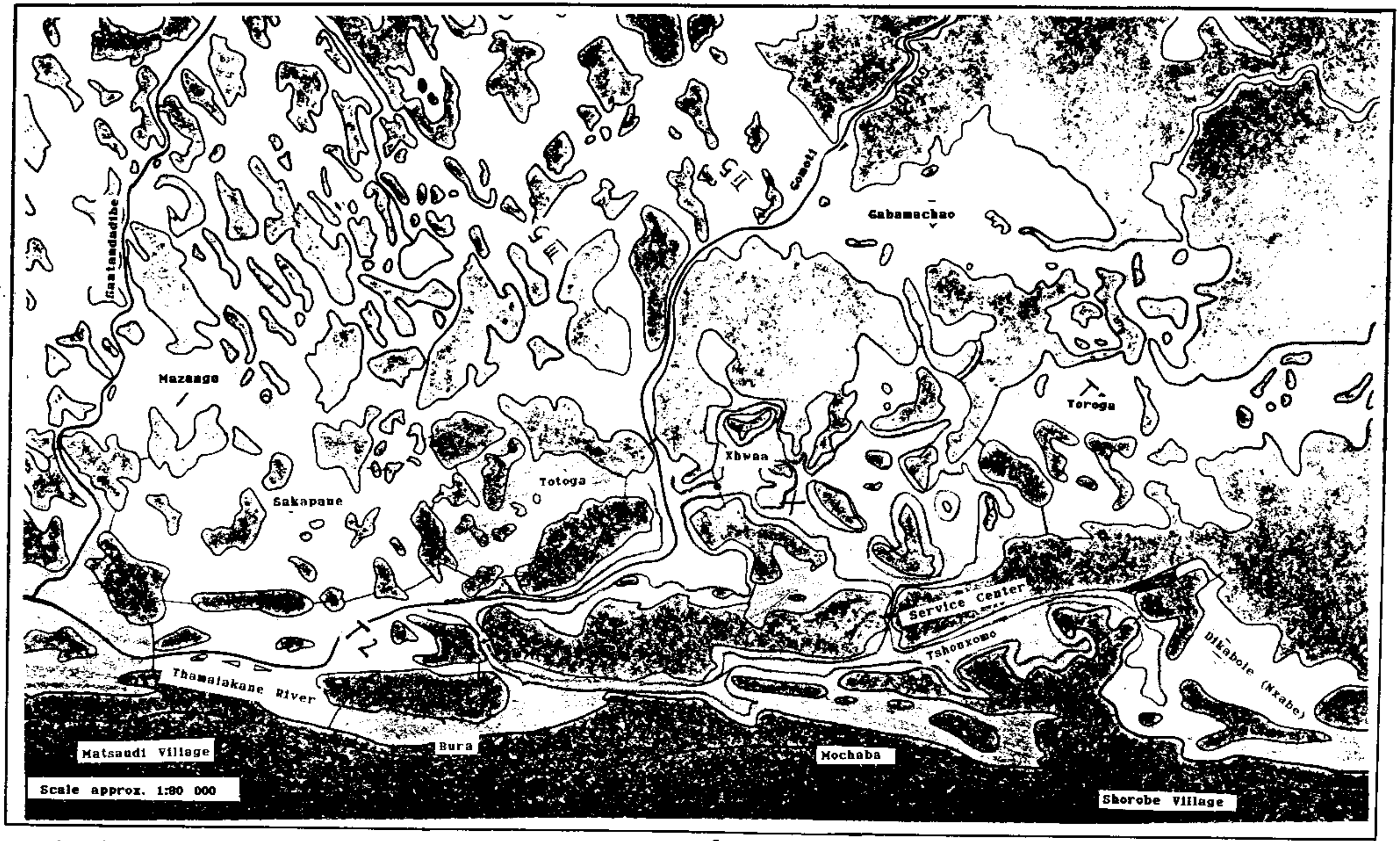
Flood Extent
1988/89 Season





Map 4

Flood Extent 1986
Xasanare Area

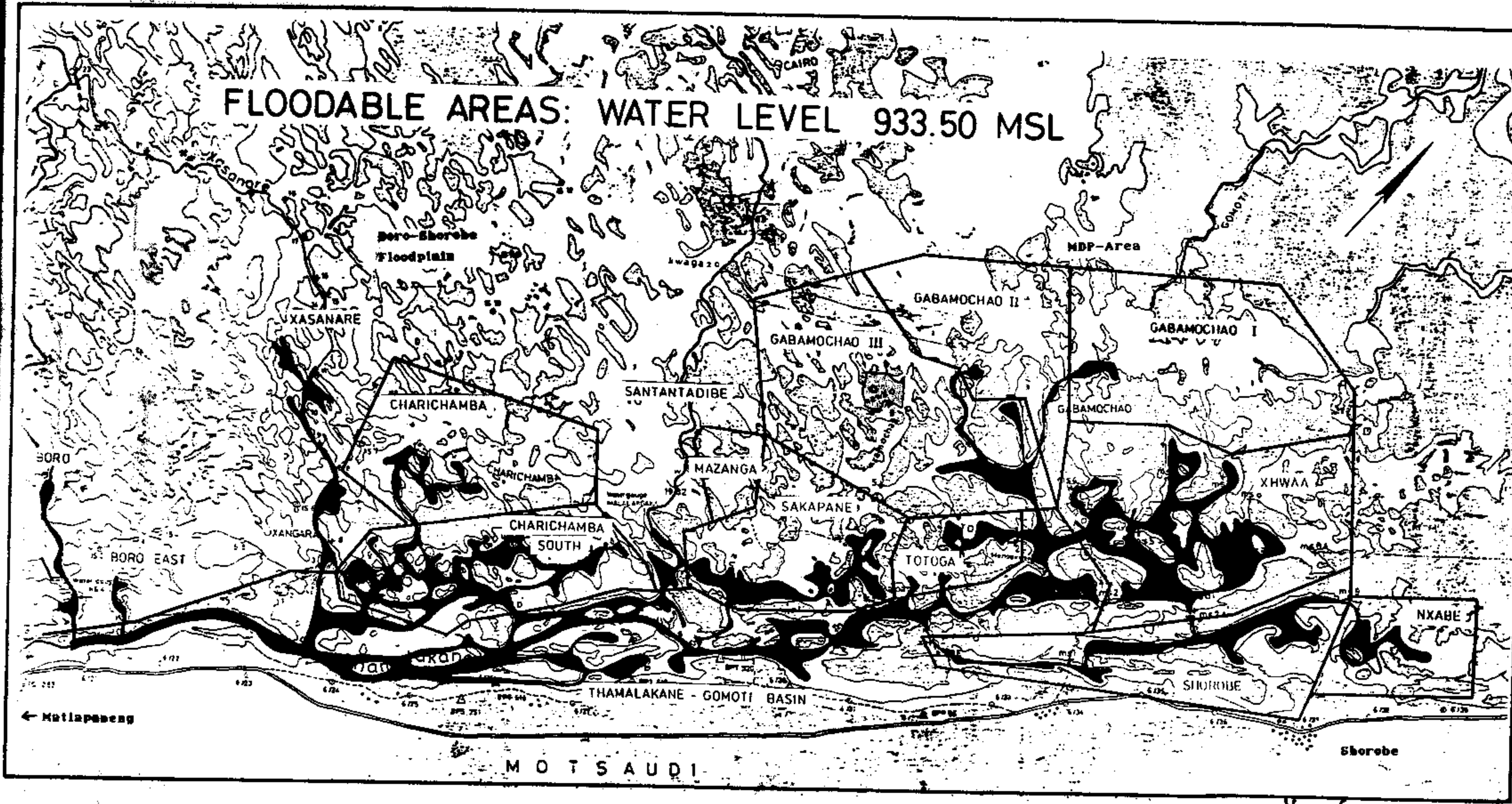


note: only the flood extent in MDP core area
(Xhwaa, Tshonoxomo.Dikabole) is shown

Source: reduced from
1:15 000 maps
MDP 1984

Map 5

Flood Extent
1984/85 Season

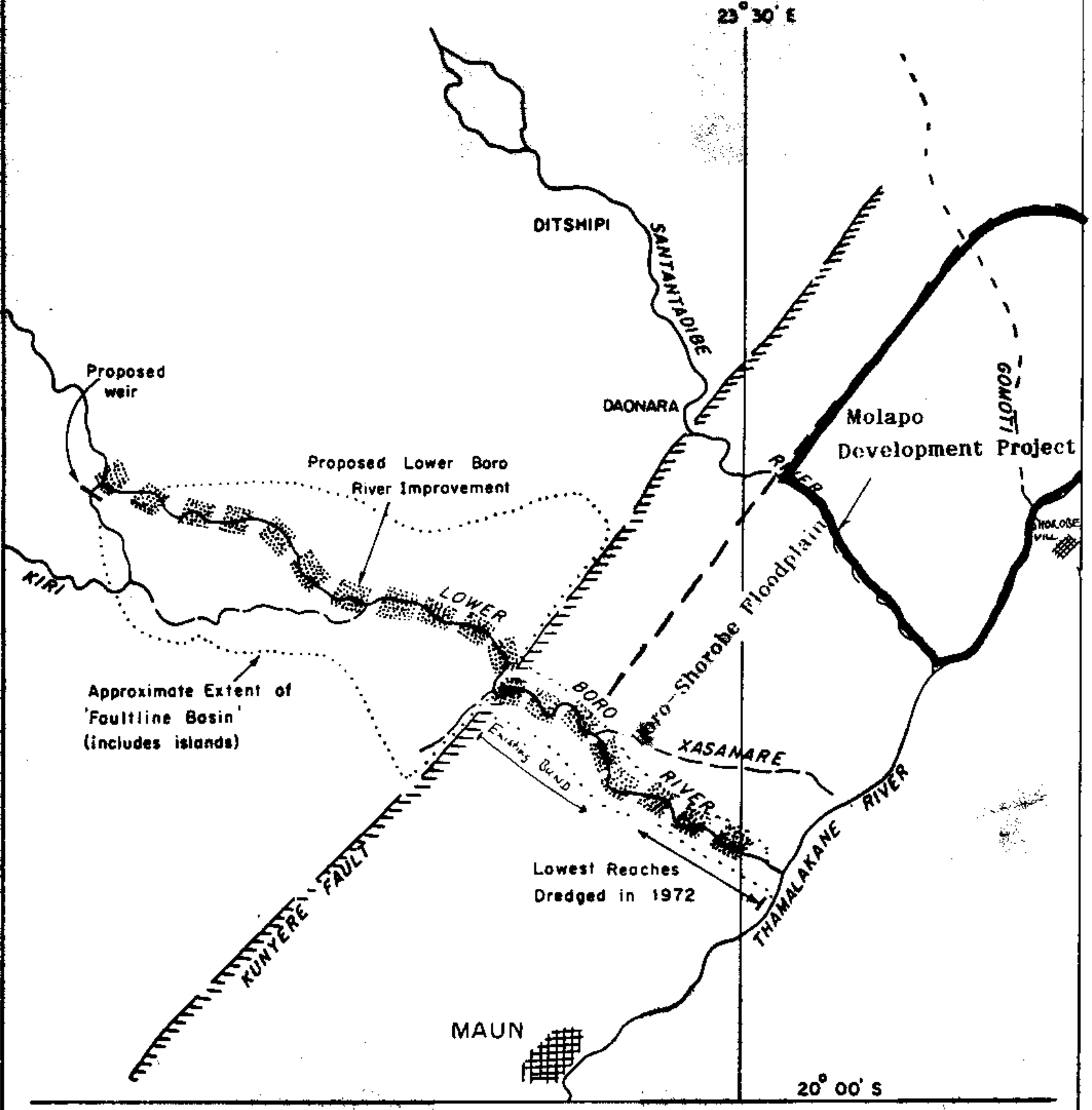


Scale 1 : 100 000

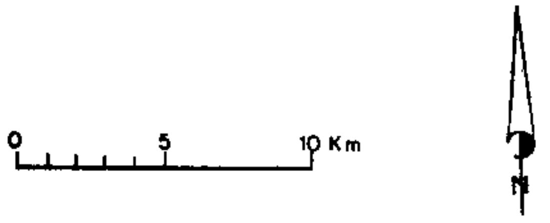
Map 6

Floodable Areas at 933.5 MSL

only Boro-backflow is considered



modified after a map
in: SMEC 1987



Map 7

Lower Boro
Dredging Scheme

from: SMEC 1987

****

MOLAPO DEVELOPMENT PROJECT

MONTHLY RAINFALL DATA SEASON 1988/89

****

Table A.1 Monthly Rainfall Data Season 1988/89

Month :	Maun AVG 22-85	Maun Met	Maun ARS#	Xhwaa	Mazanga
Jul 88 :	0.1	0.0	0.0	0.0	0.0
Aug :	0.3	0.0	0.0	0.0	0.0
Sep :	2.6	7.6	7.0	2.0	2.0
Oct :	16.6	17.0	12.9	19.2	18.4
Nov :	50.3	14.6	10.1	3.7	2.0
Dec :	79.1	59.8	56.7	60.1	45.0
Jan :	109.7	228.5	260.5	191.0	202.5
Feb :	100.3	180.2	163.9	112.6	108.0
Mar :	73.4	47.5	51.7	46.2	28.9
Apr :	25.1	96.3	92.5	149.4	144.7
May :	5.8	0.0	0.0	0.0	0.0
Jun 89 :	0.8	0.0	0.0	0.0	0.0
Season :	464.1 mm	651.5 mm	655.3 mm	584.2 mm	551.5 mm
% Dep. fm.AVG	%	140	141	126	119

Note: all records are shown for the day of the record at 08:00 a.m.

after
Bhalotra, 1987
Dept.Met.Sercices
Gaborone

ARS#
from Sep to Nov
not all days were
reported

Sept. figures
are estimates
for Xhwaa and
Mazanga

up-date 28/05/89
File: E:BOTMETEO/RAIMON1

****

MOLAPO DEVELOPMENT PROJECT

Monthly Rainfall Data

****

Station: Xhwaa (Units in mm)

Table A.2 Station Xhwaa: Annual and Monthly Rainfall 1984-89

Month	: AVG 84-89	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
Jul :	0.0	0.0 :	0.0 :	0.0 :	0.0	0.0	
Aug :	0.0	0.0 :	0.0 :	0.0 :	0.0	0.0	
Sep :	0.4	0.0 :	0.0 :	0.0 :	0.0	2.0	
Oct :	15.9	0.0 :	13.5 :	46.9 :	0.0	19.2	
Nov :	21.2	37.9 :	11.4 :	49.5 :	3.4	3.7	
Dec :	84.0	44.4 :	117.8 :	47.8 :	150.1	60.1	
Jan :	100.1	87.4 :	45.4 :	34.8 :	141.7	191.0	
Feb :	75.8	33.5 :	61.9 :	61.2 :	109.7	112.6	
Mar :	82.9	68.1 :	36.3 :	24.7 :	239.2	46.2	
Apr :	47.6	3.0 :	51.9 :	0.0 :	33.6	149.4	
May :	0.0	0.0 :	0.0 :	0.0 :	0.0	0.0	
Jun :	0.0	0.0 :	0.0 :	0.0 :	0.0	0.0	
Season	427.9	274.3	338.2	264.9	677.7	584.2	
% Dep. from AVG	%	64	79	62	158	137	

Table A.3 Station Xhwaa: Totals for 5-Day Periods for Season 1988/89

Date :	JUL 88	AUG	SEP	OCT	NOV	DEC	JAN 89	FEB	MAR	APR	MAY	JUN 89
01-05 :	0.0	0.0	0.0	0.0	0.0	2.0	145.2	28.0	0.0	0.0	0.0	0.0
06-10 :	0.0	0.0	0.0	0.0	0.0	8.9	8.5	29.4	0.0	0.0	0.0	0.0
11-15 :	0.0	0.0	0.0	0.0	0.0	14.5	1.9	8.5	0.0	0.0	0.0	0.0
16-20 :	0.0	0.0	0.0	0.7	3.0	12.0	1.8	9.7	0.1	9.6	0.0	0.0
21-25 :	0.0	0.0	0.0	9.8	0.0	0.0	18.1	37.0	0.0	38.8	0.0	0.0
26-31 :	0.0	0.0	0.0	8.7	0.7	22.7	15.5	0.0	46.1	101.0	0.0	0.0
Monthly total (mm)	0.0	0.0	0.0	19.2	3.7	60.1	191.0	112.6	46.2	149.4	0.0	0.0

up-date 25/05/89
File: E:/Botmeteo/RAIMOX1

Table A.6 Station Maun: Monthly and Annual Values of Rainfall 1922-87

BOTSWANA METEOROLOGICAL SERVICES

MONTHLY AND ANNUAL VALUES OF PRECIPITATION (mm)

Station 130
Station Name MAUN
Open Date 10/1921

Elevation 0945 m
Latitude 19 59
Longitude 23 25

Month / Year	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL
1922/23	0.0	3.2	0.0	24.4	24.4	94.4	120.4	117.7	95.4	3.9	12.4	0.0	501.5 +
1923/24	0.0	0.0	0.0	1.0	26.1	35.6	14.4	47.4	188.7	0.0	0.0	0.0	313.2 −
1924/25	0.0	0.0	3.1	36.3	47.3	N/A	156.5	244.1	158.9	48.3	62.3	1.5	N/A ++
1925/26	0.0	0.0	13.7	1.3	9.6	83.1	62.6	27.7	78.6	14.0	9.2		[illegible] −
1926/27	0.0	0.0	0.0	16.8	38.9	102.1	38.4	41.5	10.7	17.8	0.0	0.0	266.1 −−
1927/28	0.5	0.5	0.0	67.3	3.3	39.3	151.6	39.5	0.0	0.0	0.0		[illegible] −
1928/29	0.0	0.0	0.5	4.3	71.9	97.2	113.0	53.8	14.2	0.0	0.0	0.0	345.0 −
1929/30	0.0	0.0	1.5	0.8	22.8	106.4	47.5	66.3	9.8	90.9	0.0	0.0	347.5 −
1930/31	0.0	0.0	0.0	1.2	12.7	106.7	68.8	103.0	94.1	35.9	0.0	0.0	432.9 −
1931/32	0.0	0.0	0.0	11.4	46.5	41.8	25.4	174.2	273.8	14.0	0.0		[illegible] +
1932/33	0.0	0.0	0.0	2.2	13.7	51.4	99.7	20.0	15.2	0.0	0.0	0.0	193.0 −−
1933/34	0.0	0.0	0.0	0.0	115.6	56.7	122.7	110.5	44.9	47.7	2.6	0.0	500.7 +
1934/35	0.0	0.0	0.0	3.3	56.9	49.4	73.8	56.6	16.0	13.2	0.0	0.0	269.2 −−
1935/36	0.0	0.0	0.0	4.3	57.3	63.6	106.9	47.5	269.9	28.9	33.6	0.0	612.0 +
1936/37	0.0	0.0	0.0	2.5	14.9	84.4	60.6	169.4	[illegible]	9.5	0.3	0.0	330.0 −
1937/38	0.0	0.0	0.0	0.3	16.8	44.1	138.8	46.0	19.5	48.3	0.0	0.0	313.9 −
1938/39	0.0	0.0	0.0	33.0	115.4	100.2	62.4	215.5	43.1	0.5	0.0	1.0	571.1 +
1939/40	0.0	0.0	10.4	22.1	36.2	101.2	69.2	56.5	153.1	90.9	0.0	0.0	539.6 +
1940/41	0.0	0.0	4.5	10.9	14.5	44.0	151.1	59.9	0.0	10.2	0.0	0.0	294.7 −−
1941/42	0.0	0.0	0.0	40.6	36.0	56.9	31.5	71.6	120.7	9.8	13.7	0.0	380.8 −
1942/43	0.0	0.0	0.0	30.9	0.8	96.8	93.4	11.2	57.8	32.4	18.3	0.0	391.6 −
1943/44	0.0	0.0	0.0	5.0	23.9	72.3	145.8	318.7	15.8	6.9	0.0	3.3	591.7 +
1944/45	0.0	0.0	0.0	15.9	38.1	38.4	17.9	43.0	161.8	1.8	2.0	0.0	319.1 −
1945/46	0.0	0.0	0.0	15.1	48.2	81.4	395.9	95.3	0.0	0.0	3.8	0.0	639.7 +
1946/47	0.0	0.0	0.0	10.3	21.9	16.3	83.5	32.0	125.4	0.0	0.0	0.0	289.4 −
1947/48	0.0	0.0	0.0	1.0	92.0	102.0	110.9	174.6	172.1	67.9	0.0	0.0	720.5 ++
1948/49	0.0	0.0	0.0	23.1	61.6	19.6	82.1	7.7	128.2	1.3	0.3	10.4	334.3 −
1949/50	0.0	0.0	0.0	5.1	61.6	132.9	106.9	118.7	40.4	38.3	22.8	0.0	526.7 +
1950/51	0.0	0.0	0.0	0.0	10.1	129.8	100.9	72.5	51.4	36.8	22.6	0.0	424.1 −
1951/52	0.0	0.3	0.0	61.0	70.4	88.6	91.5	108.4	10.3	0.3	10.2	0.3	441.3 −
1952/53	0.0	0.0	0.0	32.7	169.6	77.9	92.8	157.1	77.4	21.3	0.3	0.0	529.6 +
1953/54	0.0	0.0	0.0	4.8	77.1	136.8	142.1	96.7	86.9	16.1	0.0	0.0	560.5 +
1954/55	0.0	0.0	0.0	9.3	11.9	223.1	183.1	245.7	167.9	20.2	2.3	0.0	863.5 ++
1955/56	0.0	0.0	0.0	32.2	48.1	82.3	54.0	129.1	53.3	25.6	2.8	0.0	427.4 −
1956/57	0.0	0.0	11.6	4.4	42.4	64.0	72.3	104.8	92.2	14.8	0.0	1.5	408.0 −
1957/58	0.0	0.0	2.1	29.4	27.5	95.9	230.9	124.9	88.6	3.1	0.0	0.0	602.4 +
1958/59	0.0	0.0	1.1	54.3	36.1	101.8	133.1	71.0	66.0	12.5	5.3	1.8	483.0 +
1959/60	0.7	0.0	0.1	2.1	18.3	80.2	30.5	73.4	21.0	71.0	16.2	3.3	316.8 −
1960/61	0.0	0.0	0.0	2.7	64.2	49.3	111.8	133.2	145.3	12.2	24.4	0.0	533.1 +
1961/62	5.4	0.0	0.0	3.8	30.0	35.2	155.1	35.5	8.3	41.2	0.0	0.0	314.5 −
1962/63	0.0	3.9	0.0	4.4	79.9	113.6	208.7	58.0	66.6	12.8	4.8	0.3	553.0 +
1963/64	0.0	0.0	0.0	29.8	98.9	208.7	79.2	70.1	17.6	0.0	0.0	0.0	504.3 +
1964/65	0.0	0.0	0.2	16.1	50.0	49.8	33.2	54.0	6.4	58.0	0.0	0.0	267.7 −−
1965/66	0.0	0.0	2.3	0.2	35.6	52.5	101.1	160.0	123.6	59.7	0.2	17.1	552.3 +
1966/67	0.0	0.0	29.2	0.0	2.7	108.3	137.6	186.1	20.8	120.4	0.0	0.0	605.1 +

Table A.6 Station Maun: Monthly and Annual Values of Rainfall 1922-87

BOTSWANA METEOROLOGICAL SERVICES

MONTHLY AND ANNUAL VALUES OF PRECIPITATION (mm)

Station No. 130
Station Name MAUN
Open Date 10/1921

Elevation 0945 m
Latitude 19 59
Longitude 23 25

Month / Year	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL	
1967/68	0.0	0.0	0.0	8.8	111.9	64.1	109.9	104.2	81.3	65.5	33.8	0.0	579.5	+
1968/69	0.0	0.0	0.0	2.1	70.2	59.9	50.2	245.3	36.9	15.4	0.1	0.0	480.1	+
1969/70	0.0	9.6	21.0	10.1	67.6	13.0	123.6	21.2	9.2	1.4	0.0	0.0	276.7	--
1970/71	0.0	0.0	8.6	0.0	58.7	159.7	108.4	12.4	34.4	44.6	0.0	0.0	[illegible]	-
1971/72	0.0	0.0	1.6	9.7	66.8	94.4	250.3	51.5	192.9	19.9	0.0	0.0	697.0	++
1972/73	0.0	0.0	0.0	10.5	2.0	45.2	80.8	67.5	21.9	14.8	0.0	0.0	242.7	--
1973/74	0.0	0.0	0.0	100.3	43.9	252.2	347.0	365.7	17.9	50.1	0.0	0.0	1187.6	++
1974/75	0.0	0.0	11.1	6.5	98.7	27.8	161.1	60.9	191.4	71.3	3.5	0.0	632.2	+
1975/76	0.0	0.0	0.0	1.2	10.5	71.2	113.6	68.1	108.3	3.7	2.7	0.0	377.3	-
1976/77	0.0	0.0	12.0	25.3	74.2	37.7	114.8	98.4	126.5	19.2	4.0	0.0	512.1	+
1977/78	0.0	1.2	31.9	3.1	77.1	226.7	91.9	226.2	37.4	12.1	14.4	12.0	734.0	++
1978/79	0.0	0.0	0.2	11.2	19.0	73.2	124.8	30.2	25.8	7.3	[illegible]	[illegible]	[illegible]	--
1979/80	0.0	0.1	0.0	26.8	20.1	36.5	91.0	290.5	42.5	1.2	0.0	0.0	508.7	+
1980/81	0.0	0.0	1.9	3.0	74.0	27.7	126.3	160.6	92.9	5.2	4.5	0.0	496.1	+
1981/82	0.0	0.0	0.0	8.2	74.7	53.6	24.5	17.0	11.3	14.9	0.0	0.0	209.2	--
1982/83	0.0	0.0	0.0	101.1	84.2	34.6	98.6	11.4	25.1	19.5	15.8	1.0	391.3	-
1983/84	0.0	0.0	0.0	20.0	53.5	152.4	20.0	17.9	81.8	8.3	0.9	0.0	355.8	-
1984/85	0.0	0.3	0.5	20.2	92.5	12.6	76.8	41.8	55.1	2.4	0.0	0.0	302.2	-
1985/86	0.0	0.0	0.0	21.6	7.8	134.7	52.8	70.0	34.6	52.4	10.7	0.0	385.6	-
1986/87	0.0	0.0	19.2	49.6	49.3	57.1	32.2	60.3	27.3	0.0	0.0	0.0	295.0	--
1987/88	0.0	0.0	3.9	8.5	6.1	92.3	38.2	104.0	79.4	19.2	0.0	0.0	351.6	-

++ >650
+ 465-650
- [illegible]
-- <300

Table A.7 Monthly Rainfall Data - Okavango Delta 1987/88 and 1988/89

MOLAPO DEVELOPMENT PROJECT

Monthly Rainfall Data - Okavango Delta

Table : Monthly Rainfall Data for Various Okavango Stations   Period: Seasons 1987/88 and 1988/89

(Units: mm)

Month	Met. Serv. Stations: Maun	Gumare	Shakawe	Sehitwa	Seronga	DWA Stations: Kwihum	Gaenga	Txaba	Xakue	MDP Stations: Xhwaa	Mazanga	subtotal N-Delta	subtotal C-Delta	subtotal S-Delta	total Okav.Delta
JUL 87	0.0	0.0				1.2		0.0		0.0	0.0	0	1	0	0
AUG	0.0	0.0	0.0	0.0	0.0	1.2		0.0		0.0	0.0	0	1	0	0
SEP	0.0	7.7	0.0	0.0	0.0	9.8		9.0		0.0	0.0	0	9	0	3
OCT	0.0	7.7	0.0	0.0	0.0	0.2		0.6		0.0	0.0	0	0	0	0
NOV	56.1	0.9	70.0	72.5	63.0	3.4		1.4		3.4	14.9	67	2	37	35
DEC	92.3	80.8	89.3	18.0	63.0	71.0		77.8		149.2	85.4	76	74	86	79
JAN 88	38.2	36.0	63.9	18.0	31.0	52.8		49.4		141.7	44.9	47	51	61	53
FEB	66.4	203.4	213.1	267.9	229.0	225.0		114.4		109.7	89.0	221	170	133	175
MAR	79.9	52.0	49.4	52.0	126.0	27.0		216.2		239.2	216.7	88	122	147	119
APR	19.2	42.5	49.5	77.0	59.0	1.4		0.0		33.6	31.3	54	1	40	32
MAY	0.0	0.0	0.0	0.0	0.0	4.2		1.4		0.0	0.0	0	3	0	1
JUN 88	0.0	0.0	0.0	0.0	0.0	0.4		1.9		0.0	0.0	0	1	0	0
SEASON 87/88:	352	431	535	505	571	398	0	472	0	677	482	553	435	504	497
% Dep. of total	71	87	108	102	115	80	0	95	0	136	97	111	87	101	100
JUL 88	0.0	0.0	0.0	0.0	0.0	0.0	0.8	41.8	6.0	0.0	0.0	0	10	0	3
AUG	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0	0	0	0
SEP	7.6	2.3	8.7	0.0	7.5	8.2	0.0	0.0	9.2	2.0	2.0	8	4	3	5
OCT	17.0	0.0	25.9	15.0	1.0	77.2	0.0	0.0	6.6	19.2	18.4	13	17	17	16
NOV	14.6	35.8	27.9	0.0	35.0	16.2	16.2	6.4	17.2	3.7	2.0	31	18	5	18
DEC	59.8	83.1	72.8	0.0	129.0	38.0	40.0	88.6	76.0	60.1	45.0	101	65	41	69
JAN 89	228.5	247.5	330.3	137.0	377.0	261.0	173.0	179.6	157.0	191.0	202.5	354	204	190	249
FEB	180.2	206.5	241.2	271.0	95.1	74.8	50.0	60.5	50.0	112.6	108.0	168	88	168	141
MAR	47.5	38.4	112.8	27.0	38.5	50.0	40.0	50.0	50.0	46.2	28.9	76	46	37	53
APR	96.3	91.5	46.6	46.0	29.0	100.0	100.0	100.0	100.0	149.4	144.7	38	98	109	82
MAY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
JUN 89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Season 88/89:	652	705	866	496	712	626	420	527	472	584	551	789	550	571	637
% Dep. of total Delta	102	111	136	78	112	98	66	83	74	92	87	124	86	90	100
total APR-MAR 1988/89	574	656	869	527	742	532	320	645	372	468	438	806	456	502	588

Source: Department of Meteorological Services, May 1989
DWA, Hydrology Section Maun, May 1989
MDP, WM-Section May 1989

up-date 24/05/89
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MOLAPO DEVELOPMENT PROJECT

Mean Evaporation at Maun

Table A.8 Mean Evaporation at Maun (units in mm)

Month	MAUN AVG Class A 1	MAUN AVG EO 2	MAUN AVG EO/Cl.A 3	MAUN AVG ETc swamp 4	MAUN AVG ETc s.s. 5	MAUN AVG PET 6	MAUN Lake ET 7	MAUN AVG Epan 8	MAUN AVG EO 9	MAUN AVG PET 10
JUL	205	128	0.62	147	109	111	154	6.6	4.1	3.6
AUG	227	165	0.73	190	140	147	170	7.3	5.3	4.7
SEP	275	207	0.75	238	176	185	206	9.2	6.9	6.2
OCT	299	237	0.79	273	201	211	224	9.6	7.6	6.8
NOV	264	220	0.83	253	187	197	198	8.8	7.3	6.6
DEC	249	222	0.89	255	189	196	187	8.0	7.2	6.3
JAN	239	209	0.87	240	178	180	179	7.7	6.7	5.8
FEB	209	175	0.84	201	149	155	157	7.5	6.3	5.5
MAR	217	191	0.88	220	162	165	163	7.0	6.2	5.3
APR	200	160	0.80	184	136	139	150	6.7	5.3	4.6
MAY	188	140	0.74	161	119	123	141	6.1	4.5	4.0
JUN	158	115	0.73	132	98	101	119	5.3	3.8	3.4
Annual tot	2730	2169	0.79	2494	1844	1910	2048	7.5	5.9	5.2
Annual /mo	228	181		208	154	159	171	mm/d	mm/d	mm/d
Annual /d	7.5	5.9		6.8	5.1	5.2	5.6	2730	2170	1911
	mm	mm	factor	mm	mm					

Explanation:

1 - Evaporation Class A pan (correction factor 1.16); in: Bhalotra, Dep.Meteorological Services, 1987.1
2 - Evaporation Free Water Surface (modified Penman, after SMEC,1987); in: Bhalotra 1987
3 - Ratio EO to Epan
4 - Evaporation open swamps and aquatic weeds; EO * 1.15 (after SMEC, 1987, p.106)
5 - Evaporation of seasonal swamps; EO * 0.85 (after SMEC 1987, p.106 and SMEC 1987, Vol.III, p.21)
6 - Potential Evapotranspiration (modified Penman, after FAO 1977 and SMEC 1987); in: Bhalotra 1987.1
7 - Lake Evaporation estimates; Epan * 0.75; SMEC 1987, (Vol.III.p.20)

up-date 1/8/89
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