PAST AND PRESENT WATER REGIME OF THE OKAVANGO DELTA

In the relatively short period for which verbal evidence and written account of the pattern of water distribution of the Okavango Delta is available, fairly radical changes have taken place. The major causes of these changes are seismic activity, consolidation of vegetation blockages via sedimentation and large aquatic animal movement. The result of seismic activity altering base levels in an area of extremely low gradient (1: 5 000) must be the most radical factor and will of necessity result in aquatic vegetation changes. All three factors mentioned above can act independently on one another but they more likely all interact in bringing about permanent changes of water distribution. The living blocks of *Cyperus papyrus* used in downstream navigation and the subsequent abandonment of such rafts together with seismicity has probably been the prime factors in the evolution of the Thaoge River blockages and the Nqogha blockage.

Minor alteration of water distribution is caused by large scale termitarium establishment and the evolution of aquatic vegetation and its friction to the passage of water. Clear-cut evidence of major and minor channel alteration exists from recent vegetation patterns depicted on aerial photographs (1969) in areas where no channels are even evident. Present ancient landforms provide some evidence of the past pattern of major water flow (Grove, 1969) outside the Delta. From all this evidence one can attempt to construct a hypothetical ancient to more recent water regime.

POSTULATED ANCIENT WATER REGIME : BEFORE 1849

The full extent of the rift system southwards from East Africa is poorly documented (Fairhead and Girdler, 1969). Using joint epicentral determination (J.E.D.) Fairhead and Girdler (op cit) show a western rift extension from Lake Mweru continuing southwards through Zambia, Rhodesia, Botswana and into the Republic of South Africa possibly as low as 24°S with incipient rifting presently extending this far. It should be noted that the man-made Kariba Dam once filled and lying on this western branch of the rift valley has been the cause of earthquakes (Fairhead and Girdler, *op. cit.)*; when supposedly no earth tremors were recorded from that area before. The mass of water overlying the Delta may also be contributing to the prevalence of seismic activity in this area. Scholtz, *et al.* (1975) believe the Okavango Delta to be the southwestern end of a belt of seismicity, apparently marking an incipiently rifting arm of the East African rift system; and that the tectonic activity associated with the Delta may be the earliest stage of rifting.

Schwarz (1920) had many erroneous ideas about climate and especially rainfall, but recognises ancient drainage lines tending to the southwestern corner of Botswana linking the Okavango and Orange drainage patterns. This is borne out by Gaigher and Pott (1973) in explaining affinities and similarities in fish fauna dating back to the mid-Pliocene of the Tertiary Era. This is probably the origin of the "great pan systems" of southwestern Botswana and the Northern Cape Province (*Tinley pers.comm.).

Some factor, possibly wind-blown deposits laying down the Kalahari Sands, has altered the drainage from a southwestern tending pattern to a southeastern tending one. Seismicity is not ruled out, but most major faulting in the Ngamiland and surrounding area tends on a northeastern to southwestern axis. Scholtz *et. al.* (1975) show the origin of the Delta's sleeve as parallel northwest to southeast tending faultlines, and Gaigher and Pott (*op. cit.*) date the late Pliocene of the Tertiary Era as a period when the Okavango, Upper Zambesi and Upper Limpopo drainage patterns were linked.

In Pleistocene times a vast inland drainage basin, the Makgadikgadi-Okavango Basin, is postulated (De Heinzelin, 1964). This basin was fed from the north by the Okavango, Kwando/Linyanti, Zambesi and possibly the Luangwa River systems, terminating in an inland lake, the Makgadikgadi Lake. This lake initially had an outlet or overflow to the Limpopo River. The large channel which the Limpopo River has cut certainly bears out that this drainage system carried a greater quantity of water in earlier times. Due to the general absence of gradient in Botswana, the country geomorphologically is open to the formation of large inland lakes and deltas. After this period geological activity has caused uplift along Botswana's eastern frontier forming a divide in drainage pattern and largely cutting down on added discharge water to the Limpopo River. Fossil diatoms collected recently on either side of this divide show probable previous linkages of these water systems, and prospecting for diamonds initially yielded the first discoveries from alluvial soils to the east of the divide, whereas the Kimberlite bearing diamond pipes occur on the west of this divide (Civil Engineering Equipment Digest, 1972).

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PAST WATER REGIME : 1849 – 1968

Significantly, on Green's second visit to Lake Ngami in 1855, he agreed with the opinion expressed by one of its discoverers, "Those who had a desire to visit the Lake had better be quick about it, otherwise they would arrive to see a dry one" (Green, 1857). Most early visitors to Lake Ngami gave varying reports as to its previous size and differing reports as to the direction of water flow in the Nghabe or Lake River. It does seem probable that when Lake Ngami reached its greatest size that the Nghabe River did serve as an outlet or during periods when maximum floodwater discharge from the Thaoge River was flowing into the Lake. Under present conditions this is impossible and the Lake River drains towards the now virtually fossil Lake Ngami.

Of the early visitors, only Andersson (1856) and Green (*op. cit.*) penetrated the western Delta travelling up the Thaoge River in the hopes of establishing a navigable trade link to the west coast. Both explorers travelled up by mekoro and boat respectively as far as the baYei capital in the vicinity of Tubu Island. Green who had a custom boat specially constructed for this trip had to proceed beyond Tubu Island by foot up the western bank to Andara, and gave up all hope of an extensive navigable water course for trade. Schultz and Hammer (1897) investigated the possibilities of a trade link from the Zambesi/Chobe/Linyanti/Kwando System to the Okavango but also abandoned their ideas.

Until the time of Moremi II the baTawana apparently paid annual tribute to the haMambukushu to assure the continued season flow of water down to the Lake from Andara; as the haMambukushu were acknowledged as rainmakers and those responsible for all water coming down the system (Stigand 1923). Apparently burning (probably of the *Cyperus papyrus* obstructions) was carried out to increase the water flow down the Thaoge River. Physical efforts were made lower down the Thaoge system by the local inhabitants apparently to cut water flow to "Lake Ngami" supposedly to discourage Boer and other settlement around this area (Botswana National Archives, 1932).

The Lake appears to have truly dried up for the first time in 1895/96 (Stigand, *op. cit.).* At this stage movement of the old baTawana capital occurred several times. The capital town sites were chosen, established and changed, either due to excessive water flooding the sites or insufficient supply forcing upstream migration. These sites varied between Toteng and Tsau. Tsau was eventually chosen as the permanent capital (Stigand, 1913), but due to further dessication the capital town was moved to Maun in 1915, where it still exists today.

Captain A.G. Stigand, the then resident magistrate for Ngamiland, travelled the Delta extensively during 1909 to 1920, and provided the first reliable map of the Delta and documented the existing conditions at that time. During this period the Gomoti River delivered the greatest water discharge out of the Delta and into the Thamalakane River. Prior to these dates it is possible that the Mogohelo or Khwai River systems delivered their greatest discharge out of the Delta towards the "Mababe Marsh". When Livingstone visited the "Mababe Marsh" in 1851 it certainly still contained a small quantity of water (Schapera, 1960); and the existing extensions of the Khwai and Mogohelo drainage towards the Mababe Depression (the Mochaba and Zankuio Rivers respectively), certainly still bear evidence of channels which carried a good water discharge in the past. These same channels' distant extensions receive little or no water discharge even in exessive present flood years, viz. 1973/74 and 1974/75; and no floodwater reaches the Mababe River or the Depression at present.

Further faulting along the Linyanti/Chobe River systems have lead to this system's capture by the Zambesi River, and has deprived firstly the Mababe Depression and then the Savuti Marsh of discharge waters. The lower Savuti River channel and the Savuti Marsh dried up completely in about 1888 (Stigand: *In* Du Toit, 1925) and was only reflooded in about the mid 1950's probably as a result of excessive floodwaters in conjunction with surface blockages forming in the Linyanti/Chobe River system below the Savuti River mouth offtake. The presence of numerous hippopotami in the Kwando/Linyanti system and in the Savuti channel have probably played a significant role in the re-establishment of this Savuti System.

During the 1930's Colonel Naus (a self-styled hydrological engineer) commenced "channel improvement" at the M'borogha River split forming the Santantadibe and Gomoti Rivers headwaters. Naus' ideas of some methods for increasing channel discharge were erroneous, but he recognised the necessity of initially clearing the channel of vegetation and the **continual maintenance** of such clearing. Naus also conducted "channel improvement" via dams with narrow outlets on the Thamalakane River. During this period (as well as during Stigand's residence in Ngamiland) the Boro River was an annual river, whose discharge was only reliable for a few months of the year (less than 3 months) depending on the seasonal flood regime (Naus, 1936 b).

Naus (1934) had some good but conflicting ideas of the value of hippopotami in the Delta. "The principal causes of the water losses are hippo roads and melapos. Hippo are too numerous at places, their numbers should be reduced by expert killing, bearing in mind that they are exterminated nearer to civilisation where a number of these animals would be useful. The natives should not be allowed to kill them south of the N'Borogha and Santantadibe junction.

Melapos and hippo roads should be closed up." Naus does not take into account that hippopotami can move over large distances and that it is impossible to close hippopotamus paths with any lasting effect in such level areas where they are not confined to a single channel.

Naus' "improvement" work was questionable and although he convinced the administrators and the residents, the engineers Jeffares and Brind succeeded in getting his work terminated (Clarke, 1938). The hydrological engineers focused attention at this stage on the main Thaoge and Nqogha River blockages (Botswana National Archives, 1939). Martinus Drotsky was employed with large gangs of African labour to clear *Cyperus papyrus* vegetation and to straighten the channel in the main Thaoge River blockage (Fig. 25) as well as to conduct clearing work on the Nqogha blockage. All this work was in vain, since it was never properly completed or monitored, and in the absence of re-creating a channel without sufficient depth, velocity and discharge the aquatic vegetation will just recolonise the channel as happened here. Brind and McIlraith (± 1950) even developed a papyrus cutting machine but due to operating difficulties and lack of finance these clearing operations ceased.

During the 1940's the Santantadibe River was providing the major water discharge from the Delta into the Thamalakane River. Naus' work may have played some role here, but seismicity was probably the major factor. During the 1960's the Boro River evolved to provide the maximum discharge from the Delta into the Thamalakane River probably as a result of seismicity in conjunction with the total consolidation of the Nqogha blockage.

PRESENT WATER REGIME : 1969 – 1975

Only since 1969, when the Surveys and Training for the Development of Water Resources and Agricultural Production (BOT I Survey) was commenced by the Food and Agriculture Organisation (FAO) of the United Nations, was gauging and discharge of the overall Delta commenced. Inflow discharges are available for a longer period from the Okavango River where it transverses South West Africa. Some gauging stations in the Delta were closed after a short period (due to reasonably stable flow or difficulties in continuity monitoring such) and new gauging stations opened during the excessive floods of 1973/74 and 1974/75. However the overall position is a lack of data in general and an insufficient duration of recordings to provide accurate statistics and to predict future conditions. Nevertheless a base has been established and this is produced below.

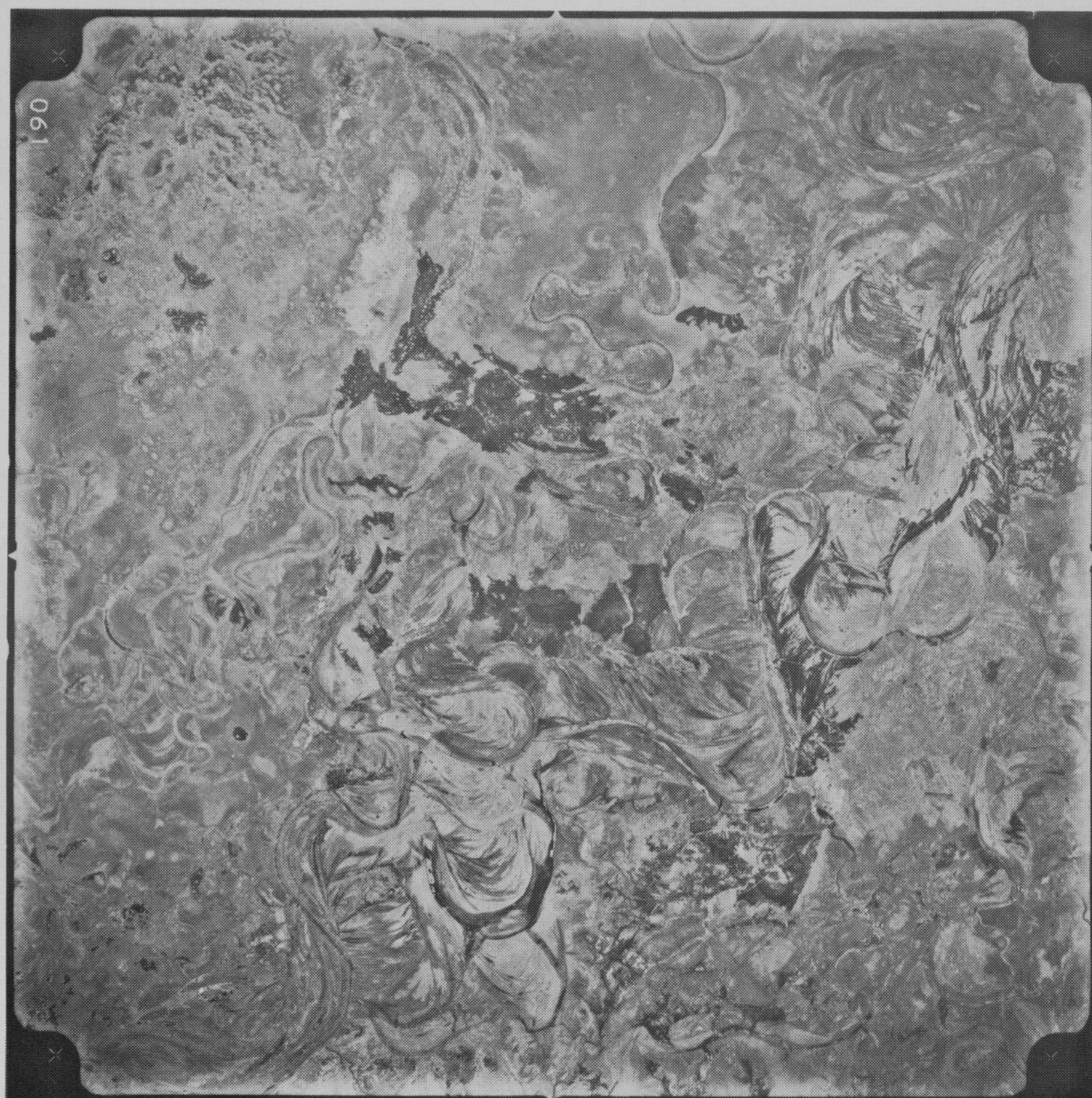

FIGURE 25 – The vast meanders of the ancient Thaoge River and its now virtually dead floodplain system, Okavango Delta, Botswana.

A hydrological year or season embraces average monthly flow rates in m^3/sec from October of one year to September of the following year. In many instances at certain gauging stations only one flow rate recording per month is available; whilst at less accessible gauging stations the frequency of flow rate recordings is even less. Some flow rate data prior to 1972 for certain stations are obviously incorrect and have to be adjusted. Such adjustments are naturally open to criticism and variation by different interpreters.

The Okavango River arises in southeastern Angola where the major tributory, the Cubango River has a catchment area of 115 000 km^2 and an average annual rainfall of 983 mm (Range 605 to 1 127 mm). This catchment area embraces the margin of the Bieplanalto (Benquela Plateau) whose surface is formed of crystalline rocks of the Fundamental Complex with a high, all-year-run-off, near the western end of the South Equatorial Divide (Wellington, 1955). The second major tributary is the Cuito River whose catchment area of 65 400 km^2 lies to the east in porous sandveld with a mean annual rainfall of 876 mm (Range 476 to 1 100 mm). The Cubango River thus forms the major and more reliable source feeding the Okavango River. In spite of this the average discharge of the Cubango River at Rundu is approximately 5 8000 x 10^6 m^3 per annum; and at Andara after the Cuito River as joined the mainstream approximately 11 000 x 10^6 m^3 per annum. This provides a discharge difference of the order of 600 x 10^6 m^3 in the two major tributries.

After the junction of the two major tributaries near Dirico the single channel of the Okavango River is formed. Further downstream at the gauging point of Mukwe (5 km northwest of the junction of latitude 18°S and longitude 21°E) good flow rate gaugings exist from the 1949/50 season. This Mukwe station gives an average annual inflow of 10 561, 20 x 10^6 m^3, or an average flow rate of 338 m^3/s. Figure 25 shows a histogram of peak discharge month.

The Okavango River continues flowing eastwards until Andara where it swings to a southerly direction and flows over the Popa Falls and then enters northwestern Botswana as a single channel at Mohembo. Shortly after Mohembo the Okavango River forms the "sleeve" of the Delta at the base of which the main continuation is the Nqogha River and a now minor distributary the Thaoge River takes off to form the western bank of the Delta. During the 1700's and the first part of the 1800's this Thaoge River was the main continuation of the Okavango River feeding "Lake Ngami". After this bifurcation water spreads out to form a large permanently inundated swamp area.

Figure 27 shows the present various channels and their average annual discharge rates for the available flow data. The present main continuation of the Okavango River; the Nqogha River at Duba (K3) gauging station shows an average discharge of about 94 m^3/s (1969/70 Average

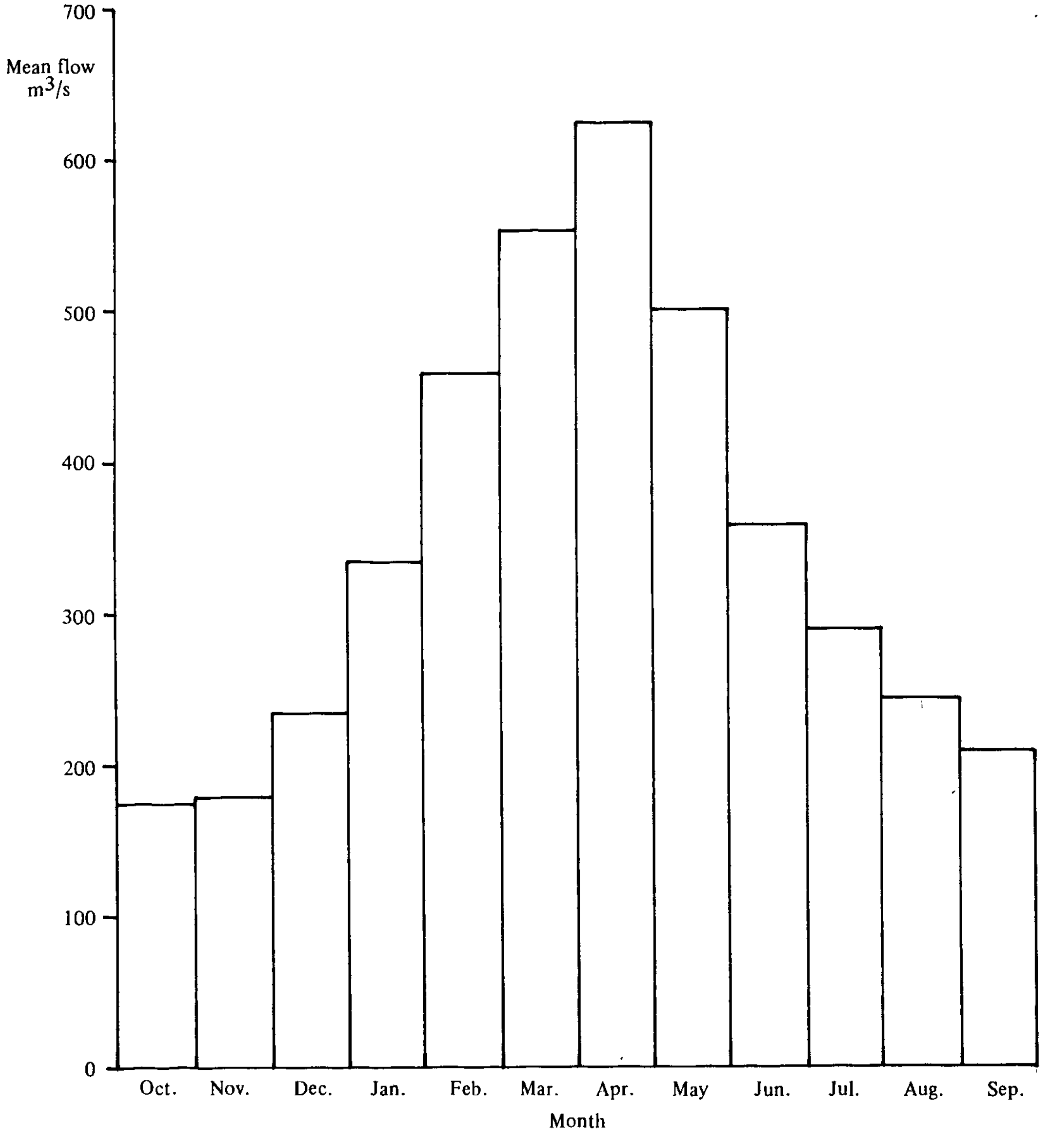

FIGURE 26 – Mean monthly flow rates (m^3/s) of the Okavango River at Mukwe in South West Africa for the period 1949/50 to 1973/74.

for 10 months). Since November and December are the months omitted the average may be considered slightly less. About 40 km downstream of Duba the Gaenga (K4) gauging station provides an average discharge of about 49 m^3/s (3 seasons' average discharge for 9 months). Both these stations are located on an upper channel and maximum monthly flow variation for Duba is 16 m^3/s and for Gaenga is 8 m^3/s between months of lowest flow rate versus months of highest flow rate. Below Gaenga the man-made "Smith's Channel" established in late 1973 is delivering an average of 10,38 m^3/s (9 recordings since established) of flow, but at an ever-increasing discharge in accordance with the flooding season. This channel in my opinion will deliver an ever-increasing quantity of water down the upper eastern system and may evolve to become the major Nqogha continuation.

From here downstream it is necessary to deal with the middle and outlet channel series of systems independently, starting from the east and proceeding to the west.

The Moanashira/Khwai/Mochaba/Kudumane drainage

At the gauging station KQ1 on the Moanashira River the average discharge is 10,38 m^3/s (1969/70, Average for 10 months). This discharge could be increased slightly since April and May recordings do not exist but the floodwaters had probably not yet arrived then. The maximum variation recorded for 1969/70 is 5,5 m^3/s. At the gauging station KQ2 near the base of the perennial swamps the average discharge is 3,10 m^3/s (3 seasons' average discharge for 8 months). At the gauging station KQ3 on the Khwai River (North Gate bridge) flow has been too unreliable for gauging, and the river often dried up completely for a few months during 1971, 1972 and 1973. Only during 1974 and 1975 was the water supply good at this gauge. The Mochaba River received a small flow of water during the 1973/74 and 1974/75 seasons, but the Kudumane and Mababe Rivers were dry throughout.

The M'borogha/Nambope System

These two middle channels are dealt with independently of the outlet channels arising from their system. These two middle channels fall almost totally within the study area and there can be no doubt that both were carrying a significantly greater discharge before events (seismic blockages and *Cyperus papyrus* rafts) altered conditions to the east of the northern tip of Chief's Island.

A major channel flowing north of Chief's Island and passing the bulk of water down its eastern margin and probably feeding the Nambope River which was its downstream continuation has

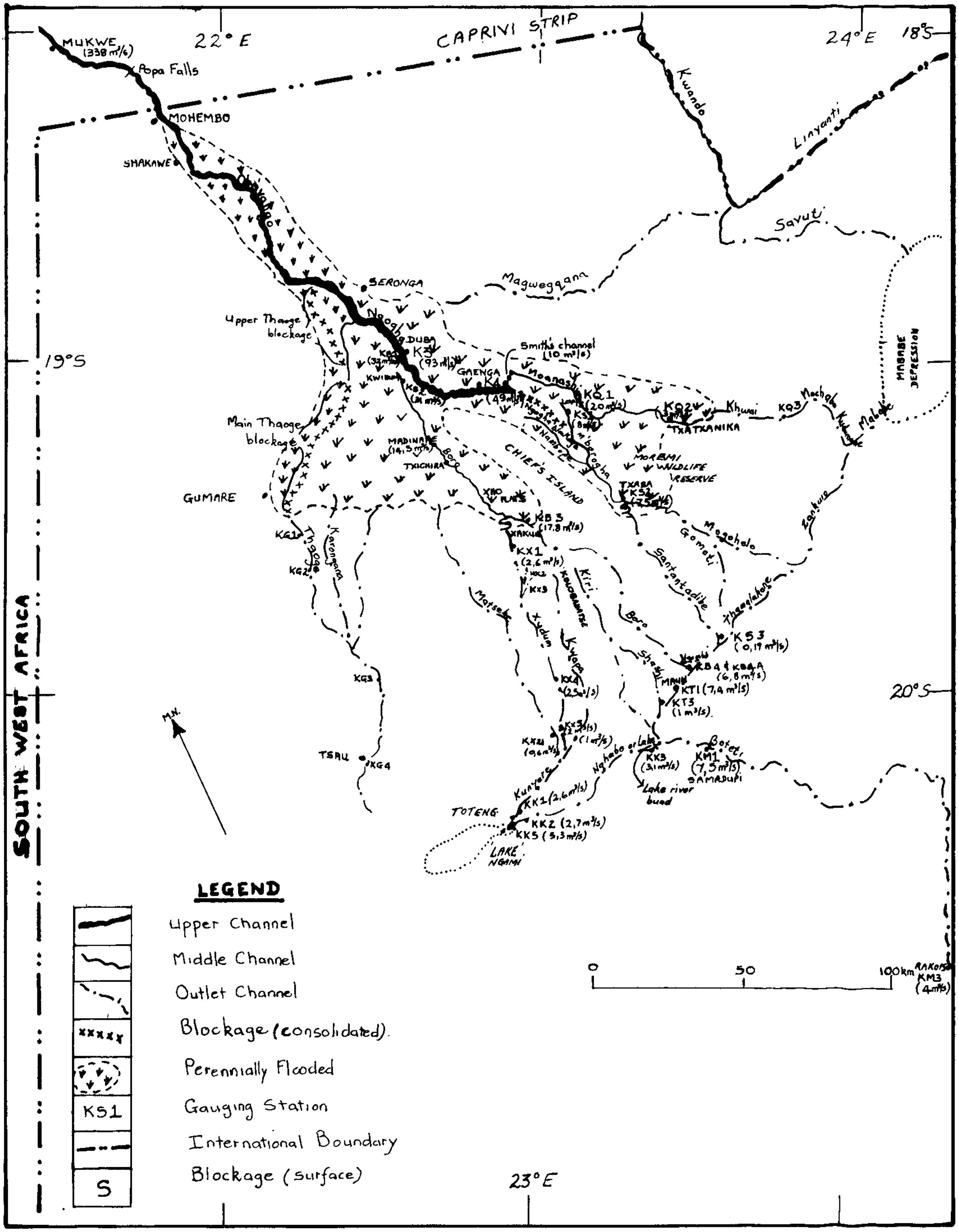

FIGURE 27 – Okavango Delta, Botswana, channel system and mean annual flow rate at main gauging stations (KGI, KQI, KBI, KTI, KKI, KMI etc).

become blocked and fouled with aquatic vegetation thus strangling this system. The consolidation of the old Nqogha blockage has likewise cut off major discharge down the M'borogha River and hence the dual reasons for the diminishing discharge from outlet channels arising to the immediate east of lower Chief's Island. Under the present regime these conditions can only perpetually worsen. At the KS1 (Lopis or Qusai) gauging station there is an average discharge of 8,32 m^3/s (3 seasons' average discharge for 6 months) and at KS2 (Xaba) an average discharge of 7,59 m^3/s (6 seasons' average discharge for 9 months). The high average at Xaba gauging station is maintained by the inflow of the Nambope River to the M'borogha River above Xaba Island. No flow measurements were available for the Nambope River.

The Mogohelo/Zankuio drainage

No gauging sites exist and neither are any flow measurements taken in this drainage system due to the fact of its progressive evolution towards a decreased discharge probably from the early 1900's. During the extreme high flood years of 1973/74 and 1974/ 75 floodwaters pushed well down into the Zankuio River, but reached nowhere near to its link with the Mababe River. With the decreased discharge of floodwaters down the M'borogha/Nambope Rivers drainage, this system can probably be considered as drying up.

The Gomoti River drainage

The Gomoti River is also no longer gauged. Naus (1937) reported that this River was drying out, and conditions have progressively worsened so much that the Gomoti River only delivers a small discharge into the Thamalakane River in extreme high flood years viz. 1973/74 and 1974/75.

The Santantadibe River drainage

Ellenberger's (1931) boat trip and report show the Santantadibe River to be in fairly poor order (September/October).

Roberts (1955) reported the Santantadibe River as the only channel permitting a fairly free passage by boat at this time (July) of the year, and to offer the most favourable route for conducting water from the swamps. Naus (1936 b) reported practically the whole discharge from the M'borogha as feeding the Santantadibe River, whilst the Gomoti River was only being fed through swamp leakages. Discharge conditions have obviously improved initially down the Santantadibe River at the expense of water flowing down the Gomoti River. These conditions have persisted until the 1960's when the Santantadibe discharge has become negligible when compared with that of the Boro River. At the Malalakaka (KS3) gauging station the average discharge is 0,19 m^3/s (4 seasons' average of 7 months). The Santantadibe River system under present conditions can also be considered as slowly drying up.

All three above drainage systems have been radically effected by loss of upstream discharge, caused by blockages and seismicity. From earlier reports of Ellenberger (1931) and Naus (1936 a) it is clearly evident that hippopotami were far more numerous in these systems, and that other channels existed then (Naus, 1935).

The Jao/Ncwarelanwana/Boro System

Collectively this whole system is known as the Boro River today. Stigand (1925) states "The Boro River has been dry for the past 4 or 5 years except at the height of the Flood season, when an inconsiderable amount of water comes down it." During 1931 (August-September) Ellenberger travelled up this system and reports travelling over last season's mealie lands in the lower Boro River. Jeffares (1938) states the Boro River discharged flood water for 5 months of the 1937/38 season providing about 9 m^3/s at peak flow on July 27th, 1937 but down to about 2 m^3/s by the 5th of October.

The Boro River cross channel inflow (KB1) gauging station shows an average discharge of 32,67 m^3/s (1 season average for 9 months).

The Kwihum (KB2) gauging station shows an average discharge of 31,68 m^3/s (2 seasons' average for 9 months), whilst lower at Madinare Island the Boro River shows an average discharge of 14,50 m^3/s (3 seasons' average for 8 months). At the mid-Boro River gauging station of Xakwe (KB3) the average discharge is 17,84 m^3/s (6 seasons' average for 9 months). This downstream increase is attributed to added water provided from the west into the Xho Flats area. At the Boro River junction with the Thamalakane River gauging station (KB4 and KB4A) the average discharge is 6,86 m^3/s (7 seasons' average for 11 months). This station was dry for 2 months in the 1969/70 and for 3 months in the 1972/73 floodseasons. This Boro River drainage is undoubtedly the system which will be concentrated on for improving the Delta's outflow since it is the system evolving to greatest discharge in recent years. The Ngombi or Xasinare primary floodplain (melopo) is significantly important in the lower Boro River drainage and was discharging up to 3,48 m^3/s during peak conditions in poor flood years prior to being bunded off by the Anglo American Corporation and on average took 28,91 per cent of Boro flow during 1972. The Boranyane delivers a small discharge in high flood seasons.

The Kiri/Shashi/Xotega drainage system

This system varies from being dry throughout the season (1972/73) to flowing throughout the season (1974/75) after a previous good flood season. Under average conditions it can be expected to be dry for 6 months of the hydrological year. Average discharge at the Shashi junction bridge (KT3) is 1,02 m^3/s (7 seasons' average for 12 months).

The Kwapa/Xudum/Matsebe/Kunyere drainage system

This system has not been as carefully monitored as some of the other more reliable systems, as it is dry or contributes very little discharge in all except good flood seasons. The lower reaches of the Xudum and Matsebe Rivers delivered greater average sustained discharge from heavy local rainfall viz. 1973/74 than from the good floodwaters of the 1974/75 season, although peak discharge was highest in the 1974/75 season. This serves to illustrate the importance of "the previous degree of saturation factor" and the importance of heavy local rainfall.

The lower reaches of the Kwapa River show an average discharge of 1,03 m^3/s (2 seasons' average for 12 months) in good flood seasons, but at this point it is still dry for about 7 months of such seasons.

The Xudum River is the most important one of this drainage system, delivering the greatest and most sustained discharge. The upper Xudum River at KX1 discharges 2,67 m^3/s (3 seasons' average for 8 months). This discharge includes the 1972/73 poor flood season and the Xudum River at this point is dry for 6 months in poor flood seasons, and for an average of 2 months in good flood seasons. The central Xudum River at KX4 discharges on average 2,59 m^3/s (2 seasons' average for 11 months), but has received inflow from two melapos (KX2 and KX3) providing about 0,25 to 0,50 m^3/s respectively in good flood or rain seasons. KX4 is dry on average for 4 months of good flood seasons. The lower Xudum River at KX5 discharges on average 2,05 m^3/s (2 seasons' average for 12 months); and is dry for an average of 6 months in good flood seasons. In poor flood seasons KX5 receives little water or may even be dry throughout the season.

The Matsebe River's lower reaches show an average discharge of 0,67 m^3/s (2 seasons' average for 12 months); but only flows in this region in good flood years and even then is dry for an average period of 6 months per season.

The Kunyere River is of importance, as it and the Nghabe or Lake River are the only two rivers now feeding "Lake Ngami". In recent years the discharge of the Kunyere River has visually decreased, (*M. Clements pers.comm.) apparently due to blockages of the upper reaches of the rivers draining into the Kunyere River (mainly the Upper Xudum River). Flow rate recordings for the Kunyere River apparently show some obvious errors (**Wollander, pers.comm.) and these have been revised on the advice of the above government official. Since gauging commenced it is clearly apparent that Clements' observations are correct and the discharge in this river system has dropped drastically, probably due to changes in the upper reaches of the systems feeding it (Table 43).

The average flow is 3,19 m^3/s (5 seasons' average for 12 months omitting 1972/73) or 2,66 m^3/s (6 seasons' average for 12 months) if the totally dry 1972/73 season is included. On average, the Kunyere River is dry for four to five months during good seasons and for 10 to 12 months during poor seasons. The importance of this drop in discharge to the continued existence of Lake Ngami cannot be over-emphasised.

The Thaoge/Karongana drainage system

There is no doubt from past evidence (Andersson, 1856; Green 1857; Stigand 1923) and the large ancient floodplain systems that the Thaoge River was the former main continuation of the Okavango River ending its discharge into "Lake Ngami". Blockages in the upper reaches of the Thoage River from *Cyperus papyrus* rafts and possibly seismic activity have resulted in this great river's death. Unless massive changes take place in the Upper Delta it is unlikely that the Thaoge River will ever be re-instated to its former discharge.

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Table 43. Average seasonal discharge rates (m^3/s) of the Kunyere River, Okavango Delta, Botswana, 1968/69 to 1973/74.

SEASON	AVERAGE FLOW OVER 12 MONTHS	MONTHS DRY OR NO FLOW
1968/69	9,71	5
1969/70	4,30	4
1970/71	0,67	9
1971/72	0,06	10
1972/73	0,00	12
1973/74	1,22	7

Due to the prevailing situation little monitoring of this system takes place, and as such only isolated significant measurements can be quoted. At Nokaneng gauging station KG1 the 1968/69 average discharge was 0,55 m^3/s (3 months recordings). During March and April 1974 the average discharge rose to 6,24 m^3/s. At gauging station KG2 no water had reached the gauge since installed, (19 April 1969) by 1 February 1974. On 9 March 1974 the guage could not be found as water was probably flowing right over it. At Masamo gauging station KG3, 3,70 m^3/s was flowing on 21 June 1974. Note here that a large amount of this water (approximately 1,5 m^3/s) is derived from the Karongano and its associated river systems. At the Tsau bridge gauging station KG4 a peak of 6,69 m^3/s was flowing on the 19 April 1974. A large amount of this water must have been derived from local catchment above the gauging station.

The Thamalakane/Boteti/Nghabe drainage system

This system embraces all drainage collected from the central and lower eastern sectors of the Delta, providing a minor percentage of discharge to "Lake Ngami" and the major discharge eastwards towards the Makgadikgadi pan system. The average discharges presented here are over a longer period due to their importance for human and industrial utilisation and the easier accessibility to gauging stations.

The Maun bridge (KTI) gauging station on the Thamalakane River provides an average discharge of 7,40 m^3/s (7 seasons' average of 11 months). The discharge recordings vary from zero flow (March to June 1973) to 37,03 m^3/s in July 1975. Due to several questionable discharge recordings the average of 7,40 m^3/s may be regarded as slightly low, or the KMI gauge average discharge slightly high.

Between gauging station KTI and KMI the Shashi and Xotega Rivers add discharge to the Thamalakane River. This is of the order of 2,0 to 2,5 m^3/s annual average at high flow and between 0 and 1,5 m^3/s annual average in poor seasons accounting for the increase at KMI.

The Samadupi (KMI) gauging station on the Boteti River provides an average discharge of 7,58 m^3/s (5 seasons' average for 12 months). The discharge recordings vary from zero flow (April to July 1973) to 38,0 m^3/s in August 1975. A rise in water level of just below 2 m occurs between low and peak flood conditions. The average dry period is one month, varying from 4 dry months in poor flood seasons to continually discharging water in good flood seasons. The Makalamabedi gauging station at Ramothupi Drift (KM2) is not assessed since data are incorrect. The Rakops gauging station (KM3) provides an average discharge of 4,13 m^3/s (6 seasons' average for 11 months). On average KM3 shows no flow for almost 6 months of the year and discharge varies from zero flow to 26,2 m^3/s recorded on 20 August 1975.

Further down the Boteti River no reliable discharge rates could be obtained but Bauer (1975), who produced a "mathematical swamp model", has estimated the discharge at Mopipi from hydrographs to show a time lag of between one and two weeks between Rakops and Mopipi and the discharge peak to reach about 85 per cent of the Rakops flow. A more accurate average discharge figure is probably in the region of 80 per cent of the Rakops flow.

For the period 1952/53 to 1968/69 the Ngabe River received 40 per cent of the Thamalakane discharge and the Boteti River 60 per cent. The bund established just after the Ngabe River take-off resulted in only 28 per cent and 9 per cent of the Thamalakane River's discharge flowing down the Ngabe River in the 1969/70 and 1970/71 seasons respectively. This effectively robbed Lake Ngami of 46,99 and 24,76 x 10^6 m^3 of water during these seasons respectively, and together with the decrease in Junyere River flow is assisting to kill the Lake. On average the Ngabe River should discharge about 3,1 m^3/s annually at KK3 and about 2,7 m^3/s at gauging station KK2. Table 44 illustrates the actual flow in the Thamalakane River and the expected and actual flows in the Ngabe River at KK2 for the period 1968/69 to 1974/75 and shows the loss due to the bund. This loss would normally lead to a combined average inflow in Lake Ngami of 5,36 m^3/s at KK5 from the Kunyere and Ngabe Rivers. The main inflow rate at Lake Ngami given by the UNDP BOT I Survey of 9,57 m^3/s is considered an overestimate as their average discharge at Maun Bridge KTI is considered excessively high.

Average discharge for KK5 varies from no flow to a peak of 16,74 m^3/s for August 1975 but this gauge is dry on average for eight to nine months of the year.

Table 44 **Actual flow rates (m^3/s) in the Thamalakane and Shashi Rivers and actual and expected flow rates in the Ngabe River affected by bunding at the base of the Okavango Delta,Botswana,during the period 1968/69 to 1974/75.**

SEASON	MEAN ANNUAL FLOW RATES				
	Thamalakane KT1	Shashi KT3	Thamalakane KT2	Ngabe KK3 Expected range	Ngabe KK3 Actual flow
1968/69	9,54	2,23	11,77	3,06 – 4,12	3,07
1969/70	6,72	1,05	7,77	2,02 – 2,72	0,88
1970/71	3,17	0,29	3,46	0,90 – 1,21	0,27
1971/72	2,49	0,01	2,50	0,65 – 0,86	0,00
1972/73	1,37	0,00	1,37	0,36 – 0,48	0,00
1973/74	10,59	1,27	11,86	3,08 – 4,15	1,60
1974/75	17,89	2,30	20,19	5,25 – 7,06	4,44

WATER MANIPULATIONS AND ITS EFFECTS ON THE ECOLOGY OF THE STUDY AREA

The limited manipulation work of channel improvement and "melapo" bunding (Fig. 28) carried out to date by Anglo American Corporation can only have localised effects on the lower Boro River and its floodplain system. These manipulations in no way effect the study area. The bund however established by Anglo American at the headwaters of the Ngabhe Eiver has seriously diminished flow rate and quantity of water reaching Lake Ngami, and successfully provided greater discharge down the Boteti River.

Natural Alterations

Flooding patterns of the system fluctuate from excessive inundation depths and floodwater duration in good flood seasons to zero inundation more often in poor flood seasons. The prevailing situation is that from the vegetation point of view some parts of the mid and upper-eastern floodplain tracts are showing a drying out tendency and are slowly evolving towards marginal and dryland vegetation types. Chief's Island itself has evolved as an increasingly larger sized land mass by absence of floodwater penetrating both ancient Primary and Secondary Floodplain Communities. By being deprived of surface water, woody vegetation encroachment

FIGURE 28 – Bunding of Primary Floodplain Communities by Anglo American Corporation offstream of the lower Boro River floodplain system during 1973, Okavango Delta, Botswana.

and development has served to unite adjacent islands and to expand this dryland mass. This is clearly more evident and recent in the northern Chief's Island area where old residents pointed out areas which they claimed used to be open grasslands, (Secondary Floodplain Communities) but which were now covered by one or other of the marginal or dryland woody plant communities. Piajio area on the northwest side of northern Chief's Island has been encroached by woody plants, and today supports a denser stand of woody species than that which is depicted by the 1937 oblique aerial photographs. The Piajio area Primary and Secondary Floodplain Communities in earlier years cut right across Chief's Islands. No water even penetrates some of these more ancient flooded areas today even in excessive flood years viz. 1973/74 or 1974/75. Several old "channels" or ancient Primary Floodplain Communities with clear-cut channels in both the extreme northern Chief's Island area and the central and upper eastern floodplain areas receive no water in poor seasons and small quantities in high flood seasons.

On the western floodplains the margin of Chief's Island is expanding. This process will have temporarily been curbed by the excessive 1973/74 and 1974/75 floodseasons; but it is predicted that this tendency will continue unless the Boro River carries an increased average water discharge. The present tendency of Delta distributary discharge seems to be evolving to a greater volume of water being carried by the Boro River.

The continual establishment (during dry conditions) and erosion (during wet conditions) of termitaria leads to the latters' significance in altering base levels (Fig. 29).

Man-made Alterations

The overall tendency of Delta evolution appears to be an expansion of the permanently flooded area at the expense of the seasonally flooded area (Clements **pers.comm.**) with which I agree.

If floodwater conditions remained as for the 1973/74 and 1974/75 flood seasons, no manipulations or improvements to outflow would be required whatsoever. Since these conditions can never be maintained, manipulations will sometime be brought into effect with the prime object in mind being to provide sufficient sustained outflow. Several logical methods are available and each and its possible effects will be dealt with independently.

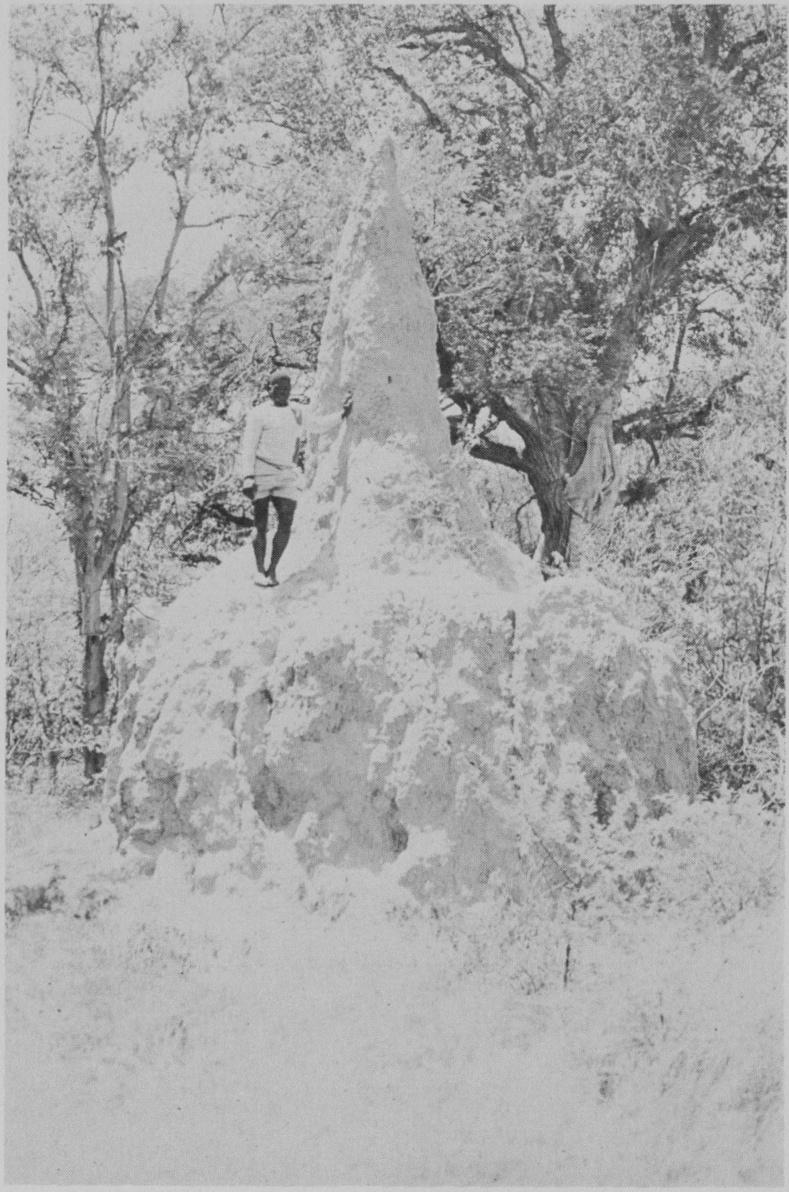

FIGURE 29 – The enormous size of termitaria in the Okavango Delta, Botswana and their subsequent evolution to form raised ground levels for woody vegetation establishment and local altered base levels can easily be gauged from this figure.

Peripheral Pipeline

The establishment of a pipeline has been investigated by previous workers (Lund, 1965, Sweco, 1973) but discounted due to the high economic cost involved. From an ecological, sociological and overall reliability point of view due to the seismic activity prevailing, the pipeline offers the only method without possibly causing irreversable internal Delta manipulations. All other schemes are dependent on the stability of the present reigning water regime and the increase in output down the Boro River system. The cost of such a pipeline due to the distances involved and the locality and gradient is, however, prohibitive.

This scheme would involve water being withdrawn from a suitable point at the base of the Delta's sleeve in the vicinity of Sepopa (Fig. 30). Water would then have to be piped via Gomare, Nokaneng, Tsau, Sehitwa and Toteng to Maun and Shorobe. Steel pipes should be used to keep friction losses at a minimum and thus ensure that the hydraulic grade line remains above the pipe and that positive flow is maintained. Pipe diameter affects friction loss and thus pipes must be sized to keep the hydraulic grade line between the straight line joining Sepopa and Maun and ground level. Pipes must follow the ground contours at a constant depth where possible.

Pumping on the main line is disregarded because of the isolated conditions affecting maintenance, and because of the large distances involved, the pumping head required to significantly alter the hydraulic gradient would involve numerous pumps and their maintenance. The water would have to be chlorinated at Sepopa to eliminate bacteria which corrode the pipe or grow in the pipe and restrict its free-flow cross-section. A further small dose of chlorine would be required at each distribution point. This would involve a 'chlorine gas' plant at Sepopa and Maun and smaller 'hypochlorite' plants at each of the other distribution points.

At each distribution point water from the pipeline would first go to a reservoir with two days storage capacity. It would then pass through the chlorination plant from where it would be pumped into a water tower, which would give it sufficient head for distribution. This would provide for human and live-stock requirements on the basis of 100 ℓ/head/day for humans, 50 ℓ/head/day and 5 ℓ/head/day for large and small stock respectively. The approximate cost of such a scheme is in the vicinity of R42 million, but may be in error by as much as R10 million (*P. Hahn, *pers. comm.*).

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* P. Hahn, Design Branch, City Engineers Dept., P.O. Box 4323, Johannesburg.

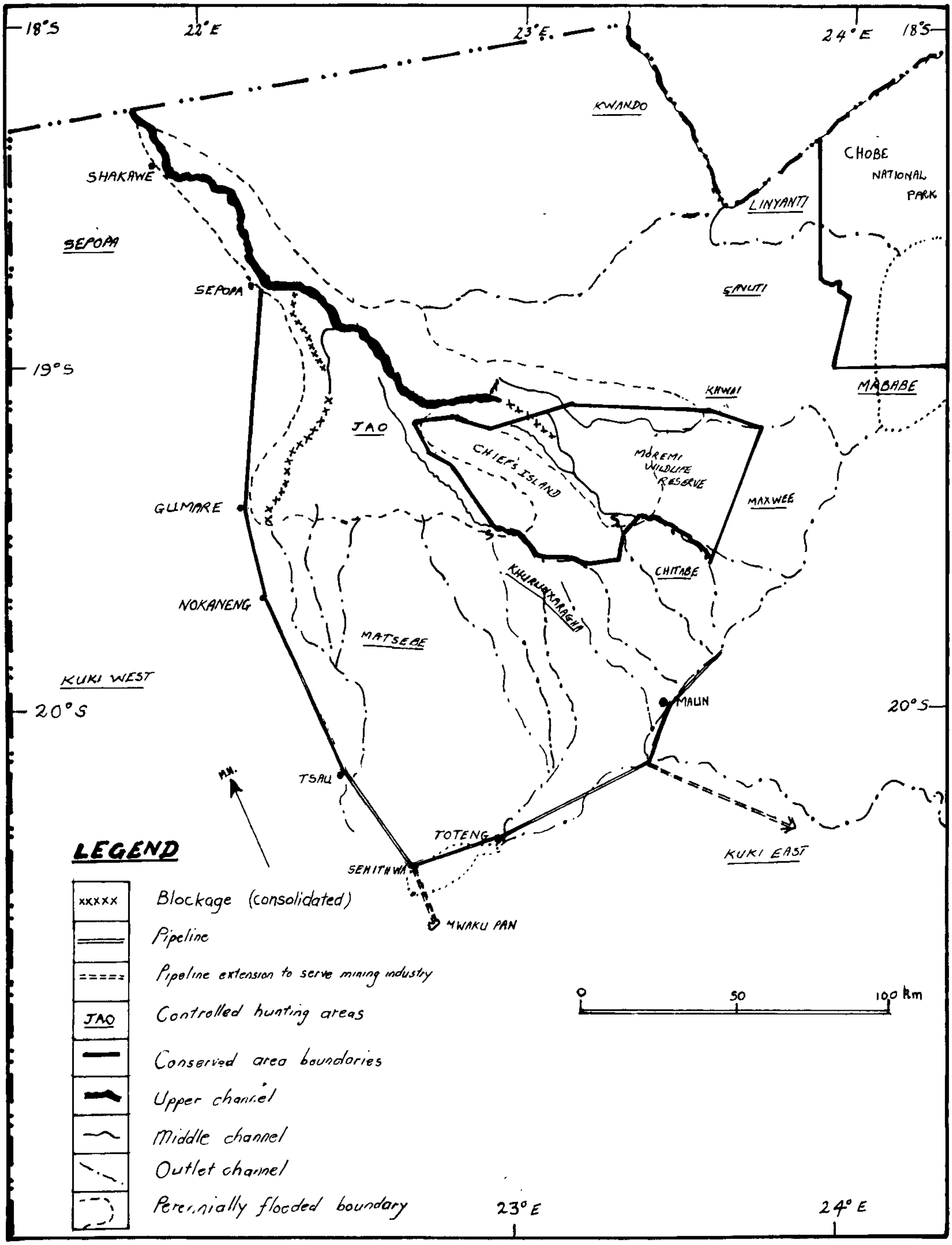

FIGURE 30 – Okavango Delta, Botswana, proposed pipeline and controlled hunting areas.

It is possible to supply all the water needs of Orapa and Letlakane diamond mines as an extension to the proposed scheme. In such a case all the pipes from Sepopa will have to be of larger diameter, implying higher pipe, transport, laying and accessory costs; and in addition the Maun-Mopipi pipeline. The estimated cost of the whole scheme would be R110 million.

Further modifications could also supply the Copper deposits of Ncauko Pan and later the coal deposits to be exploited at Matsitamma. The water demands made for irrigation projects are unrealistic, since the soils are generally poor and Ngamiland having a low agricultural potential does not warrant such water to be sensibly piped.

Improved outflow and control in the lower Boro and upper Boteti/Nghabe River system

This scheme firstly involves the removal of the Lake River bund to ensure the old water distribution down the Nghabe and Boteti Rivers, and thus a fair supply to Lake Ngami. The present bund should be transformed into a shallow control section, and then a flow control structure established at Samedupi on the Boteti River. This latter control structure should form an integral part of the wall for a reservoir dam at Samedupi (if the following proposed scheme is adopted). The following stage would be to complete the dredging up to the Kunyere fault line which the Anglo American Corporation was prevented in completing. Bunding of this lower Boro River section should be allowed to prevent water loss and enhance flow out of this lower section where floodplains are hardly required.

Low overfall weirs to form shallow storage facilities at sites from which water could be pumped to off-stream cattle ranches may be required.

This scheme would slightly effect the lower Boro River ecology but involves no manipulations higher up in the Delta and thus due to its much lower costs is probably the best scheme for improved output. Should flow down the Boro River be altered significantly the scheme may prove to be inadequate.

Storage on the Thamalakane/Boteti/Nghabe River System

This scheme is a direct extension of the previous scheme. It involves the extension of the Samedupi control structure to the dimensions required for a reservoir dam, and the construction of a control reservoir dam at Toteng.

These two dams would effectively form a river valley storage reservoir with a maximum capacity of 168 x 10^6 m^3 (Ernest, 1976). Ernest (*op. cit.*) claims that this scheme will not affect natural flooding pattern downstream which has to be maintained for the riverine populations, but would guarantee a minimum continuous outflow. This could be directly pumped from a small reservoir at the Mopipi terminus into the existing high lift system thus saving on low lift pumping costs and improving the quality of water to Orapa.

This scheme is dependent on increased Boro River outflow to fill the river valley reservoir, and thus would involve further manipulations on the Boro River affecting its middle reaches ecology. Also, should water distribution in the Delta change significantly, the scheme will prove inadequate in supplying water demands.

Redistribution of flow in the central branches of the seasonal swamps via bunding, culverts and control weirs.

This scheme involves restriction and prevention of floodwaters entering certain Delta areas, and thus recovering potential infiltration and evapotranspiration losses in the central Delta axis. The bunding would be irreversible but the control gates would remain open to allow flooding under "normal" conditions, but will remain closed throughout when insufficient flows are forecasted.

The bund line will follow the Khurunaragha/Txichira line of islands ridge, starting near Kolobahtse and extending northwards as water supply demand increases. This will effectively retain Kiri River water from reaching the Khwapa River in all but good flood years. As the control line extends northwards so it will also cut Boro River losses to the Xudum and Matsebe River systems. Since this will drastically affect the Kunyere River, being the natural intercepter channel for the above three affected systems, Kraatz (1975) preposes creating a diversion weir on the Xotega River to recompensate flow down the Kunyere River for local inhabitants and to feed towards Lake Ngami. Ernest (*op. cit.*) mentions the upstream limit of bunding as dictated by need to maintain flow in the Matsebe channel for wildlife and cattle. Further work will require channel cutting for improvement of flow between the Xotega/Kiri and Shashe River systems and finally additional 'upstream measures' to further increase outflow if required. These presumably infer Boro River channel improvement and bunding from Xakwe southwards on that river to the Kunyere fault line. Kraatz (*op. cit.*) has also proposed drainage trenches in the Boro River's *Cyperus papyrus* filter community intake to increase the Boro inflow.

This scheme, if carried out, will definitely affect the ecology of the lower Khwapa, Xudum and Matsebe River's and their floodplains. If the entire ridge is controlled the prime wildlife floodplain systems of upper Khurunxaragha and Ngabegha will effectively die. The further bunding on the Boro River from Xakwe southwards cannot be condoned as this will kill the middle and lower Boro floodplain systems. Any manipulations in the Boro River intake can have far reaching effects in blockage formation from sudd. Boro River channel improvement to increase outflow without the use of bunding should rather be resorted to.

Improvement of the Thaoge River channel

Large water demands have been made by Sweco (1973) for irrigation schemes on the old Thaoge floodplain system. Although these soils offer a better agricultural potential then others of the Delta or Ngamiland they cannot be considered as prime arable land and this scheme may well never reach its proposed production.

However, any water required for agricultural production in this area will have to be obtained from rehabilitation of the Thaoge River as proposed by Ernest (1976). Basically this involves the recleaning of the middle Thaoge between Gomare and the Karongana confluence, with some bends requiring shortcutting over this 130 km strip. Next, the middle Thaoge would have to be connected to the base of the permanent swamp in the northwest via a bypass channel of some 22 km in length, which partially exists but would require improvement in width and depth over crucial parts. Further channel cleaning and shortcutting upstream of Gomare and a 4 km channel excavation to bypass consolidated blockages should in all restore a perennial flow as far as Tsau. However none of this work is worthwhile unless large-scale crop irrigation can be successfully conducted on the Nokaneng Flats.

The scheme which will provide for minimal alteration to the ecosystem and maximum sustained water take-off without any loss via evapotranspiration is the piping of water from the upper-Delta. Each distributary system will lose a small amount of water proportional to the present flow. Any further natural internal Delta changes affecting water distribution cannot affect the pipeline unless seismic activity affects the pipeline itself. Although excessively expensive to establish, the upkeep costs will be minimal once it is in operation. No irreversible damage can be caused to the Delta and the predictability of the scheme is sound.

In conjunction with the peripheral pipeline the establishment of the Thamalakane reservoir with control weirs at Samadupi and Toteng could be considered. This will provide for a further backup supply for human, stock agriculture, mining and other industrial use, as well as creating a potential for fisheries and tourism. Part of "Lake Ngami" could also be kept alive from this scheme. This scheme could initially be put into operation with the peripheral pipeline to follow.

The only internal Delta manipulations should possibly be slight channel improvement to the Boro River channel itself from Xakwe southwards. The only bunding on this channel should be below the Kunyere fault line. The channel improvement on the Boro River should only be resorted to if the discharge into the Thamalakane River is below the average expected in accordance with the input at Mohembo andlocal Delta rainfall.

Some hydrological engineers have proposed supplementing the water output of the Delta from Kwando/Linyanti waters. The scheme would involve opening up of the Savuti River mouth intake off the Linyanti, improving its existing channel and continuing the channel to the old Mababe Marsh. Water would then be lifted from this point and piped to the Thamalakane River and discharged into it on the Maun side of the critical high level in it. This critical high level lies between the Gomoti and Mogohelo River discharge points into the Thamalakane River. This would involve a piping distance of less than 150 km.

Such a scheme would lessen discharge down the Chobe River system into the Zambesi River. If the scheme could be well-controlled in supplying a reasonable discharge of water down the Chobe River to maintain its floodplain system to Caprivi and northeastern Botswana and hence the Zambesi River; and also create an increased floodplain system in the Savuti/Mababe Marsh areas it would be well worthwhile. International permission would be required before any steps could be taken.

If the Chobe system could be reasonably maintained and provided the engineers allow sufficient water to extend the present Savuti Marsh floodplain system the scheme could benefit certain wildlife species in the area and provide extra water past Maun. However *Salvinia molesta* is present in the Zambezi/Chobe system and thus its possibility of reaching the Thamalakane and spreading up into the Delta would preclude such a scheme. To create an increased floodplain in the Savuti Marsh would, however, be most desirable.