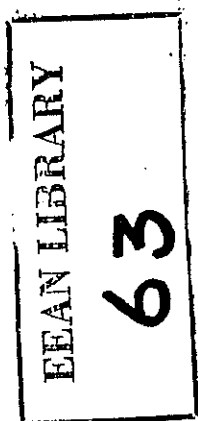


Okavango



Some Natural and Man-Made Changes  
in the Channels of the Okavango Delta

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# Some Natural and Man-Made Changes in the Channels of the Okavango Delta

by BRIAN H. WILSON

The Okavango delta shows some surprising contrasts of stability and change. In this article I shall look at some of these contrasts and at some of the changes that have occurred, both in nature and as a result of man's activities. My list is far from complete, and I have excluded those important peripherals, Lake Ngami and the Boteti river, partly because their changes are the results of changes upstream and partly because they are already moderately well chronicled.<sup>1 2 3 4 11</sup> The Magwegqana (Selinda Spillway), the Kwando, Mababe Depression and the Savuti, and the latter's recent rejuvenation are worthy of a separate study (as are the works of WENELA), and are not here further considered. Current works by Anglo American Corporation are also beyond the scope of this article. Nor am I here concerned with surveys, however important, except where they have a direct bearing on channel changes. I have generally altered place names to their modern spellings. But historical measurements have not usually been changed to the metric system.

Figure 1 shows the main channels of the delta using a simplified nomenclature. Let us look first at the largest channels, the Okavango and its continuation, the Nggokha. Sitting in a boat one is impressed by the exuberance of the waving papyrus (dominant north of about lat. 19° 30') towering over the water's edge and of its rhizomes boldly cantilevered out into the stream. Surely, it seems, such growth is irresistible. But the river, steadily dissipating some 150 horse power every kilometre in these upper reaches is still a match for the vegetation. These two, river and papyrus, have, after all, been living and struggling together for thousands of annual cycles and it is not so surprising that they have come to a balance. Their detailed relationships of depth, velocity, soil, river bed and siltation, of temperature, chemistry and related species, we do not understand. Biological research by the Ministry of Agriculture and by Anglo American Corporation have recently begun and a review of papyrus research is in progress at Makerere.

We have air photographs of much of the delta going back to 1937 and it is clear that many of the important channels have changed since then neither in alignment, nor width nor in exact geometric shape. The curious and rather unstable looking meander near Seronga shown in fig. 2 is an example. It has not altered in thirty-five years. This stability is typical of 260 out of the 270 kilometres of the main Okavango/Nggokha channel between Mohembo and Letetemetso Island, alias Hanamozeyo (see fig. 1).

But note also the wide channel in fig. 3 which is something of a backwater with no open inlet, and it surely carries much less flow than it must have done when it was originally formed. Why, one wonders, has it not closed up or grown over, even though the flow regime has changed?

In fig. 5 one sees evidence of many changes in channel configuration that have taken place in past ages. To figure out the sequence of the changes and to put a time scale to them would be a difficult but fascinating study. For the present we simply note that these changes appear to be considerably remote in time.

So far I have been discussing only the upper channels of the delta, but five days in a boat between Shakawe and Maun impresses upon one that the water flows through many different types of channel which must be separately considered. I list them as follows:

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*Fig. 2 (right)*

*Meanders on the main stream near Seronga which have not changed in 35 years.*

*SCALE (both photos)*

*1 km*



*Fig. 3 (left)*

*An unusually wide and straight channel emerges from a series of Madiba and then becomes suddenly constricted. In spite of these sharp contrasts, the boundaries between open water and vegetation have remained exactly the same for 35 years. From Boro inflow area about latitude 19.*

(a) *Upper Channels*; typically the Okavango/Nggokha between Mohembo and Letetemetso. These are broad channels from 15 to 130 metres wide, typically 5 to 7 metres deep with beds of Kalahari sand and no bottom vegetation, bounded dominantly by papyrus, particularly on the insides of bends, and also with much *Phragmites* and lesser patches of *Miscanthidium* (moxaa). The upper channels are perennial, strongly flowing with typical velocities of 0,6 metres per second and flows exceeding 25 cubic metres per second. Upper channels are generally stable but the balance of change appears to be slightly in favour of the river as against the vegetation.

(b) *Middle Channels* are separated from the upper channels which feed them either by 'filters' (see below), by blockages or by 'restricted take offs'. They vary very considerably in width and flow from almost zero upwards. One of the largest, the Moanachira is undoubtedly now a 'middle channel' but it has the dimensions and shape of an upper channel which in former ages it appears to have been. Middle channels are part of the perennial swamps, characterised by much papyrus. Their seasonal rise and fall is often quite small (0,2 metres). They are less stable than upper channels, seeming less confident in their ability to dominate the vegetation. Yet cut-offs (short cuts) sometimes occur.

(c) *Outlet Channels* carry water away from the perennially flooded area. They are the most variable channels in width, depth, vegetation and flow, in both time and space. They have hardly any papyrus but there is generally an abundance of other vigorous submerged and emergent aquatic plants. Outlet channels are at the mercy of any changes upstream, and they also have their own problems of rapid vegetational growth. It is mainly but not entirely here that the fig (*Ficus verruculosa*) abounds, particularly in the eastern rivers, and has the effect of strangling the channels.

(d) *Flats* are shallow, perennially flooded areas lightly covered with a variety of aquatic vegetation. When going by boat through flats, you simply follow the track of the previous boat or the previous hippo. There is no concentrated flow of water. Flats appear to be relatively stable though some recent sand bars are to be found.

(e) *'Filters'* are relatively stable, flooded areas with thick enough vegetation to prevent boats or floating debris from passing through, but have large cross-sections and short axial lengths such that water can pass through in quantity with little loss of head. They are of considerable importance.

(f) *Blockages* will be described in detail later.

(g) A *'Restricted Take-Off'* is shown, typically, in fig. 4 where the Thaoge leads off the Nggokha. A minor channel here leaves the main channel at a sharp angle, such that it draws off less than its fair share of floating debris. Restricted take-offs are of importance to the Thaoge and Boro rivers. Before about 1960 the Moanachira take-off opposite Letetemetso Island seems to have been 'restricted', but the progress of the Nggokha blockage (see below) meant that a greater proportion of flow and debris was diverted to the Moanachira.

(h) *Short Cuts* occur where a channel, either naturally or with encouragement from man, breaks through a bend and shortens its length.

(i) *Madiba*, to use the Tswana word (singular *lediba*), frequently, and incorrectly, called 'lagoons', are oxbow lakes formed as relics of ancient river channels, which, for some unknown reason, have remained clear of vegetation. They are beautiful features of the scenery but do not seem to play a very important part in channel development or deterioration except perhaps in the Boro inflow area, in conjunction with 'filters'.

The general stability of the upper channels has been noted. But let us look at the exceptions in that area, it being important to note that they are exceptions. Fig. 6 shows three short cuts and their development. They, with the WENELA short-cut on the barge route from Sepopa



*Fig. 4 (left)*

*"Restricted Take-Off"  
Thaoge (left) taking off from the Okavango (flo  
down the page)*

*SCALE (both photos)*



*1 km*



*Fig. 5 Jumble of Ancient Channels*

to Seronga, are the only ones in the last forty years or so in 270 km of Okavango/Nggokha upper channel. But what of their effect? Suppose we are interested in maximising the outlet flow at Maun, are we not to welcome anything which will shorten the route? By no means, A short cut represents an imbalance; a local surge of energy churning up the river bed and breaking away chunks of papyrus which are carried off downstream. There is, in fact, a continual generation of papyrus debris in the upper channels, and it cannot all be attributed to short-cuts. Sit beside the river at Sepopa for half an hour and watch the pieces floating past; single dead stalks flat on the surface, living stalks standing up with a fraction of a square metre of floating sudd, more rarely a couple of square metres or the branch of a tree. Over a year this must amount to several hundred tons (dry weight). It will take a long time to rot or sink but, down the middle of the river it will only take two and a half days to get from Sepopa to Letetemetso.

The delta is inherently a set of river channels which divide and get narrower and narrower away from the source. It follows that somewhere and sometime the dimensions of the floating debris will approach the width (or perhaps depth) of the river channels and will get stuck. Once a large piece is held, smaller pieces will pile in behind it. Though it may break away again and be swept a little downstream, eventual blockage is inevitable. And it must be cumulative, though it can be modified by break-throughs and short-cuts. Fig. 7 shows a typical papyrus blockage.

In principle, therefore, blockages are inevitable and we do not need to postulate earthquakes, climatic changes or the intervention of man to account for them. But why they start to occur at particular places may be influenced by such things.

Over the last twenty years the most active blockage has been on the Nggokha below Letetemetso Island. Fig. 8 shows its progress in the last thirty-five years, accurately documented by the air photos of 1937, 1951 and 1969. Opposite Letetemetso there is a small channel through to the Moanachira river, which is the site of the presently active blockages. This channel carries a relatively small proportion of the Nggokha's outflow and a relatively small proportion of the Moanachira's inflow, the balance being a transfer through the 'filter' which exists between these two rivers. But the channel is important for navigation. Crocodile hunters formerly and hydrologists latterly have struggled to get their boats through it. But though a gang may clear the Letetemetso channel effectively in a week or so, it inevitably gets plugged again quite soon. At each partial clearance, by man or nature, some debris is passed downstream and is steadily blocking up the Bokoro *lediba* shown in fig. 8. Some also passes on to Xherega *lediba* (alias Dobe) where, in this case, it catches on the shallow bottom.

Papyrus blockages normally form first on the surface of a channel whose depth is often 3 to 5 metres. At first there may be considerable and rapid flow beneath the surface, but as the blockage gets longer, colonised by more vegetation and perhaps silted up a bit, the sub-surface flow is reduced, sometimes to nil. Brind<sup>5</sup> also describes a special type of blockage which may begin at a time of low water if a previously floating mat of papyrus becomes directly fixed to the stream bed. This type of blockage appears to be confined to the Thaoge.

Left to nature the Nggokha blockage will go on spreading upstream, having first closed the Letetemetso channel. The Moanachira, Khwai, Borokha, Santantadibe system (that is the rivers east of Chief's Island) may not necessarily suffer drastically as there is a large 'filter' area. To navigation this would be tiresome, though alternative channels could be opened across the filter area.

The Nggokha blockage probably began about fifty years ago. One may speculate what happened to the debris before that time. Was it caught further downstream or was it, perhaps, mostly, in those days, deposited in the Thaoge?

The other main blockage of historical time which has worried far more people, is that on



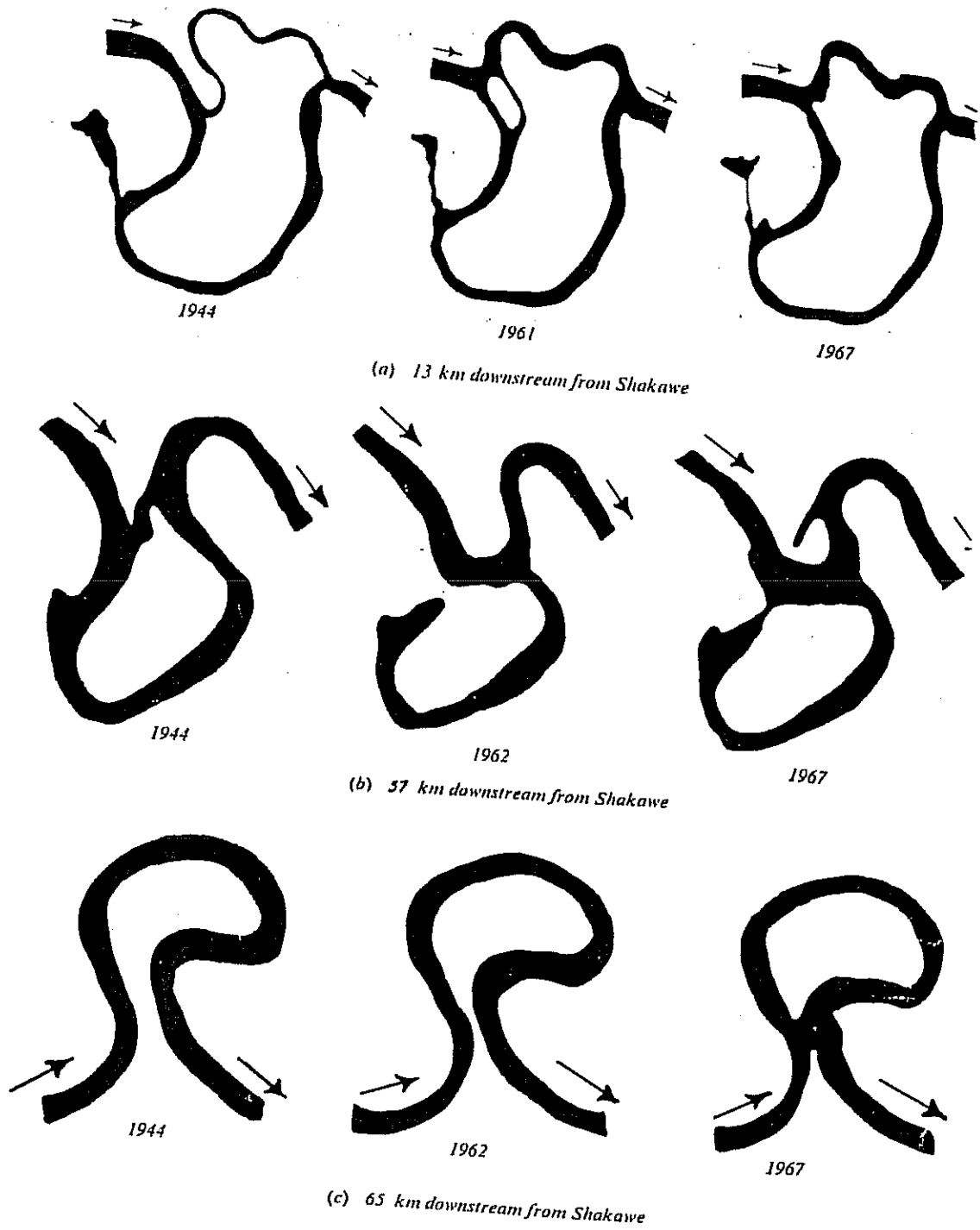


Fig. 6 THE DEVELOPMENT OF SHORT-CUTS

the Thaoge. Lake Ngami in the 19th century received its major flow from that source. In August 1854 Andersson<sup>6</sup> ascended the river from the lake by boat for thirteen days at five miles a day and found never less than five foot depth of water. Livingstone<sup>7</sup> gives a second-hand report of the river seasonally running to the Lake with great rapidity: 'large trees are frequently brought down and even springbucks and other antelopes have been seen whirling round and round in the middle of the stream as it hurried on their carcasses to the Lake'. This seems to represent a sudden surge, perhaps occasioned by breakthrough upstream. Such behaviour is quite untypical of the flow of any other Okavango outlet channel today. Moreover a floating tree would surely catch and start a blockage before long.

According to Stigand's excellent map (obtainable from the Department of Surveys and Lands)<sup>8</sup> the Thaoge began to dry up about 1883 and ceased to run into the lake about 1884 ... (a second-hand report<sup>9</sup> tells of the Thaoge reaching the lake in 1907 but this may contain some confusion).

There is also a story, or fable, that about 1860 Chief Moremi built a dam a few miles north west of Lake Ngami to prevent water getting into the lake where 'marauding Bechuanas ... henchmen of Arab slave traders' and, later, unwelcome Boers had based themselves. The dam, it is said, within a few years finally and effectively sealed the channel.<sup>10</sup> The story, as related, contains historical inconsistencies suggesting, possibly, a dual origin.

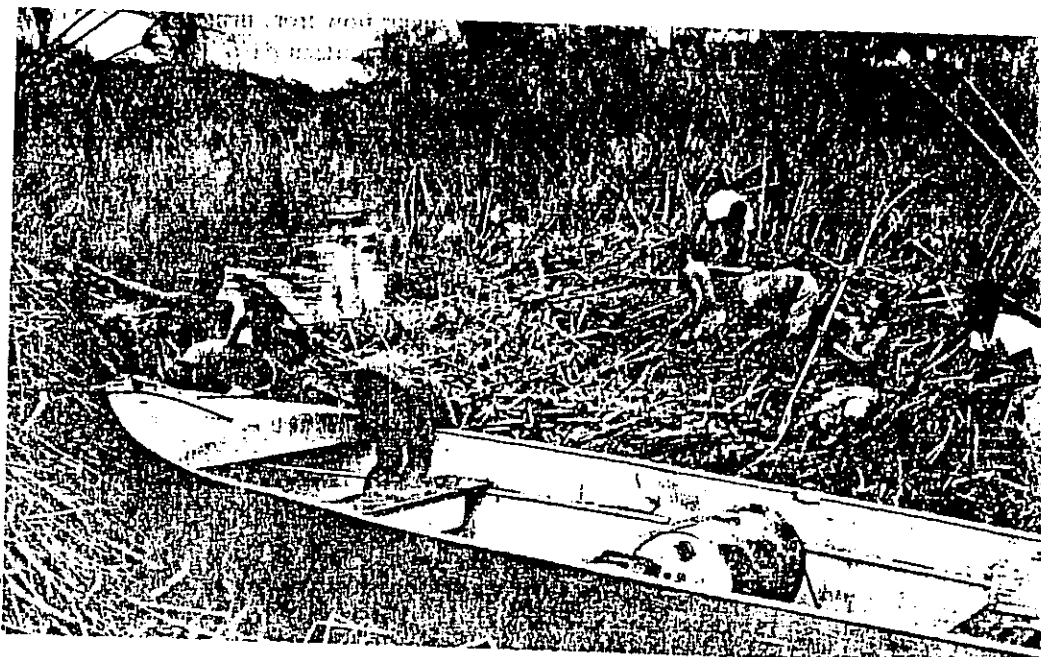
Nowadays, in good flood years, such as 1968 the Thaoge just reaches to Makukung about 16 km in a straight line from the lake. Climatic change has been ruled out as the cause of the alteration.<sup>11</sup>

Blockages on the Thaoge have been in four general areas: the upper plug of 43 km which is effectively by-passed, the main papyrus plug of 155 km, the former papyrus blockages cleared mainly by Drotsky, as described later and the 'outlet channel', being the last 60 km to Tsau which formerly was blocked by aquatic vegetation other than papyrus, as well as by man-made obstructions such as fences and earth banks.

The ancient channel at the site of the upper plug, judging by its shape, must have carried a large quantity of water exceeding the Nggokha. There is a tradition<sup>12</sup> with, of course, an associated fable that the Nggokha was formed about a hundred and forty years ago. This would be consistent with the blocking up of the upper Thaoge.

Brind<sup>13</sup> plots the progress of the upper, active, limit of the main papyrus blockage from 1944 to 1951 (10 km) and from 1951 to 1952 (4½ km). Surprisingly, however, the blockage did not progress any further upstream. Read, FAO Hydrologist, in 1969 found that the position of the limit of the blockage was exactly the same as it was in 1951, and the additional 1952 blockage, which must therefore have been a short plug, was no longer there. How can this be explained? Present stability is perhaps due to the 'restricted take-off' (see above) where the Thaoge takes off from the Nggokha, and by the comparatively low flows in this section of the river which do not generate much papyrus debris. But why was it not stable before 1951? Was papyrus, perhaps, still breaking away from the lower end of the upper blockage? What caused the change? Could it have been related to the intense seismic activity of 1952? It could have been, but one would like to be able to detail the chain of cause and effect.

In their formation neither the Nggokha nor the Thaoge blockages were the unaided work of nature. Tlou<sup>14</sup> has referred to the 'significant technological break-through' of the introduction of the papyrus raft invented by the baYei. But for the rivers, this 'break-through' has been more than matched by its powers of 'blocking up'. The papyrus raft, *huzhenje* or *lekawa* is a hippo-proof and delightful method (as I can testify) of travelling down river with a load, at very small expense. Mr Rambwe of Seronga made one for me in 1969 and, with a *mokoro*, which is desirable as a tender, piloted a party of six from Shakawe to Sepopa, at the speed



*Fig. 7 (a) A plug of floating papyrus debris caught in the Letetemetso channel. It is still possible to force boat through and the water flows underneath the floating mat.*



*Fig. 7 (b) Papyrus debris continues to collect against the initial plug. Later the mat will be colonised by living papyrus and other vegetation. Navigation becomes excessively difficult, the flow of water is slowly strangled, and in time the river dies.*

*Photo: P.A. Smith*

of the current, of 2 to 3½ km/h. It was a small *lekawa*, 2,8 m by 2,7 m and at the end of the 100 km journey we were finally able by very great effort to manoeuvre it and tie it up in a backwater where it could do no harm. But traditionally *makawa* seem to have been just abandoned, it being very difficult to do anything else. In 1937 Naus<sup>15</sup> writes to the Resident Commissioner: 'I know that it is not possible to forbid the natives using these rafts to transport their grain, as the hippos would smash up dugouts but ... it might be possible to get the Acting Chief to request (them) to pull the rafts out of the river after ... their journey'. It was probably the development of road transport rather than exortation which caused *makawa* to decline and Brind<sup>16</sup> in 1953 writes: '... this form of travel seems to have died out for some time'. Mr Peter Smith, however, found an abandoned *lekawa* caught in the Letetemetso channel in 1972.

At the beginning of this century, or earlier, the bad effects of abandoned *makawa* were noticed by travellers. Streitwolf<sup>17</sup> cited by Passarge<sup>18</sup> quoted by Stigand<sup>19</sup> speaks of blockages on the Thaoge being caused by such abandoned rafts: 'little floating islands 15 to 17 ft diameter by some 5½ ft deep ... blocking the entrance of the effluent channel in the papyrus bank bounding the Okavango'. Ellenberger<sup>20</sup> gives full details of many such blockages on the Nggokha. As I have shown, once a blockage is initiated, by whatever means, it will usually tend to grow.

There may well have been periodic attempts to clear blockages of immediate local concern before 1930 but I have not found record of them. There is however record of a diversion about 1919 by Headman Keatametse at Nxabexau, a dozen miles north of Nokaneng, who brought water for 20 000 cattle to a tsetse free area.<sup>21</sup>

Until 1922 when Stigand prepared his map<sup>8</sup> and his paper<sup>19</sup> the hydrography of the interior of the delta must be regarded as pre-history though, by contrast, there are several descriptions of the Thaoge and the western margins of the delta in the last century.

The first recorded attempts by Government to change the course of nature appear to be in 1931 when Mr V. Ellenberger (then Assistant Resident Magistrate, Ngamiland) was sent up from Maun to Mohembo by river to report on the 'possibility of opening up, by the removal of obstructions, of a well defined channel ... navigable by motor driven craft ...' from Mohembo to the Rakops railway station which, it was then hoped, would soon exist as part of the Livingstone to Walvis Bay railway then being surveyed.

Ellenberger's trip took five weeks, going up the Boro (September 1931), on to Mohembo and returning via the Nggokha and Santantadibe. In a second trip of four days he studied the Gomoti. His 56 page report<sup>20</sup> includes a detailed route map, based on Stigand but with important details added. 'The Santantadibe River' he writes 'will probably dry up within the next two or three months. This has never happened before and affords a striking illustration of the gravity of the position.' But apart from the hippos (fiercer, it seems, than they are today) the main navigational worry was the Nggokha blockage. Its upstream limit at that time was twenty four kilometres downstream of its present position at the Moanachira take-off (compare also Sgt. Davies' report of 1933<sup>23</sup> indicating the blockage to have then begun thirteen kilometres below the Moanachira take-off.) A typical entry from Ellenberger's log book while in the Nggokha blockage is 'river 15 yards wide, 12 ft deep, totally blocked by papyrus rafts'. Later, less typically '26.9.31 8 p.m. All thoroughly exhausted. Have no alternative but to spend the night in the boats, Mosquitoes bad. 10.15 p.m. Eclipse of the Moon!' The eclipse prevented further efforts to get through, as hoped, by moonlight.

It took him two and a half days to force his way through or round these blockages before he regained the Nggokha river at the downstream end. But he did get through. Nowadays this would be impossible; too thick at the upstream end and too dry in the middle. Is it just a mechanical vegetational blockage, or has there been seismic uplift (or subsidence)? Against the

uplift theory it must be said that Letetemetso Island at the top end of the blockage is (in 1972) deeper in the water than formerly, evidenced by many drowned palm trees.

In 1931 in the depth of the economic depression it was not easy to get money for maintenance or development, but to Colonel Charles Rey, the Resident Commissioner, the clearance of Ngamiland waterways was of great importance. Work started in April 1932 with Mr Scott Norwebb in charge and paid 10 shillings a day. He started work on the Thaoge upstream of Tsau removing bush fences and sand bars in the river bed. Labour was at first voluntary and there was a good turn-out, averaging 55 men. But the work seems to have been successful and the Resident Magistrate agreed that: 'the arrival of the water at Tsau should be suitably commemorated and Sgt. Smith was authorised to buy two beasts at 25 shillings each so that the labourers might have a feast' (a query from the Financial Secretary was feared!).<sup>24</sup>

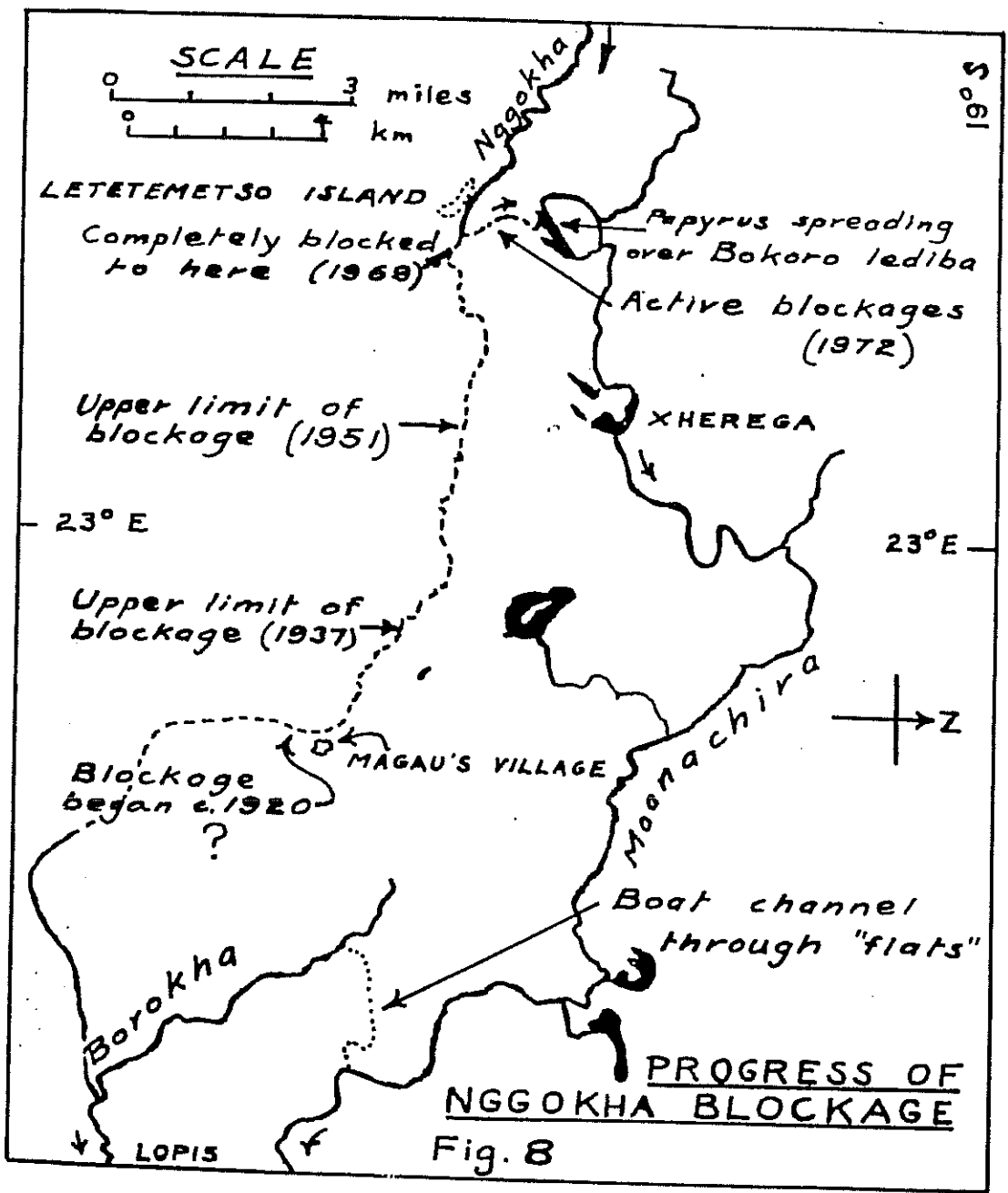
In August of the same year Mr Martinus A. Drotsky, then living at Makukung, was engaged at £10 a month to open up blockages on the Nggokha river and he decided to use papyrus rafts to float his labourers down to the site. Work was held up by a serious epidemic of influenza in which many people died. The blockage nevertheless seems to have been effectively cleared for a time. Sergeant Davies<sup>25</sup> making a report on Drotsky's work was agreeably surprised at the amount completed but says, obliquely: 'the work would have been satisfactory in every way had a wider channel been cut'. One may guess that the narrow channel soon blocked again, just as it does in the Letetemetso channel today.

On the Gomoti river, which was then the most important contributor to the Thamalakane, Headman Motseakhumo was appointed to clear the channel, especially by cutting *seqowaqowa* trees (*Ficus verruculosa*). Motseakhumo was reported to have made: 'such a success of the Gomoti river for the sum of £10 plus rations for his Mokuba assistants'.<sup>26</sup>

The following year Brind, the Government Engineer, submitted a proposal for clearing the Savuti, but this was not followed up.

A year or two before, there had arrived in Maun a traveller and hunter, Charles F. Naus. His antecedents always remained a mystery but he claimed to be an architect, an engineer and a colonel. Offering his services to the Government he was promptly turned down on grounds of the financial stringency. But this was not the end, for Naus fitted in with the ideas of Colonel Rey, the Resident Commissioner, for the development of the Ngamiland waterways<sup>27</sup> and he must have fitted in with his ideas of the enthusiastic gentleman amateur. He began work in August 1933 under a Colonial Development Fund grant of £1000.<sup>28</sup> His temporary appointment was formalised in November 1933 and continued for four years. It was an energetic, if turbulent, period.

Naus' first idea was that the Santantadibe and Gomoti rivers must be cleared of obstructive vegetation by fire. To this end dams were to be built which would stop the flow and allow the channels to dry out (Jeffares<sup>2</sup> suggests that burning may have been an effective traditional form of maintenance which had fallen into disuse). Naus picked a site at lat. 19°23,3' long 23° 13,6' SW of Txaba which he regarded as the beginning of the Santantadibe river after its take-off from the Borokha. Construction began in December 1933. There were then no air photographs and no accurate maps but his correspondence shows that he knew the geography of the delta quite well. Today this general area, though not his precise dam site, is the beginning of a minor blockage area where the well-defined 'middle channel' of the Borokha gives way to the several narrow, rather undefined and easily blocked 'outlet channels' which become the Santantadibe and the Gomoti. There was thus some logic in choosing a site in this area, though why he picked that exact spot is not known. The dam was reported to be 1 050 ft long by 24 ft broad by 14 ft high. When the dam was nearly finished Naus was impressed by the current sweeping through the small gap which remained to be closed. He thereupon abandoned



the idea of drying up the river bed (though he did later continue the burning of reeds and vegetation) and he formed a curious theory that dams with gaps in them somehow increased, and not diminished, the total flow. He does not seem to have distinguished between ideas of velocity (metres per second) and discharge (cubic metres per second). But he had the ear of the Resident Commissioner, and against the advice of the Government Engineer he was allowed to proceed with building another five or seven 'dams' with gaps in them on the Thamalakane, Boteti and Lake rivers.

One of these remains to this day as the Matlapaneng bridge, a beautiful and popular picnic spot near Maun. As originally built it had two openings for the water to pass through, a further three being added later by the PWD. Photos of the newly constructed bridge in 1934 are kept in the Archives.<sup>22</sup> This 'dam' proved very useful for road traffic, the previous crossing having been a drift, just upstream of the 'dam'. One can see a photo of Colonel Rey's car being pulled across the old drift by oxen in 1930 in a paper by Rey.<sup>29</sup>

Two others of Naus' dams proved useful causeways; those at Maun, on the site of the present concrete bridge, and at Samedupi, (where a low bridge has now recently been built). It is certain that these dams did not cause increased flow of the rivers but at the time, not only Naus, but also local residents and Colonel Rey himself believed that they did.

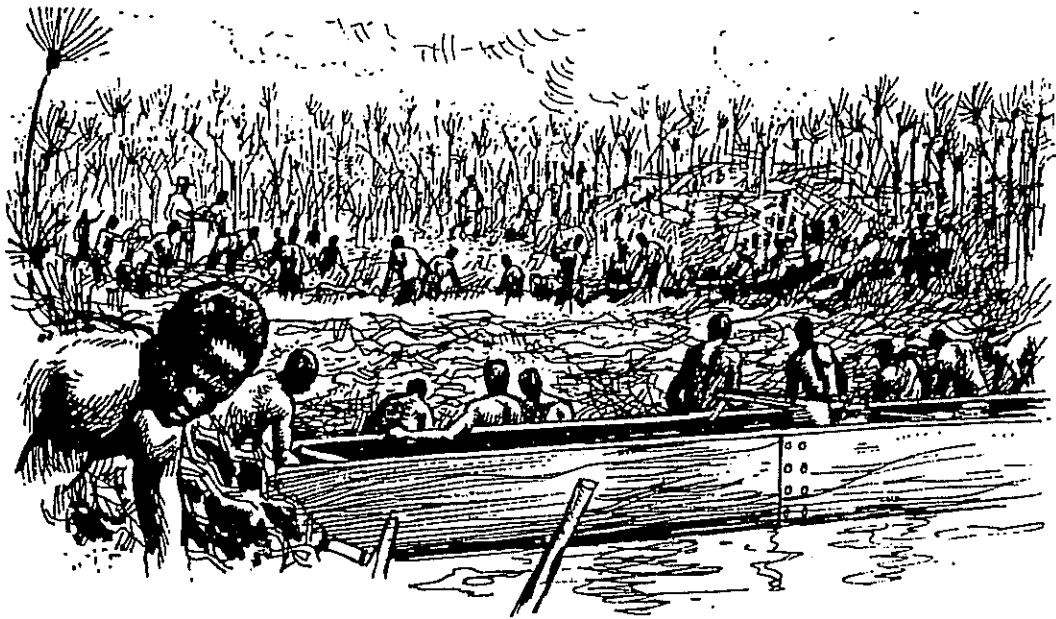
Rey had at first been appropriately sceptical<sup>30</sup> writing a five page minute on the subject, but on one of his many visits to Maun (he was a great traveller, and this particular visit was in September 1934) he was completely convinced, one might say 'taken in' by Naus. Rey, unfortunately, consistently went against the advice of the Government Engineer, Brind, concerning Naus.

The High Commissioner, in Pretoria, seems to have had doubts. A chartered civil engineer from Pretoria, Mr J.L. Hill, was commissioned to examine the files and report on Naus' work, which he did in a nine page report in April 1935.<sup>31</sup> Later the same year another chartered civil engineer, H.R. Roberts, and the Agricultural Adviser to the High Commissioner, R.W. Thornton, made a joint visit and submitted detailed reports.<sup>32 33</sup> This was followed in 1937 by the survey by Jeffares,<sup>2</sup> (who had earlier surveyed the route of the proposed Livingstone to Wavis Bay railway). Meanwhile Naus appears to have continued clearing work on the Santantadibe river system, though there is little mention of further dams.

Much of his work seems to have been concentrated in the Txaba area (lat. 19° 23' long 23° 14'), that is, near his first dam. He made a detailed sketch map<sup>31</sup> with explanations of the work done. Part of his concern was to encourage the Santantadibe at the expense of the rival Gomoti, which was even then a dying river. Naus made experiments on the destruction of *Ficus verruculosa* trees by injecting sulphuric acid. He also made an interesting proposal, never yet carried out, but in principle sound, to erect 'cable and hooks' at Gaenga (lat. 19° 04,1' long 22° 49,1', then known as Kabamukuni Landing) to catch the papyrus debris as it came down the river and before it could add to the Nggokha blockage.

Some of Naus' work on the Santantadibe and Thamalakane rivers could be classed as channel maintenance. Maintenance, like doing the family wash, seldom shows permanent results, but is nevertheless not to be despised. The Thamalakane, an 'outlet channel' with a very flat gradient, is notorious for its rapid growth of vegetational obstructions. It has been cleared several times by various people; useful for a short time, but never with permanent effect.

£2 900 from Colonial Development funds had been provided in 1935 for channel clearance and Naus,<sup>35 36</sup> was allocated £800 of this for clearing a sand bar and other obstructions in a twenty five kilometre reach of the Santantadibe upstream of the Thamalakane junction. (Read, FAO Hydrologist, in 1968/9 remarked upon the old channel of the Santantadibe having been much wider than the present one. Was it the old natural channel or was it perhaps Naus' widening



(a) The blocked Thougé river, looking upstream. Labourers clearing the papyrus



(b) A few days after the initial clearing a secondary obstruction of matted roots etc rises to the surface and has to be removed.

Fig. 9 DROTSKY'S CLEARING OPERATIONS ON THE THAOGÉ 1938-41  
(Illustrations by R. Bailey adapted from old photographs)





(c) Digging a canal to short - circuit a long river loop.

works that Read noticed?) The outflow of the Santantadibe declined considerably after Naus' time.

The Boro then flowed into the Thamalakane for less than three months of the year.<sup>37</sup> Naus believed it was a wasteful river and should be blocked at its upper end. This was, fortunately, never done, as the Boro has become, since about 1952, the main supplier of the Thamalakane. But no one in 1936 could know that.

There was at least one dam or bund constructed by Naus in the Shorobe area which appears to have benefited some people and, perhaps, harmed others.

Colonel Rey retired in 1937. His enthusiasm had brought purpose, funds and several valuable surveys to the Ngamiland waterways. But with his going, Naus had lost his patron. Rey's successor, C.N.A. Clarke, early made a thorough tour of Ngamiland, including two days in a *mokoro* with Naus. After a joint conference with Naus, Brind and Jeffares, Clarke stopped the work on the Santantadibe, transferring Naus to the Thaoge, where he was to work directly under Brind (now the first Director of Public Works) acting under the advice of a consulting engineer, Mr Hawkins. Naus was not happy about this arrangement and resigned shortly afterwards. He had put in a great deal of hard work, though some of it was misguided.

With Naus' resignation, Brind's assistant engineer, Beveridge, re-engaged Martinus Drotsky who had done such good work in 1932.

What would have happened, one wonders, if only Rey had backed Drotsky under Brind, instead of Naus? Drotsky had an exceptional capacity for organising effective work by hand labour, without ever, it seems, writing a letter. Naus was also a hard worker but he was apt to be carried away by his own dreams, and would not take criticism. This is a pity, because several of his ideas had creative seeds in them. But to him they were not seeds; they were already germinated, mature and proven and he convinced himself and Rey by his own optimism. With these extra four years of the Naus period it is possible that Drotsky might, before the war eventually cut off funds, have achieved permanent and lasting improvements to the Thaoge.

This is conjecture, with many 'ifs'. But as it was the Drotsky period of 1937 to 1942 (when the CDF grant of £3 500 of 1939 finally expired)<sup>38</sup> contained the most successful channel clearance ever done in the Okavango.

Within two and a half months of his appointment in October 1937 Drotsky had cleared 10.4 miles of channel starting from about Tsau and working upstream. At first he encountered light weed growth and cleared it 7 ft wide. By December 1937 he was into papyrus and able to clear 920 ft a week with 20 ft width at a cost of 2d per square yard. Money appears to have run out by August 1938 but work began again with the new grant in February 1939.<sup>39 40</sup>

Fig. 9 shows some views of the clearing operation. A curious and encouraging fact emerged; that whereas phragmites and other weeds would grow up again shortly after clearing, papyrus, properly cleared below water level and in the conditions of the lower Thaoge, did not, and the channels remained permanently clear. The men, standing in the water up to their waists or chests and working upstream, would cut the papyrus, and the debris would be piled up on the side with the help, later, of a home-made derrick mounted on two steel boats. Cane knives were used, and later sudd saws were ordered from the Crown Agents. Some of these were, written off and thrown away only a few years ago. They consisted of heavy serrated knives, each on the end of a wooden pole.

Behind this initial clearing: 'commenced to appear, some 70 or 80 yds. downstream ... the 'first uplift'. This first uplift when it has fully developed consists of a mat of densely interlaced fine fibrous roots each root being of the thickness of ordinary sewing cotton. The depth of this mat is some 12 inches. Its surface floats from 1½ to 2 inches above the water and shows a light growth of fine grass. Drotsky has some 10 boys employed in taking this raft in armfuls and pushing it up onto the bank.'<sup>41</sup>

The Thaoge being very sinuous, it proved better to cut the corners with a comparatively narrow and shallow canal rather than follow the stream all the way round. In section a typical such canal, as measured in 1972, was: width of bed 4.9 metres, top width 9.4 metres, and depth of excavation 1.6 metres. The original river was 1.7 metres deeper than the new canal.

Thornton<sup>42</sup> in 1944, in a ten page report on agricultural and water development in Ngamiland, describes the work of the PWD: 'in clearing the Thaoge River of papyrus and other growth, plus the construction of canals cutting across the course of the river. There are in all thirteen canals, six of which we traversed, and the distance cleared, plus the canals, which cover some 9 miles, amounts to approximately 70 miles. This is a magnificent piece of work, carried out at low cost. The actual work was performed by Mr Martinus Drotsky and I wish to state here that I doubt whether another man could be found in the Bechuanaland Protectorate who would undertake a work of this nature ... I know of no parallel where a work of this nature has been carried out with the aid of only a couple of steel boats and ... (hand tools)'. Thornton went on to recommend a provisional grant of £25 000 for the work on the Thaoge to be continued under Drotsky.

Fig. 10 shows the extent of Drotsky's operations, which ended with a channel from the Karangana river, as there were neither time nor funds to complete the clearing in the Thaoge itself.

I inspected some of Drotsky's canals in August 1972. They were clear and unobstructed, but, alas, completely empty of water, the blockages having increased upstream. It was also a low flood year. An old two inch pipe post in the Karangana river bed at lat. 19° 37.7' long 22° 18.1' had a rust mark showing a typical former water level 1.67 metres above bed level. All these channels were, in August 1972, dry. North-east of Gumare a few Drotsky-type short-cut canals are to be found, but I do not know when they were dug.

After 1942 small annual amounts were provided for maintenance until 1960/61. The DC's annual report for 1946<sup>43</sup> speaks of a 'foreman and ten labourers working throughout the year

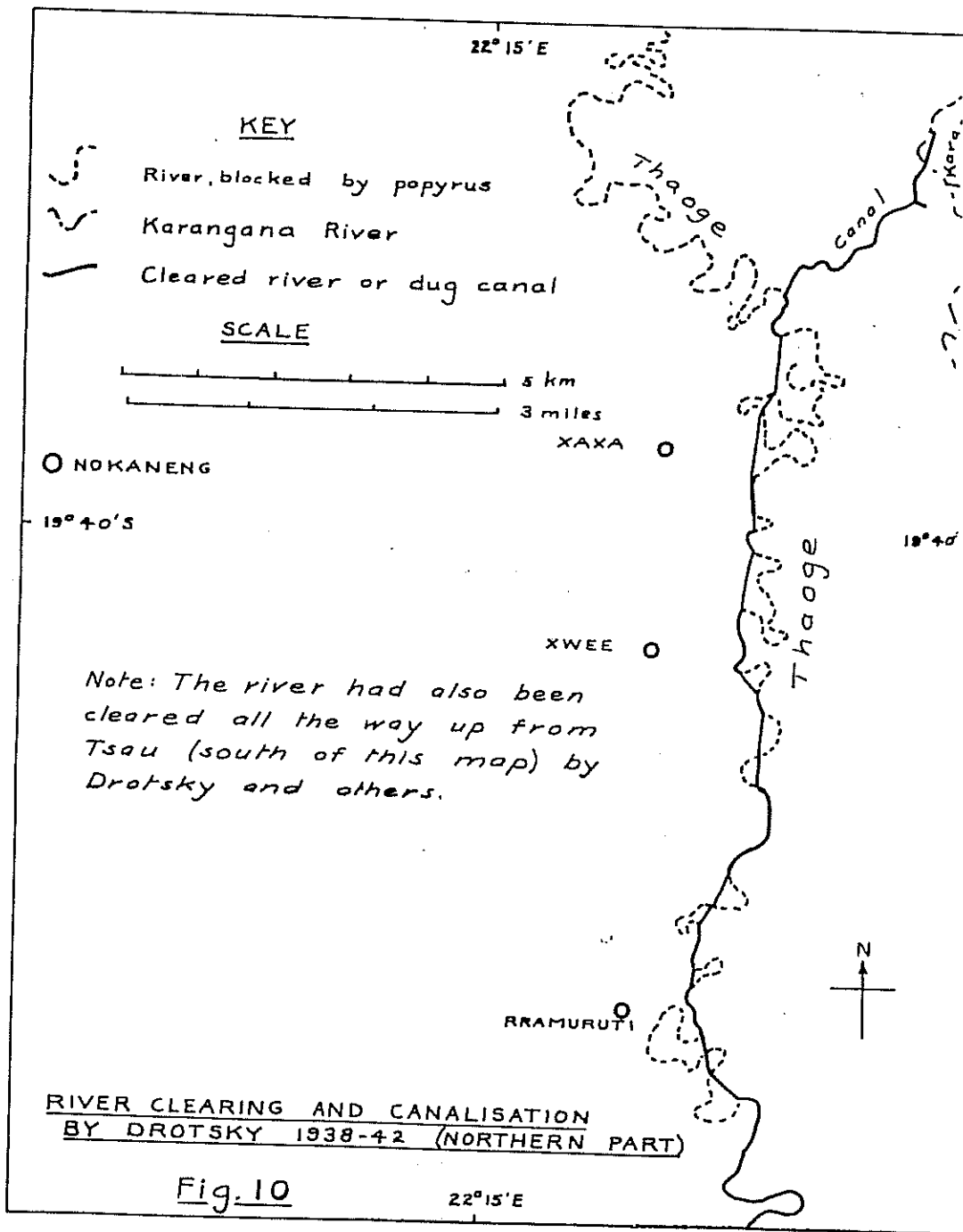


Fig. 10



on the Thage bed, now clear as far north as Matetemetso 10 miles north of Nokaneng. The Thage channel is completely blocked by papyrus from Ikoga to Matetemetso, a distance of ... approximately 100 miles along the river.' But maintenance on this scale, and without Drotsky, was not going to solve the problem. During a series of droughts, particularly 1948 and 1949 fifteen more miles of Thage channel were cleared by the local inhabitants, for planting, when the papyrus dried out.

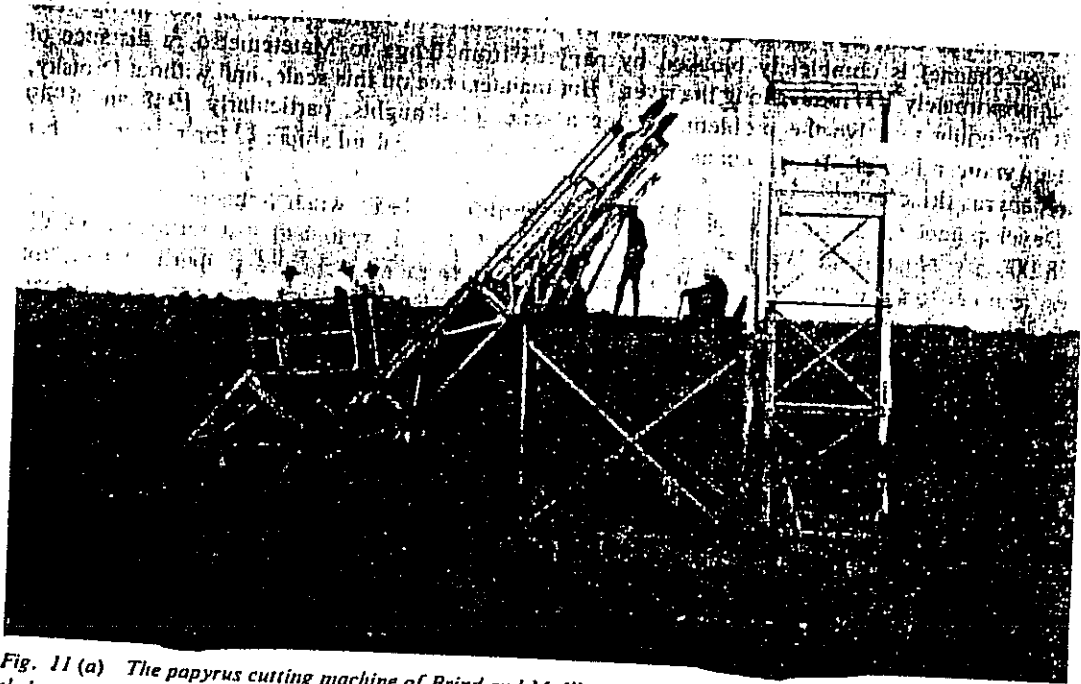
Development funds were not again provided until June 1950 when Scheme D 1412, with £28 000 for Ngamiland Waterways, was commenced. Brind, who had just retired as DPW, now returned on a contract, assisted by McIlraith, his former Mechanical Superintendent, for full time work on the three years' waterways scheme. Drotsky was employed as Foreman Mechanic.

This article is not concerned with the main aspects of Brind's work, which was a hydrographic and hydrological survey of the delta with recommendations for future development. There was enough here for any normal engineer for three years and more. But Brind found time from his other work to conceive, design, and have built and assembled a special papyrus cutting machine. It is shown assembled and afloat in fig. 10 at its test site lat.  $19^{\circ} 24,5'$  long  $22^{\circ} 11,1'$  near Gumare. Brind acknowledged the good work done by Drotsky but he believed that as one moved upstream to the more critical blockage areas, the thicker papyrus and deeper water would be less and less amenable to hand labour. In any case further clearing was bound to be expensive so it was necessary to be sure of doing a thorough job to gain corresponding benefits. The economic possibilities of development seemed great. As an engineer Brind may have had a bias towards machinery, but it should be noted that he was something of an 'intermediate technologist' and had earlier been responsible, with McIlraith, for the design and production of the 'Brimac' borehole pump requiring no engine but driven by ox or donkey. Some of these are still to be seen in Botswana but I do not know of any still working.

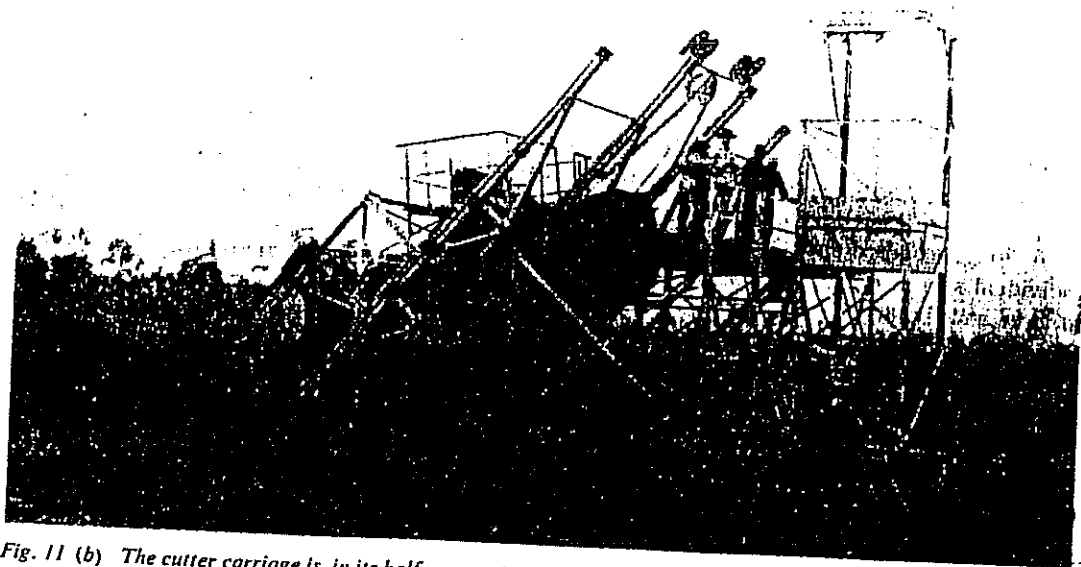
In operation the 24 ft wide, floating machine was winched forward by hand upstream on its six pontoons against the working face of papyrus. Power-driven reciprocating cutters were lowered into the floating mat of papyrus to sever a strip 24 ft x 4 ft in three portions 8 ft wide. As the cutters were raised the pieces of papyrus mat were drawn up a ramp onto a platform and afterwards thrown sideways to the side of the channel.

The giant size of the machine was dictated by two things: the need to make a channel wide enough to stay reasonably clear of weeds, and the need to have a high unloading platform to clear the tops of the surrounding papyrus. (I find no mention of the possibility of first burning the papyrus to water level.) In all the machine was about 24 ft. high by 24 ft. wide by about 30 ft. long, weighed about 45 tons and drew 4 ft. of water. It was assembled at Gumare from individual sections, fabricated in South Africa. Transport of all the portions from Francistown in three and five ton lorries took four weeks. But too much time had already been lost. Delivery in Johannesburg had been expected in November 1952 but was three months delayed. After assembly and launching at a prepared face the trial began. There were teething troubles. A quadrant gear broke and would have to be replaced by a stronger design. The vertical roots of the papyrus between floating rhizomes and the river bed were more extensive than expected so that the underwater shoe to sever them would need modification. But there was no time and there was no money. Much paper work on the field surveys remained to be done and Brind had to go back to Mafeking to see to it.

Brind's task had been to produce a prototype papyrus clearing machine. He had done it, and the direct cost was £8 240. The troubles were disappointing but not fundamental. Brind regarded the machine in principle as a success. The required modifications were minor. But, alas, without them the machine could do nothing. People spoke flippantly of 'Brind's merry-



*Fig. 11 (a) The papyrus cutting machine of Brind and McIlraith on trial near Gumare in 1953. The cutters on their carriage on the left have been lowered down the sloping ramp into the papyrus mat. The men on the left are beside the engine and gear box.*



*Fig. 11 (b) The cutter carriage is in its half way position ready to descend for second cut. In the interval between the two pictures the carriage, with its load of cut papyrus mat, was raised another 3 metres up the ramp and discharged its load onto the platform beside the group of men. On the right is the counter-weight in its tower.*

go-round' and misleading stories of its 'failure' are still laughed at. Brind left the Protectorate about March 1954. He left data and proposals, though his full report was not available until June 1955, when he was already in another job in Kenya.

Based on Brind's recommendation a major CD & W Scheme was drafted in 1954<sup>44</sup> totalling £383 075 for 'Development in Ngamiland'. Bold proposals were made for water conservation and agricultural development including £74 000 for river clearing on the Thaoge. Brind's machine was to be modified for £4 000 (we do not know precisely what these modifications were to be) and three additional machines, somewhat lighter, were to be built at £9 500 each with running costs of £700 annually each. Ninety-seven miles of blockage, weighing two million tons, were to be cleared in three years.

In the meantime the Symon Report<sup>45</sup> had been issued which advised that large scale development in Ngamiland would be premature, though further clearing of the Thaoge might still be advantageous. But by August 1956 it was apparent that the administration's development priorities lay elsewhere.<sup>46</sup> After advising against further expenditure, the RC told the High Commissioner that Brind's: 'machinery ... will be maintained in proper condition'. This intention was not, however, followed and shortly afterwards official pressure began to have the embarrassing monster removed from Gumare, where it still floated unused and unserviceable. After an engineer's report and a board of survey it was finally dismantled towards the end of 1957 and some of the components were used at Maun, Kazungula and elsewhere for unrelated purposes.

Of active channel improvement by man there is little more to be said until Anglo American introduced their dredger in 1971 (and this will not be discussed here). Some waterways maintenance continued on a small scale until 1961, and in 1956 a navigational channel was to be improved between Seronga and Jao. In 1953 a machine was ordered for clearance of the lighter aquatic vegetation, but I have not discovered what became of it.

About the time when Brind and McIlraith were completing the design of their machine, on September 11th 1952 there occurred something which may possibly have had more effect on the Okavango than man's efforts. There was a severe earth tremor lasting forty-five seconds, with a pause of ten seconds and a further ten seconds of tremor.<sup>49</sup> On the next two days Brind, McIlraith and others noticed further tremors, that of the 13th being followed by intermittent faint rumbling for over ten minutes. The Department of Geological Survey and Mines<sup>47</sup> has records of these and of some two dozen other seismic events centred in the Okavango between May 1952 and May 1953. The largest was recorded on a seismograph as far away as California. Pike<sup>48</sup> has shown that in the period 1951/3 there occurred a change in the regime of the Boro and Thamalakane rivers with a marked increase in flow and he has suggested a seismic cause. The suggestion is highly interesting though not proven. An alternative explanation could be that the high 1951 flood, finding an unusually dry river bed with minimum obstruction from vegetation, was able to scour out a better channel (this is not put forward as a developed theory but merely to show that the postulation of seismic causes may not be necessary). What is proved is that earthquakes are frequently active in the area and could surely have a big effect for better or for worse.

For the future we must also consider other extraneous effects of nature or man. Climate change is the most talked of but probably the least important. Exotic water weeds could make serious adverse changes. *Salvinia molesta* (Kariba weed) and *Pistia stratiotes* (Nile cabbage) are already in the Chobe, and *Eichhornia crassipes* (water hyacinth) is in both the Limpopo and the Kafue catchments. Agricultural and hydro electric developments in Angola could, in the long run, affect the Okavango river regime somewhat. Water extractions upstream are bound to increase. But we can take comfort, perhaps, that even if all the people in the world were to arrive in Shakawe, they would have difficulty in drinking the river dry.

## ACKNOWLEDGEMENTS

My special thanks are due to Mr G.N. Mpologeng for help in the Botswana National Archives, to Mr Peter A. Smith for detailed comments and photographs, to Mr R. Bailey of Agricultural Extension for the illustrations of fig. 9. to the Permanent Secretary, Ministry of Commerce, Industry and Water Affairs for approving this article and, most of all, to the Editors for their tactful persistence.

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Abbreviation: BNA = Botswana National Archives

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## A Floating Island in the Okavango: Some Observations Made by Brian Wilson

by S.C. CHILD\*  
and P.A. SHAW\*\*

### Dedication

This paper is based on notes and observations recorded by Brian Wilson before his untimely death in 1989. Brian was the first hydrologist employed by the Government of Botswana, and occupied a number of senior positions in the Department of Water Affairs between 1965 and 1982. He was responsible for the establishment of the Hydrological Division of that Department, and in particular for the establishment of the initial hydrometric network in the Okavango and the instigation of two major water investigations which form the basis of current knowledge of that unique environment. Brian made an invaluable contribution to the understanding of the hydrology of the Okavango Delta, and is sadly missed by those who continue this work.

Floating mats of vegetation are a common feature of swamp ecosystems. In the Okavango Delta the blockage of channels by *Papyrus* mats, and the hydrological changes that result, have been well documented (Wilson 1973, McCarthy et al, 1987), whilst human use of *Papyrus* mats as a means of downstream transport has been reported from the 19th century onwards (e.g. Andersson 1857). However, it is difficult to monitor individual vegetation mats or to determine their fate over long periods of time. This is due largely to the homogeneity of the vegetation community and difficulty of access in the permanent swamp of the Okavango Delta.

One exception to this is an unusual floating 'island' in the Panhandle, which has been readily discernible from aerial photographs since aerial reconnaissance began in that area in 1944. The sub-circular island, measuring approximately 160 m x 125 m, lies within an elongated lagoon (*lediba*) measuring 400 m x 200 m, at lat. 18° 40' S, long. 22° 12' E, some 9 km north of Sepopa (Figure 1). The island, like the surrounding swamp, is composed largely of *Papyrus*, with subsidiary communities of sedges and the aquatic fern *Thelypteris*. Deep water underlies both the island and the lagoon margins.

The position of the island on sequential aerial photography from 1944 to 1983 is shown in Figure 2, whilst orientation and net rotation of the island on its elliptic orbit can be estimated from the position of a small indentation, marked with a dot. From an initial central position in 1944 the island reached the south western side in 1962, and the northern corner in 1967, before migrating the length

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of the lagoon in the following two years. By 1974 the island, still at the southern end of the lagoon, had rotated clockwise some 45° and stabilised, for in 1983 it still occupied this position.

The island was observed from the air in February 1990. It is now firmly locked into the southern position (Figure 3), although it is not yet contiguous with the lagoon margins, for narrow channels are apparent on the east and west sides, whilst a small area of open water is still apparent on the southern margin.

How such a floating island could originate is not clear. It is probable that it has evolved within the lagoon rather than being derived from outside, either by direct growth, or by breaking away from the lagoon margin. Once formed it is free to drift in response to wind-derived currents until it becomes enmeshed in the lagoon margins. In all of the photographs it has contact with at least one point on the lagoon edge, and it is probable that it undergoes long periods of stability in a single position, until liberated by strong winds.

Surprisingly the island has changed very little in size or shape over the past 50 years, although the present phase of stability has, in part, been due to a reduction in the size of the lagoon by up to 10 metres since the 1960s. This suggests that the rate of *Papyrus* colonisation of deep, still water in the absence of sedimentation is relatively slow, a factor which accounts for the persistence of *maliba* in the Okavango system. By contrast the rapid and pronounced hydrological changes brought about by *Papyrus* in channel systems are due initially to blockage by floating vegetation and plant debris, with colonisation and deposition of transported sand as subsequent processes.

#### Acknowledgements

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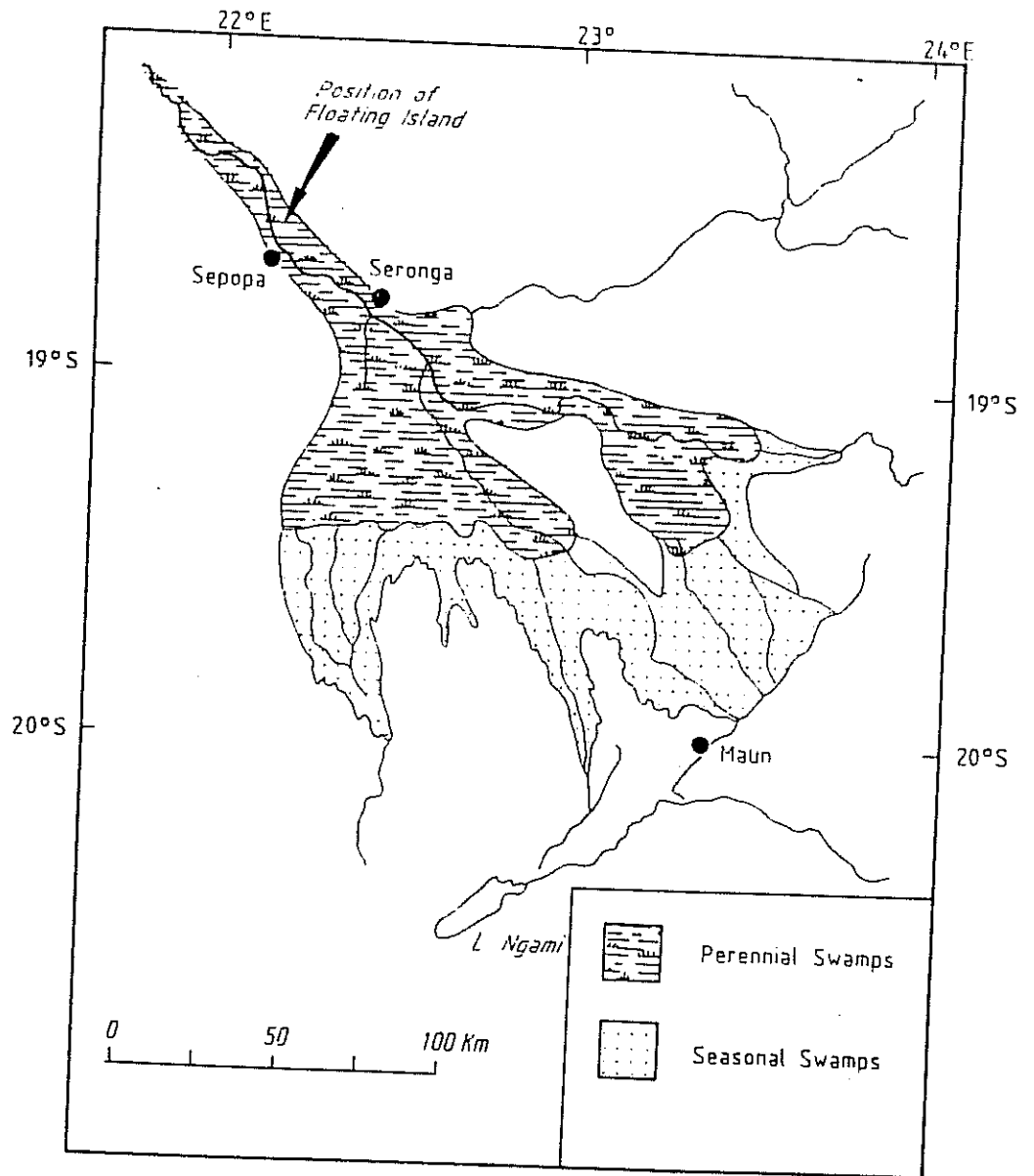


FIGURE 1 Location of the floating island

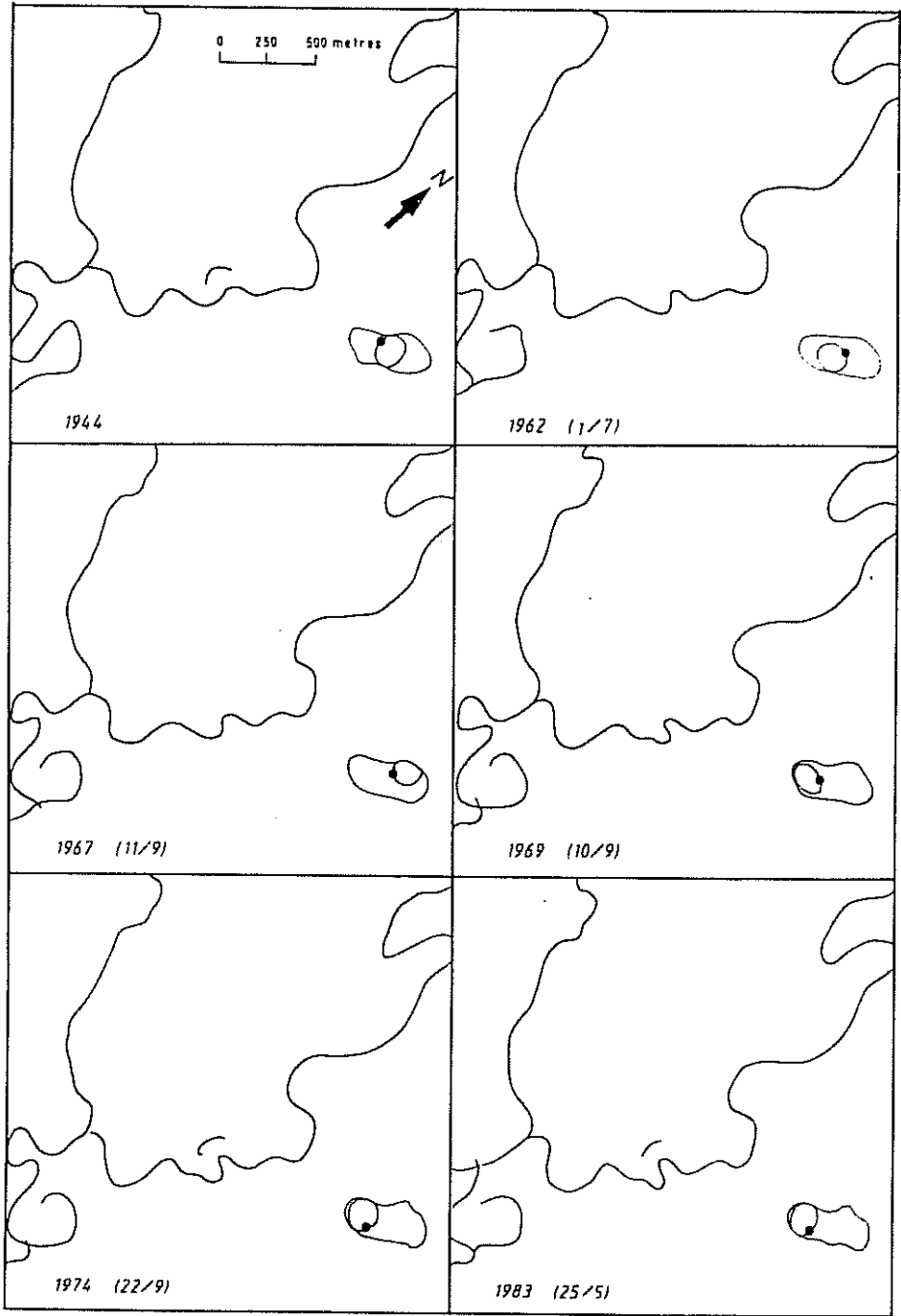
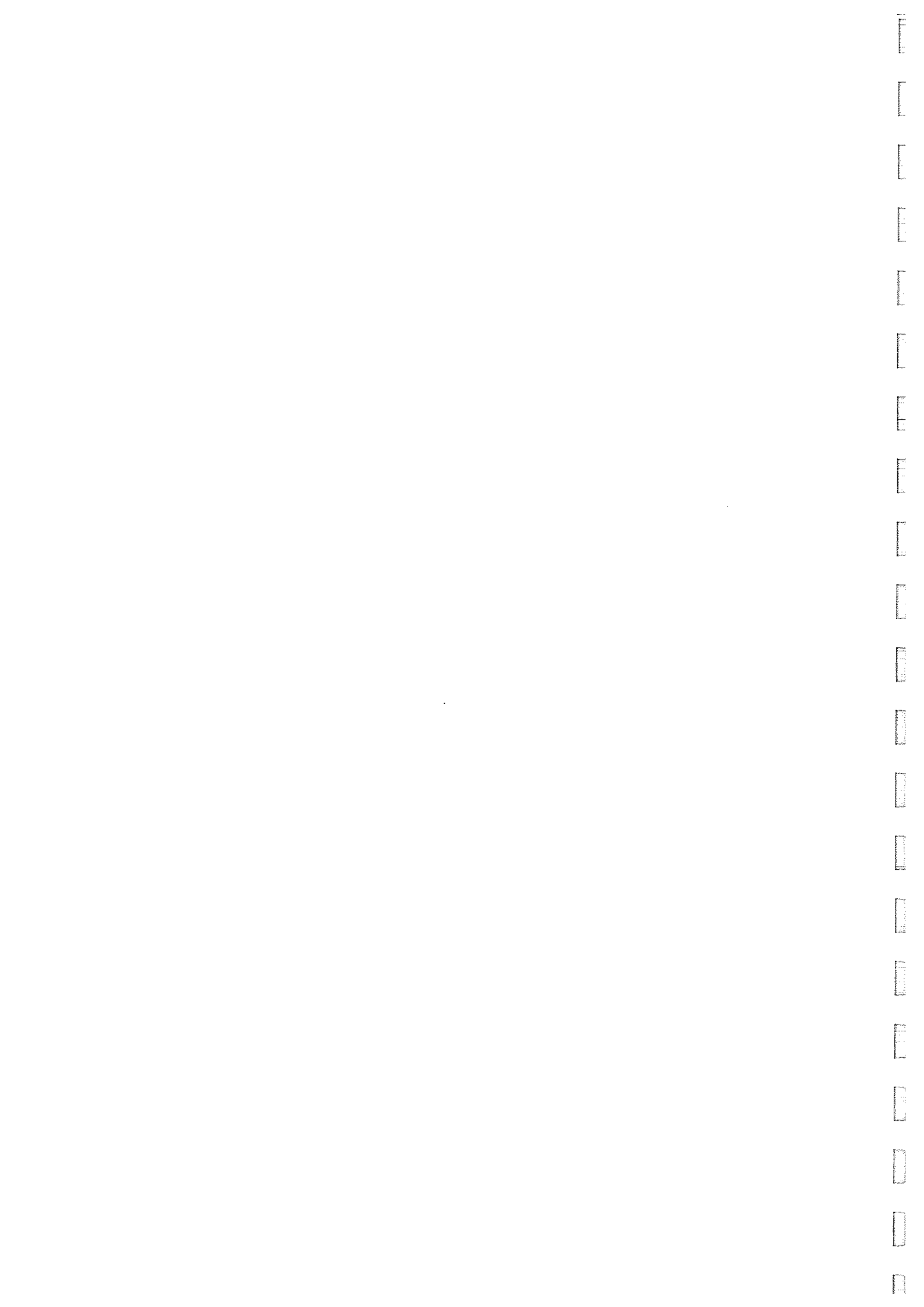


FIGURE 2 Positions of the floating island, 1944-1983



**FIGURE 3**

**Oblique aerial photograph of the floating island at the southwest end of the lagoon, February 1990**



Okavango



12-07-1995

# THE OKAVANGO

## HOW TO USE ITS WATERS BEST?

S. RAADSMA - Snowy Mountain's Engineering Corporation

### PREFACE

The Okavango River, the third largest in Africa, originates in Angola. After bisecting the Caprivi Strip, the river enters Botswana where tectonic movements of the past have resulted in an uplift which has effectively blocked the river course. This has resulted in the formation of an inland delta, roughly 22 000 km<sup>2</sup> with a permanent swamp of 5 000 km<sup>2</sup> and another 5 000 to 7 000 km<sup>2</sup> of seasonably flooded land, divided in bowl shaped flood plains and elongated depressions (melapo) separated by permanent islands.

The Okavango River and its delta is the main surface water source in Botswana and is regarded a major resource in the nation's strive for economic independence and sustained development. Its natural resources have been studied during the last two decades to a varying degree of detail. On behalf of the Government of Botswana the Snowy Mountains Engineering Corporation of Australia has carried out a study of the potential use of land and water resources along the southern fringe of the delta, emphasising integrated surface water development, including the possible development of 10 000 ha for irrigated food crop production in that region. Increased agricultural production, if viable, obviously would benefit the region and the nation.

Being remote from urban centres, the delta is recognised worldwide as an unique geographic and ecological system providing a growing source of income from rapidly increasing tourism. Consequently, an assessment of the environmental impact of proposed technical matters was included in the study as a separate though integrated aspect.

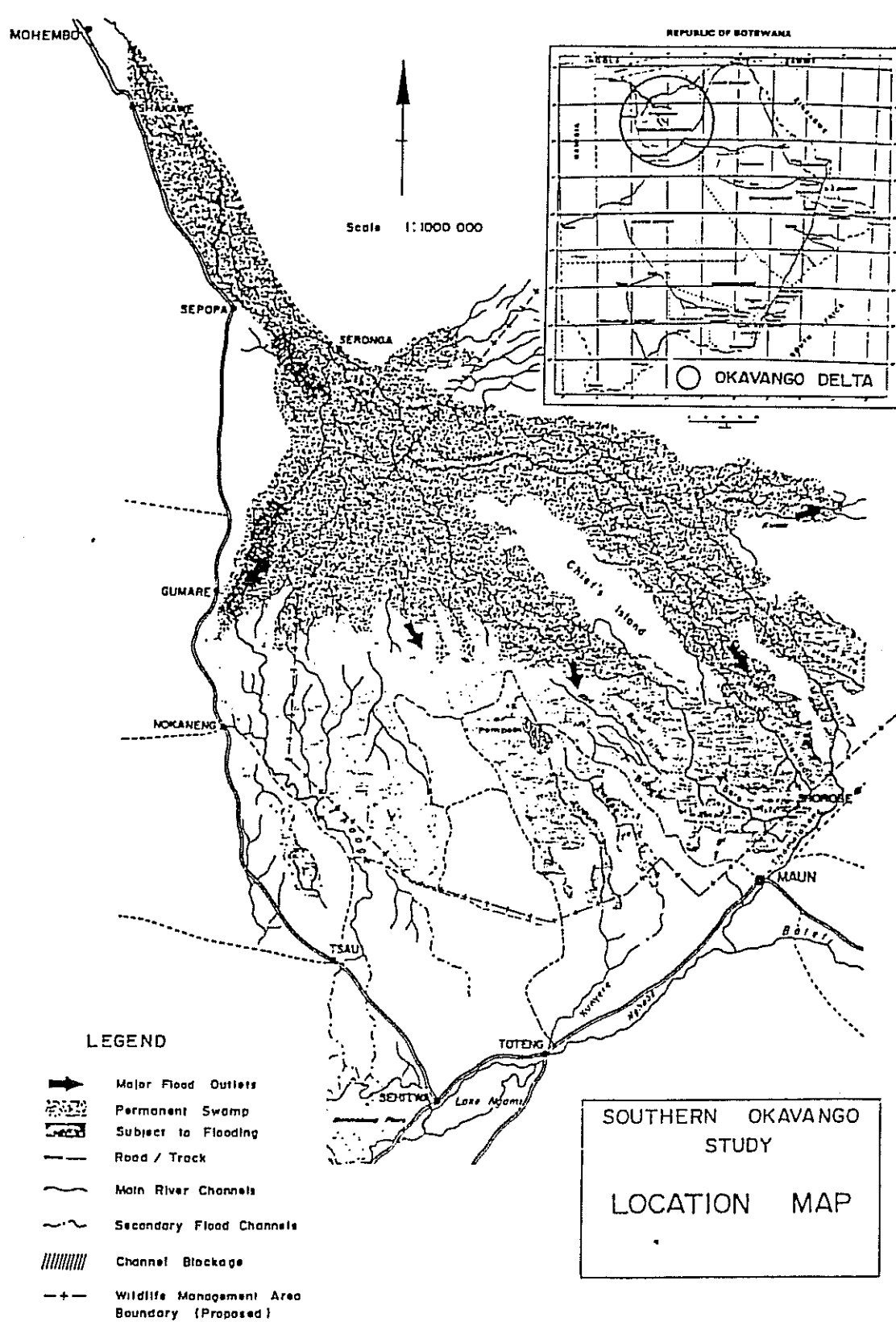
In trying to evaluate the importance of the Okavango waters for national development, a number of economic indicators have to be addressed, followed by a short description of the delta's physical features. Outflow supplementation and water regulation schemes considered will be discussed and their benefits for traditional and potential water users will be reviewed in relation to their costs. An attempt to extrapolate potential benefits of the water on a national scale will conclude this address.

### INTRODUCTION

#### THE NATIONAL ECONOMY

Botswana, with an estimated population of about 1.1 million people, has a relatively favourable per capita income, a sound economy and a real growth of the Gross Domestic Product of about 11% per annum over the past decade with the mining sector being the major force (diamonds, nickel/copper, coal). Diamonds, cattle, copper and tourism account for nearly all foreign exchange earnings. However, the country is very dependant upon

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imports of most fresh foods, fuels, processed and manufactured goods and management skills.

With an overall population growth of about 3.4% and export earnings, which may remain at a more or less stagnant level, the economic growth rates are anticipated to diminish over the coming years. Most settlement is concentrated in the east of the country where urban centres are growing rapidly, again a process which cannot be reserved easily in the next decade.

In spite of the increasing concentration in the urban centres, approximately 80% of the population is rural and largely dependant on the agricultural sector, contributing only about 5% to the GDP (1984). This percentage has been falling in absolute terms in recent years partly due to prolonged drought conditions. About 80% of the wealth of the agricultural sector is derived from cattle (beef exports are second only to diamonds in value) but half the national cattle herd is held by only 5% of the rural population.

Less than 5% of Botswana's land area is estimated to be cultivable, of which about one-tenth is planted in any one year, and one third of that was harvested in recent years. Here again production and income are heavily skewed with half the crop production coming from about 4% of the land planted. Overall basic food production is declining, caused by arid climate, poor soils, migration of workers away from agricultural production, etc. Annual imports already exceed 200 000 tonnes of grain and 30 000 tonnes of fruit, vegetables and processed foods.

The current National Plan (NDP6, 1985-1990) places substantial emphasis of expanding rural work opportunities and to increasing productivity in arable agriculture.

Irrigation will have to play an important role in the strive for food self reliance and diversification. At present there is little more than 1 000 ha under technical irrigation in Botswana.

#### THE STUDY AREA

The study area designated the Southern Okavango Delta lies between the Thamalakane and Nhabé Rivers, stretching from Shorobe to Toteng and the buffalo fence. It includes the northern part of Lake Ngami where it was thought that lake bed soils would provide large uniform areas suitable for irrigation.

Maun is the main centre of Local Government with district offices, a major abattoir and a thriving tourist industry being the gateway to the Okavango Delta. The area has an estimated population - of around 23 000 including some 19 000 people in Maun.

The rural population with an average family size of 6.2 persons is mainly living in small villages and dispersed homestead clusters. Most households derive their income from subsistence agriculture, mainly livestock, some food crop production, and supplemented by non-agricultural activities e.g. services, temporarily employment in the delta or elsewhere in and outside Botswana. The population growth rate in the outlying areas is estimated at 2.6% but at 5% for Maun, indicating that the rural areas experience a considerable out-migration whilst Maun is growing at a higher than average rate.

The above mentioned facts underline a major problem facing Botswana (one which is well known in many developed and developing countries) : an exodus from the land and an influx of people to urban centres which cannot cope with this unpredicted growth. Realistic development projects are therefore required in the rural areas to turn the tide and the implementation of an integrated water development plan for the Southern Okavango Delta has been looked upon as having potential for such a project.

#### LAND AND WATER RESOURCES AND PRESENT USAGE

##### LAND RESOURCES

Irrigation projects require suitable lands in addition to water. Originally it was thought that in the melapo area, between the Thamalakane and Boro Rivers and the buffalo fence, at least 5 000 ha would be available for large scale irrigation development to establish food crop production on a commercial scale. However, the melapo are flood plains with considerable variation in shape and natural fertility. There is a difference in elevation of a few metres between the sand islands and the elongated, scattered channels and depressions, which are considerably higher in clay and organic matter content.

To allow large scale mechanised farming under surface irrigation would require land levelling to re-shape sufficient large areas, which is not feasible given the heterogeneity of the soils. Potential hazards of soil salinity and sodicity prohibit the use of

sprinkling irrigation on a large scale, e.g. on areas in excess of 10 ha to 20 ha. Considerable expense would be involved in bringing water to the scattered areas whilst natural drainage of excess rain and flood waters is prohibited by the overall topography and could require expensive pumping.

At the onset of the study it was hoped that large tracks of uniform suitable soils could be found in the bed of Lake Ngami. The area and the lands along the Nhaba and upper Boteti rivers were surveyed by the Soil Survey section of MOA, assisted by FAO, which section also had carried out a soil survey in the Molapo area.

Detailed soil investigations were carried out by the Consultant concentrating on the most promising areas to prepare a land capability map for irrigated agriculture. Unfortunately, the lake bed soils of Lake Ngami proved to be too acid for agriculture and some 9 750 ha of sandy soils could only be classified marginally suited to spray irrigation development, including 800 ha with a thin layer of organic silt deposits.

Another 6 100 ha of very similar soils has been identified along the Nhaba River together with about 800 ha of soils with calcrete containing less permeable layers at relatively shallow depth partly used for rainfed farming at present. In view of their characteristics these soils are not suited to surface irrigation methods but only to spray irrigation.

After allowances are made for areas with variable and unsuitable topography, spray irrigation layouts, wind breaks, infrastructure including cattle crossing, etc., approximately 10 000 ha of land is available for irrigated agriculture. However, the soils are very low in natural fertility, have a very low moisture holding capacity and need frequent irrigation, require a high capital investment and a high level of management skill to make any large scale farming operations successful.

Topographical surveys were carried out by Baker Surveys of Francistown culminating into maps of the investigated areas to a scale 1:10 000 with contours at 1 m and 0.5 m vertical intervals. Remote sensing analysis was undertaken by the University of Botswana to determine the size of areas with permanent water and seasonably flooded areas in the Okavango Delta.

## WATER RESOURCES

The Okavango Delta is composed primarily of fine water-borne sands and is of comparatively recent origin, apparently brought about by a seismic upthrust perpendicular to the river course. The width of the main delta outfall, the Boteti River valley, suggests that the Okavango flowed directly in south-easterly direction to the Makgadikgadi Pans in earlier periods.

The Nhaba of Lake River is an overflow from Lake Nhami, in older times a terminal sump for the Thaoge River when the latter was carrying much of the Okavango River flow. In Livingstone's times the lake had considerable dimensions, but at present, with the Thaoge being blocked by vegetation, the flow direction is reversed when back-up water from the Boteti spills into the lake.

The Okavango, at its point of inflow at Molembo, typically peaks in March/April. After meandering through a 10 to 20 km wide flood plain (the Panhandle), the river drains into a vast area of perennial swamps, increasing the latter's size from around 5 000 km<sup>2</sup> to a maximum of 12 000 km<sup>2</sup>. One of the main outflow channels is the Boro River, a clear channel through the southern part of the delta, discharging into the Thamalakane River and from there into the Boteti River. Other channels which can contribute to the annual outflow, which occurs between June and November, are the Gomoti, Santantadibe and the Kuyere, the latter discharging into Lake Ngami. During years of high flood, some Okavango water flows through the Selinda Spillway to the Linyati Swamps, part of the Zambezi system.

Analysis of historical information shows that the complex hydrology of the swamp is by no means stable. While vegetation blockages have clearly been documented as a major factor causing the instability of the delta system, changes in vegetation are a response to changing hydrological conditions such as major floods and droughts. Although hydrological conditions may sometimes be altered by human influences and seismic activities, the incidence of floods and droughts appears to be the most common initiation of regime changes. The flow regime of the Boro, one of the major delta outflows at present, has changed drastically in recent years because of recent droughts. Changes in flow regime can be expected, they can be neither completely controlled nor accurately predicted.

Available hydrological data on delta inflow and outflow have been analysed and extended where possible and a rather reliable synthetic record of the Okavango river flow has become available for 54 years (1933 - 1986). Using this record and available rainfall data as inputs to a multi-cell water balance model of the delta has allowed extension of the delta outflow over a similar period.

The annual inflow to the delta at Molembo varies from 6 000 MCM to 16 000 MCM with an average of 10 000 MCM. In terms of discharge, in an average year, the river peaks at about 650 m<sup>3</sup>/sec in April and recedes to about 150 m<sup>3</sup>/s in November. Despite the fact that rainfall on the water surface of the swamp contributes about another 4 000 MCM in a normal year, the average outflow at the base of the delta is only about 450 MCM or 4.5% of the total inflow. The outflow varies considerably, however, from just 31 MCM to 1 333 MCM (period 1969 - 1985).

The high discrepancy between inflow and outflow is accounted for by evapotranspiration from the swamps and the vegetation around their margins. Seepage to groundwater may occur within the delta, but isotope analysis carried out in the past (JNDP/FAO) has shown that groundwater recharge outside the delta does not take place from the swamps.

The Okavango river has an estimated sediment load of 660 000 tonnes/annum but very little sediment reaches the distal end of the delta. The water quality is very good with a salt content of 30 ppm at the point of inflow increasing to 80 to 160 ppm in the Thamalakane. Almost all of the salt load entering the delta thus remains there although the processes whereby this occurs are imperfectly understood.

#### PRESENT WATER USE

There are various users of the water flowing out of the Okavango Delta who are faced with a great variability of annual flows including prolonged low-flow periods.

The main users are:

##### a. Molapo

The Molapo area, where flood recession farming is carried out on an area which is entirely dependent upon the volume of the delta's outflow. The Molapo

Development Project assists the farmer with water control through bunding and providing mechanisation services to facilitate land preparation. The average area of flooded melapo is about 80 ha/year ranging from zero to 2 000 ha in some years.

b. River Bed Farming (maximum between 55 ha and 700 ha).

c. Irrigation.

There is one commercial irrigation farmer with 85 ha under centre pivot irrigation near Maun.

d. Lake Ngami.

The lake, when flooded, is a very important source of surface water and grazing areas for cattle and a haven for an extensive range of bird life. The lake has been dry for the last couple of years.

e. Fisheries.

During years with high outflows, the rivers and Lake Ngami were a considerable source of fish.

f. Livestock.

g. Tourism with emphasis on the delta proper.

h. Downstream users, along the Boteti River as far as Mopipi Swamp.

i. Orapa Mine.

Starting in 1972 the mine intended to draw its water from Mopipi Swamp, pump it into Mopipi Reservoir (volume 95 MCM) and from there through a pipeline to Orapa. Losses to evaporation are extreme, requiring a minimum flow in the Boteti at Samedupi of 180 MCM/a to ensure a supply to the mine of 7.8 MCM/a. Hydrological simulation has shown that because of droughts, the mine would only have surface water available in 31 years out of 54; the remaining 23 years alternative water supplies are required under the present low flow regime.

#### PRESENT AND FUTURE AGRICULTURE

##### AGRICULTURAL ASPECTS

Present land use for food crop production in the study area amounts roughly to 6 000 ha, partly on dry land, and about one-third on molapo soils and in river beds, with an annual average production estimated at 2 000 tonnes of grain equivalent. The commercial irrigated farmer produces a further 700 tonnes each year. Most of the land is used for communal grazing of cattle and goats with stocking rates of one unit per 7 ha to 15 ha depending on soil type.

To evaluate potential agriculture, especially irrigated agriculture, one has to analyse crop production constraints which are many fold:

#### a. Soils

As discussed, the soils available for irrigated agriculture are infertile sands with a low moisture holding capacity, low buffering capacity and are predisposed to wind erosion.

The soils of the molapo area are considerably better. However, while they are suited to improved traditional flood recession farming, they are not conducive to development of more sophisticated commercial irrigation methods on any significant scale.

#### b. Climate, Pests and Diseases

The study area has a harsh arid environment with low rainfall and high crop water requirements. The incidence of pests and diseases is high.

#### c. Location and Markets.

The study area is far from major population centres and potential markets, whilst the local market for potential products is limited.

Although a wide range of crops can be grown, the very strong comparative disadvantages make it unlikely that the study area could be competitive. The largest and best defined market which exists is for basic food grains with local preference for white maize and sorghum. However, the latter is prone to quelea attack, a real pest in the area, and thus main output would be maize.

For the future, without a water resources project, it is expected that improved flooded melapo (average 1 200 ha), rainfed melapo (3

irrigated farming (expected to stabilise at a maximum of 200 ha) would show a maximum increase in food crop production from about 2 700 tonnes to about 7 000 tonnes per year.

If water availability can be readily increased through a project, the area of flooded molapo may be expected to increase to an average of 3 200 ha per year, with a maximum production of 9 600 tonnes. With an average of 1 200 ha rainfed molapo and some dryland farming, the non-irrigated agricultural sector could thus produce about 10 000 tonnes/a.

With sufficient water available, broad area irrigation could be undertaken with maize, legumes and pulses as the main crops.

Oilseeds could also be included in the cropping pattern. With an average cropping intensity of about 140% over large areas and good management, an average production of 8 000 tonnes grain equivalent per annum may be expected from every 1 000 ha.

Vegetables (cabbages, potatoes, carrots, onions, lettuce, beans/peas and green mealies) could be grown to the limit of market absorption, estimated at present at 200 ha. Likewise citrus would do well but the demand would limit the planted area to about 100 ha.

#### IRRIGATION

Frequent irrigation would be required, for broad area crops centre pivot systems are recommended under prevailing conditions, for vegetables drip or trickle systems would be preferred and for citrus under-tree sprinkling systems.

On the basis of climatic data, the crop water requirements have been assessed and, after making allowances for effective rainfall and irrigation efficiencies, gross irrigation requirements have been calculated. Peak application could amount to 12.4 mm/d for broad area crops and 9.6 mm/d for citrus, corresponding with distribution flows of 1.6 l/sec/ha for the Lake Ngami area and 1.1 sec/ha for citrus in the Nhabe River area.

Water supply to the 4 000 ha in the Nhabe River area would be by means of direct pumping from that river. For the Lake Ngami area an outlet works would be required at a dam on the Nhabe River near Toteng and a supply canal with a length of about 25 km, providing water to pump sumps. Diesel engine drive pumps are proposed to be used

throughout the irrigation areas with buried pipelines supplying the spray installations.

Obviously development costs would be high, preliminary layouts of the irrigation schemes including detailed designs for sample areas, indicate an average capital cost of about P 6 500/ha for the Nhaba River area and P 7 600/ha for the Lake Ngami irrigation area. These costs include the cost of clearing and fencing.

#### AGRICULTURAL ECONOMICS

As important as the capital cost are the production costs which are high because of poor soil conditions and would include about P 500 of fertilizer per ha per crop and another P 500 for fuel cost (both imported). Add to that the costs of seed, pesticides, labour, transport to Maun, etc., and total production costs amount to P 950 to P 1 400/ha, depending on the crops grown.

The returns for the farmer are very much dependent upon the market prices, which are determined by the Botswana Agricultural Marketing Board, based on import replacement prices reflecting the current deficit in the areas concerned. The price of food grains for example is P 50/t higher in Maun than in Francistown, reflecting the cost of transport between the two centres.

The potential demand of Ngamiland District can be estimated at a maximum of 20 000 tonnes per annum in the not too distant future. As pointed out earlier, improved water availability for molapo farming and irrigation would meet the demand with only about 1 200 ha commercial irrigated agriculture.

Further increases in production costs would result in exporting grain from the Maun area, e.g. to Francistown. This would imply that farmers would have to sell their produce at lower than Maun prices and would have to pay an additional P 50/t for transport to Francistown. Consequently the return to irrigated and non-irrigated farming alike would considerably be reduced once demand of local markets is met, unless the market price in the production area is subsidised by the Government.

If one compares production costs and returns of a 100 ha irrigated unit in the first 1 000 ha to be developed with those of a similar unit in the next 3 000 ha, the difference is considerable; the first unit would have a return to management and development capital

of about ten times more than that of the second unit, i.e. in the order of P 52 000 versus P 5 000.

A rather similar situation applies to vegetables and citrus where market prices and thus farmers' incomes would drop considerably if more than 200 ha and 100 ha, respectively, were taken into production.

In other words, either the market prices have to be subsidised to allow large scale commercial irrigation and food crop production, including corresponding employment opportunities or irrigated agriculture, must be limited to about 1 000 ha broad area crops and 200 ha vegetable plus about 100 ha citrus with an employment opportunity for 350 permanent workers and 200 to 600 casual workers each day.

#### WATER RESOURCES DEVELOPMENT

##### GENERAL

A large number of engineering components have been considered in many combinations to develop a system which best would meet potential future demands. The components include outflow supplementation schemes and outflow regulation schemes.

To simulate the water balance of the swamps (inflow and rainfall) versus outflow, (losses and storage) a computer model was developed during the mid-1970's. Evaluation of the model prior to this study is described in a report by Dincer (1985) who also participated in this study to refine the model on the basis of additional field data through calibration.

Other techniques in flow simulation have also been used during the study including multiple regression techniques to predict annual volumes of delta outflow.

The water balance model was used to extend the outflow records of the delta to 54 years (1933-1986). The flow regime of the Boro has been used not only because that regime currently appertains; but it is also the most conservative one with which to assess water yield to compare alternative potential water resources developments.

##### FUTURE WATER DEMANDS

Potential water users are much the same as present water users, but demands per user would increase considerably if water was readily available in sufficient large quantities.

USER	PRESENT SITUATION	FUTURE WITHOUT PROJECT	FUTURE WITH PROJECT					
			Maun Reservoir Alone	Plus Sukwane Reservoir	Plus Boro Improvement	Plus To Flats Improvement Increased Melapo	Increased Irrigation	
Flood melapo	ha	800	1 200	2 600	2 500	3 200	4 000	3 750
Rainfed melapo	ha	1 150	3 150	2 800	2 500	1 800	1 000	1 250
Dryland crop	ha	3 350	3 550	3 350	3 350	3 350	3 350	3 100
Irrigation	ha	85	200	1 400	1 100	1 300	1 300	4 300
Maun Water Supply	restricted	available from reservoir in most years						
Lake Ngami supply	37yrs/54	37yrs/54	48yrs/54	48yrs/54	50yrs/54	53yrs/54	52yrs/54	52yrs/54
Riparian supply	38yrs/54	38yrs/54	39yrs/54	44yrs/54	49yrs/54	52yrs/54	52yrs/54	50yrs/54
Oropa (Mopipi) supply	31yrs/54	31yrs/54	no supply	41yrs/54	49yrs/54	52yrs/54	52yrs/54	49yrs/54

TABLE 1 PRESENT AND POTENTIAL WATER USE WITH DIFFERENT LEVELS OF DEVELOPMENT  
(AVERAGES)

Other Users:

1. Livestock: no adverse impacts on livestock, improved quality of life for stockmen near to surface water supplies.
2. Others: improved opportunities for fisheries, tourism, and an improved quality of life for reservoir dwellers.

a. Melapo

Melapo should be flooded preferably in August with an estimated 10 000 m<sup>3</sup>/ha to saturate the soils to a depth of about 2.5 m within two months of inundation thus allowing seeding in October and continuous crop growth with assistance of seasonal rainfall. The earmarked 5 000 ha of flood melapo by 1994 would thus require a minimum of 50 MCM if water supply in the melapo area is properly regulated and not supplied at random. Supply could be through back-up water from the Boro outflow into the upper Thamalakane or through the Xasanare channel, taking off from the Boro River about 15 km upstream from the Boro-Thamalakane confluence.

b. River bed farming would mainly be foregone if the river valleys are used for the water storage, only 150 ha would be affected.

c. Irrigation

Annual water requirements for broad area crops with a cropping intensity of 140% have been calculated at 11 MCM per 1 000 ha. An additional amount of 4.7 MCM per year would be required for 200 ha vegetables and 100 ha citrus.

d. Lake Ngami

Considering its overall importance, attempts have to be made for provision of 7.5 MCM for the lake in years when the Kunyere is expected to have no or very little outflow.

e. Fisheries, livestock, tourism would all benefit from water storages.

f. Downstream Water Users.

If there were to be a reservoir near Maun, riparian releases of about 42.5 MCM would be required at Samedupi sufficient for the flow to pass Rakops. Should there be a second reservoir downstream near Sukwane 14 MCM releases would be required from that reservoir to meet these downstream riparian demands.

g. Maun Domestic Water Supply.

The present water supply system to Maun from groundwater is barely sufficient to meet the requirements of the current population (19 000 people). The estimated population growth rate would result in an increase to 55 000 people by the year 2010, requiring some 3.5 MCM to be withdrawn each year from a surface water storage because indications are that groundwater is limited in availability.

h. Oropa Mine.

At present, without other water storages than Mopipi reservoir, the flow down the Boteti should amount to 180 MCM to 250 MCM to supply the mine with its current requirement of about 8 MCM/a.

There are indications that future mining operations may result in double that amount, about 15 MCM/a in another 5 years time (1992).

#### ALTERNATIVE SUPPLY FROM GROUNDWATER

##### a. Maun Domestic Water Supply.

At present Maun's water supply is from groundwater. Boreholes constructed during the last 12 to 15 years along the Thamalakane have not met expectations and have mainly been taken out of production whilst a new wellfield has been developed in recent years on the Shashe River. Indications are that available aquifers are limited in extent and depth with deeper aquifers containing saline waters. Although further groundwater exploration is required, all indications are that Maun will have to draw from surface water in future and a water treatment plant will be required.

##### b. Orapa Groundwater Supply.

During the first year of its operations (1972), surface water supply via Mopipi Reservoir failed and emergency development of groundwater was started. During the last five years of drought, groundwater exploration was extended in somewhat haphazard manner. Pumping depths are in the order of 180 m to 200 m which makes this source of water considerably more expensive than pumping from Mopipi Swamp via Mopipi Reservoir. In addition, the groundwater quality is very poor and fails to meet the standards of the World Health Organisation.

Present groundwater reserves are estimated at 150 MCM sufficient to meet current demands for another 35 to 40 years, or if demands double as expected, for about 17 to 20 years. As has been mentioned before, the surface water supply under present conditions is only sufficient in 31 out of 54 years and in 23 years of such a sequence, other water resources or alternative mining operations are required. Re-organisation

of present groundwater use and extensive exploration to establish more exactly available groundwater reserves will have to be undertaken before a decision can be expected on the measures required to guarantee water supply during the mine's productive life estimated at well over 100 years.

#### OUTFLOW REGULATION SCHEMES.

Without regulation schemes no real improvements can be made to the utilisation of the delta outflow. The relatively flat topography does not allow for water storages other than in the river valleys proper which are rather narrow and shallow. Three potential reservoirs are considered and have been investigated.

##### a. Maun Reservoir.

The concept of this reservoir was conceived during previous studies (UNDP/FAO, 1977), and would involve damming of the Boteti River at Samedupi Drift, approximately 18 km downstream of the bifurcation of the Nhabe and Thamalakane Rivers. Water would backup into the Thamalakane River as far as Shorobe and in the Nhabe River as far as Toteng, where another dam would be required to prevent outflow to Lake Ngami.

The Full Supply Level (FSL) is constrained to EL 934 to avoid flooding problems in Maun. Another structure would be required in the Thamalakane just upstream of its confluence with the Boro River to control unwanted flooding of the molapo area. The structure would consist of a large gated bund, the Thamalakane Control Structure, which would regulate the flow to the molapo area.

At FSL 934 the reservoir would have a storage capacity of 175 MCM or without the upper Thamalakane River, above the Control Structure, a volume of 153 MCM. The Minimum Operation Level (MOL) of 929 m would leave 12 MCM of storage inactive; some of this water could be used for citrus and vegetable irrigation in the Nhabe River area bed - the bulk could be reserved for Maun domestic water supply.

##### b. Kunyere Reservoir.

Another possible but not ideal damsite exists on the Kunyere River near Toteng just above the confluence of that river

and the Nhabe. A dam with FSL 934 m would create a reservoir with a storage capacity of 134 MCM. Two purposes were envisaged:

- to supply irrigation water to the Lake Ngami irrigation area, in particular for the first crop (August-December).
- to control the water level in Lake Ngami to a maximum of 920.5 thus preventing too high a rise of the groundwater table and subsequent hazards in the irrigation area.

The reservoir would be very large in area in relation to its shallow depth and would lose much water through seepage and evaporation, thus being rather ineffective.

#### c. Sukwane Reservoir.

A potential damsite is located in the Boteti River near Sukwane, approximately 20 km upstream from Rakops. A dam with FSL of 915.0 m would give an active storage of 55 MCM in a relatively narrow valley with a length of about 120 km. This reservoir could supply the Orapa mine by means of pumping through a pipeline to a reduced Mopipi Reservoir or holding pond (4 MCM to 5 MCM). Supply by gravity is not feasible because of adverse topographical conditions.

#### OUTFLOW SUPPLEMENTATION SCHEMES.

The irregular delta outflow would leave storage reservoirs nearly empty for several years, in 2 years out of 54 no outflow would occur at all. Several schemes have been conceived in the 1970's to supplement the natural outflow from the delta by means of engineering works. Two schemes were considered attractive, the Lower Boro Dredging Scheme and two Bunding Schemes to prevent water wastage in the Xudum/Xwaapa area. These schemes have been considered in detail during our study and others have been investigated.

##### a. Lower Boro River Improvement Scheme.

During floods water is ponded on both sides of the Boro upstream of the Kunyere Fault. In the early 1970's the Anglo-American Corporation dredged about 15 km of the Boro River to tap this resource, however they did not succeed in enlarging the river up to the fault line in the early 1970's.

Detailed investigations have shown that water becomes trapped well upstream of the faultline because of low channel capacity and river improvement works would be required over a length of about 35 km. Once completed an enlarged and improved channel would increase the outflow to between 45 and 55 MCM in most years. This scheme is very attractive, has few adverse environmental impacts and detailed design and contract documents for its implementation have been prepared.

##### b. The Xudum/Xwaapa Bunding Schemes.

These schemes envisage a series of bunds in low spots between Bokwi and Beacon islands and along a ridge of dry land up to the Matsibe river. Several of the 27 bunds involved would have to be gated to prevent flow into the Xudum/Xwaapa area in years with low flows into the delta. In normal and high flow years the gates would remain open. Detailed investigations have shown that in low-flow years the diverted flow would have to traverse extensive areas of shallow swamplands where it would be lost to evaporation unless a channel was made from the Xudum to the Kiri River and on to the Boro.

The remainder of these bunding schemes comprise two bunds with gated structures in the Xudum and Xwabega, a 12 km long cross channel from the Xudum to the Kiri and additional river improvement works of the Lower Kiri to discharge the flow into the lower Boro. This scheme is known as the Xudum/Kiri Cross-Channel and would yield about 45 MCM in dry years with a variation from 10 MCM to 70 MCM.

##### c. Xo Flats Channel.

As an alternative to the Xudum/Kiri Cross-Channel, investigations were made to improve one of the Boro River channels in the Xo Flats. This is an area of very flat topography where the Boro disintegrates into a maze of small channels and where large volumes of water are lost due to evaporation. A properly designed and constructed channel of about 15 to 25 km would yield about 50 MCM in dry years (variation of 40 MCM to 70 MCM) and would be very efficient in increasing the delta outflow without seriously affecting the extent and depth of the permanent swamps.



d. Other Supplementation Schemes.

A number of other outflow supplementation schemes have been considered, the most important being one to supplement the outflow of the Santantadibe River.

The Santantadibe and the Gomoti have both been regarded for decades as dying rivers. People rely on the Santantadibe in particular for water supply throughout all the year. It is thought that a small breach in the right bank of the Ngogha River near Letetemetso Island could restore regular flow into the Santantadibe. This could be tried on an experimental scale and water movement monitored under strict control.

e. Transfer from Panhandle.

An option which remains open for future consideration is to transfer water through a bypass channel from the Okavango River at Sepopa where water is abundant all year through. Because of its abundance, the effect on the delta would be small although the delta outflow would be reduced.

The scheme would be expensive but the channel could supply water to better soils along the western fringe of the delta (if available) and would be of far-reaching regional significance. It has not yet been considered in detail at this stage of the study.

RESULTS OF SYSTEMS SIMULATIONS.

System simulations have been undertaken using a 54-year sequence (1931-1985) of synthetic reservoir inflows, which were synthesized using a computer model of the delta calibrated with the current low-flow regime prevailing in the Boro. The low-flow regime has persisted through the synthesized sequence and includes the prolonged severe drought periods which were experienced in the 1930's and 1940's. Note that a non-outflow event, which occurred during the two years 1940-1942, has an estimated probability of occurrence of only once in 250-300 years. Also, that if the Boro reverts to a medium of high flow regime some time in future, the system would imply an over-design which is preferable to its converse.

The following criteria for system performance have been selected:

1. Melapo.

The largest area out of the 5 000 ha earmarked for development which can be supplied most years.

2. Irrigation.

Less than 20% of crops grown should be susceptible to crop failure because of water shortage; citrus should have a virtually guaranteed water supply.

3. Maun Water Supply.

To be guaranteed in all years except when there is no outflow from the delta (once in 250-300 years).

4. Orapa Surface Water Supply.

Should be interrupted as infrequently as possible.

Results of the system operation studies are summarised in the attached table.

a. Without the Project.

Little improvement if any in relation to present situation, irrigation from lagoons may increase to about 200 ha, Maun water supply to be based on the largest lagoon to be found in the area.

b. With the Project : Maun Reservoir and Lower Boro Improvement.

This system configuration assumes Orapa Mine chooses to continue to rely upon groundwater or other alternatives.

In this configuration a total of 5 500 ha could be irrigated, somewhat reducing the average annual area of flood molapo. Construction of Kunyere Dam and Reservoir would only increase the irrigated area with another 500 ha to about 6 000 ha.

The above mentioned alternatives, b. to d., all include sufficient water for Maun Municipal Water Supply, riparian releases downstream to Rakops and supply to Lake Ngami.

HYDRAULIC STRUCTURES.

Investigations, preliminary design and costing for all hydraulic structures

envisaged have been completed. The investigations have included geotechnical investigations of foundations and construction materials through drilling and laboratory tests and topographical surveys. Main conclusions reached are that there is sufficient clayey material in the river beds near proposed damsites for dam construction. The delta is a seismically active area and structures must be designed to resist earthquake loadings and possible foundation liquefaction has been taken into account.

Structures required for Maun Reservoir would include dams at Samedupi in the Boteti and at Toteng in the Nhabe River and the Thamalakane Control Structure.

Samedupi Dam, about 8 m high, would be a clay dam covered with rock (riprap, comprising selected pieces of silcrete from the river bed). The dam would have a wide enough crest to allow vehicle traffic in both directions. In addition to a low level outlet, four radial gates would be included in the structure to pass the floods without considerably increasing the reservoir water level at Maun.

Toteng Dam would be about 12 m high to be constructed with a clay core and calcrete would provide supporting shoulder material. Hand placed silcrete would protect the upstream face and gravel surfacing the downstream face. A carriageway across the dam and a gated outlet work would be included in the works.

Thamalakane Control Structure would consist of a low earth bund and a concrete control structure equipped with two manually operated radial gates. A crest width of 10 m will allow vehicular access across the bund.

Designs have also been made of a dam in the Kunyere just upstream of its confluence with the Nhabe River near Toteng. The dam site is not ideal because of the depth of sand overlying clay layers in the river bed requiring a cutoff of 12-14 m deep slurry trench filled with bentonite.

The height of the bank in the river bed would be 11 m to 12 m reducing to about 5 m across the left bank terrace and to 3 m on the right river bank.

Kunyere Reservoir would be connected by means of an open channel with Maun Reservoir. A gated control structure would allow control of flow in both directions and to the Lake Ngami irrigation area.

Several other structures have been designed to feasibility study level including gated bund structures for the Xudum/Kiri cross-channel and the Xasanara diversion structure on the Boro River.

Detailed design and contract documents have been prepared for the Lower Boro River Improvement works, including 36 km of enlargement and channelling of the Lower Boro River.

In accordance with the Terms of Reference, surface water supply for Orapa was assessed in less detail. Investigations showed that a dam on the Boteti River would be feasible. An 8 m high dam would be sufficient, and could be constructed with a clay core with calcrete supporting shoulders. An outlet pipe and radial gates to pass the floods would be included in the works.

Because of the extreme flat topography between Rakops and Mopipi, a gravity supply canal cannot be realised. Water would have to be pumped from Sukwane Reservoir through a pipeline to a small holding pond at Mopipi and from there through the existing pipeline to Orapa. Other options were considered but proved to be more expensive.

Cost estimates have been prepared for the various works considered:

	Million Pula
Samedupi Dam	2.4
Toteng Dam	1.2
Thamalakane Structure	0.6
Lower Boro River Improvement	7.3
Xudum/Kiri Works	6.5
Xo Flats Development	8.2
Kunyere Dam and Channel	5.3

Surface water supply to Orapa would be more expensive:

	Million Pula
Sukwane Dam	4.7
Pumping Station and Pipeline to Mopipi	34.2
	<hr/>
	38.9 million

If Orapa mine water demand doubled in about 5 years' time, another P 14.3 million would be required to increase the size of the pipeline. A pipeline from Samedupi Dam to Orapa would cost in the order of P 95 million. The above cost estimates do not include compensation costs for land use lost due to flooding in the reservoir areas which

is estimated at P 1.5 million for Maun Reservoir and P 2.2 million for Sukwane reservoir.

### ECONOMIC EVALUATION

Various costs have to be compared with benefits, which comprise agricultural benefits, fisheries, tourism, Maun water supply, Orapa water supply and a number of intangible benefits, e.g. increased regularity of supply to Lake Ngami.

The agricultural benefits included in the first instance are the agricultural value added from an average of 3 200 ha flood molapo, 1 000 ha broad area irrigation, and 300 ha vegetables and citrus.

Reservoirs would allow for fisheries to be developed on a commercial scale and tourist growth would accelerate in the Maun area.

Surface water supply to Orapa would have two main advantages, it is expected to be cheaper than groundwater in the long run and would be available for most of the economic life of the mine, whereas the presence of adequate groundwater has still to be explored.

Maun Reservoir alone would worsen the present situation of supply to Orapa and as such its costs would exceed the benefits. For Maun and Sukwane Reservoirs together with the economic rate of return is calculated at 13.6%, and at 13.9% when the Lower Boro River Improvement works are added.

An increase in irrigation area to 4 000 ha would require the Xudum/Kiri or Xo Flats development and would have a rate of return of 11%. However, the expected drop in market prices at Maun would imply that irrigated agriculture would financially be unattractive to farmers or the Government would have to subsidise broad area crop production under irrigation at an estimated cost of P 1 000 per hectare per year.

### PRELIMINARY CONCLUSIONS

Based on the reported findings the programme of development would appear to be:

- Construct Samedupi Dam, Toteng Dam, Thamalakane Control Structure.
- Promote improved flood molapo farming in Boro/Shorobe area.
- Promote commercial irrigation of high-value crops, such as citrus and vegetables, to the limit of profitable marketability, e.g. by smallholders under co-operative management.
- Allow development of large-scale commercial irrigation up to about 1 000 ha adjacent to the reservoir. Continue investigations in other parts of Botswana to locate more efficient areas for large-scale production of broad-area crops, i.e. more fertile soils with lower production costs.
- Investigate technical feasibility and socio-environmental impacts of Sukwane Dam in detail.
- Investigate alternative supply from groundwater for Orapa mine.
- If no adequate groundwater alternative, construct Sukwane Dam and pipeline to supply Orapa and implement Lower Boro River Improvement Works.
- As agricultural production increases, examine feasibility of processing facilities such as grain mills, oil crushing plant, and vegetable processing in Maun, where appropriate, encourage such facilities.

All in all, a cautious programme for development of the Southern Okavango water resources is proposed. Projects which may turn out not to be of benefit to the nation and the region, e.g. large scale irrigation on thousands of hectares in the Maun area are not recommended. A country cannot become self-sufficient in food crop production overnight and the risk of failure should not readily be accepted unless no other areas with better soils are available in Botswana.

OKAVANGO WATERS - How do we use it best - MR. S. RAADSMA

C. MOLOSIMA - Department of Water Affairs

My first question concerns seepage, does it occur and on what scale is water lost into the groundwater system around the Okavango.

Secondly, with regard to the Shashe boreholes; a study conducted by BRGL concluded that these borehole levels would be lowered if the Shashe River did not flow for 2 years. This indicates some hydraulic continuity between the production boreholes and the Shashe River. In that case, what is the scope for the artificial recharge of this wellfield by the transportation of water from the Thamaga River?

On the subject of dams, will these affect the water supply of settlements downstream and have provisions been made to overcome water shortages, should they arise?

S. RAADSMA

Your first question refers to the loss of water from the delta to groundwater. Studies conducted in the 1970's indicated that no recharge of groundwater from the delta could be shown to occur. There have been suggestions that some water may move through the groundwater system along folds, either in a north-eastern or south-western direction. However, figures now available for the water balance of the delta indicates that most of the loss from the system is due to evaporation and evapotranspiration with very little loss to groundwater.

On the question of the Shashe wellfield, I think I am correct in stating that up to 150 m<sup>3</sup> per borehole per day can be produced without any recharge for 2 years. Four boreholes are in production which brings the total capacity which can be taken from the Shashe wellfield at 600 m<sup>3</sup> per day. At the present time, water is pumped at double that rate; which has resulted in a considerable draw-down and causing much concern. As the Shashe River did not flow last year, there was very little, if any, local recharge. Upstream in the Shashe valley there is a natural sill which effectively prevents surface flow from the river towards the wellfield. The removal of this sill could be

considered and this would probably enhance recharge of the downstream wellfields.

In answer to the question about the effect of dams on downstream water supplies; our simulation calculations include 42.5 million m<sup>3</sup> to bring the flow at least past these downstream villages. So, there should not be any lack of water in the downstream area although there will not be sufficient water to bring to the Mopipi swamps.

D. PARRY

Having worked on the Okavango Water Development Project, I realise that the Terms of Reference restricted us to the southern end of the delta, but I would like to make the following point: Mr. Raadsma refers to the instability of the delta channel and its water flows and the possibility of a channel from the top of the delta. Recent research by McCarthy et al and Ellery and Ellery on the delta functioning and sedimentation, has indicated that sedimentation is the main determinant of the hydrological regime and therefore the ecological functioning of the delta. The only area with a chance of long term stability of more than 100 years is found at the top of the delta. It therefore appears that the removal of water above the delta would be a sounder development and probably ecologically preferable to that of taking water from the bottom part. Another plant ecologist, Biggs, in 1979 did a study of the Okavango Delta and came to the same conclusions. Why is not more emphasis placed on this means of utilizing water in the delta rather than continually discussing manipulations of water at the southern end?

CHAIRMAN

The water is required at the southern end of the delta. The cost of transfer by canal or pipeline from the panhandle would approximately equal Botswana's current annual water development budget and is thus not a realistic investment at this moment in time. At present, therefore, we are looking to the peripheries of the delta where, hopefully, our interventions will have as little environmental impact as possible although recent researches have indicated that some impacts will be more serious than were first anticipated.

M. MAINE

Has the possibility of purchasing water from a neighbouring country been considered?

## CHAIRMAN

The subject of major transfers of water is a very long term issue resulting in a mammoth undertaking costing billions of pula. The international discussions could take many years to resolve. It is hoped to do a pre-feasibility study of the possibility of a major transfer of water either from the Chobe/Zambezi and/or the Okavango in the near future.

### I. MUZILA

The Okavango Delta is a source of water that can possibly be used for development and other human needs. The result could be that all the water from the middle of the delta would be drained by man-made canals flowing from the middle of the delta directly to the industries. It is crucial that measures be taken to maintain the lower fringe channels and thus conserve the delta area as tourism generated in the Okavango Delta region is of importance to the Botswana economy.

### S. RAADSMA

Environmentalists are carefully monitoring the proposed channel of the Boro River Improvement Works to ensure that it will not leave a scar on the landscape. This is why a direct channel or dredging has not been proposed; instead there should be some clearing and enlargement of the existing Boro River. As the environmentalists will not allow any further advancement into the delta, it is unlikely that a channel will be dredged from the lower Boro River to the panhandle in the foreseeable or even in the ultimate future. The idea of a by-pass channel is attractive, but it may have environmental impact complications which would have to be considered. Tourists are visiting the area more and more and there is a greater danger from an overflow of tourists than from destruction of the delta by an outflow supplementation scheme.

### I. MUZILA

The delta appears to be shrinking. Forests are developing in the north-eastern regions; papyrus is invading the Gomoti River and the Mboroga River is almost dead. Why cannot the flows in these non self-flushing channels in the lower fringe be restored?

## CHAIRMAN

At present there is a flow restoration project being implemented, funded by the Netherlands government, for which we are extremely grateful. The aim of this project is to restore the flow of water to the Malopo area and to the flood recession farming regions in the Gumare area.

As Mr. Parry earlier pointed out, by its nature of being a delta, the channels within it are not stable. These can be improved, but may require continual improvement because the delta is such a dynamic system and this is what makes the hydrology so complicated.

### DR. PATTISON

There appears to be an inevitable pattern developing, in so far as after the construction of the Maun reservoir, followed by improvements to the lower Boro, as water demands increase for new developments, inroads will be made further and further into the delta resulting in a channel through the middle. We think this gradual progression is almost foreclosing other options and we also feel that it is a rather blinkered approach.

### MR. RAADSMA

The Terms of Reference of this study clearly indicated that the Government of Botswana does not want to interfere with the permanent swamps unless it is an absolute necessity and environmentalists, will have the last word in the total overall advice to the government. Fears have been raised that the engineers will proceed quietly from one step to another, but I am convinced that the Department of Water Affairs for the Government of Botswana, and the people of Botswana, are realistic enough not to take water at all costs and certainly not at the cost of damaging the delta. The Okavango is the only remaining inland delta in Africa and there are very few such deltas in the world.

### A. HATTLE

To put things into perspective, what are the swamps worth per year in terms purely of potential tourist income.

Secondly, if development and extended use of the swamp water is envisaged, this can obviously be done more effectively and efficiently if there is some kind of pre-warning of expected flows. Is there any liaison between the Angolan and Botswana Governments in terms of floods and rainfall?

S. RAADSMA

The value of tourists in the delta is approximately 40 million pula per annum.

CHAIRMAN

With regard to your second question, efforts have been made to make contact with Angola through SADECC on a number of occasions and although there are regular meetings on the energy sector, there has not been any success as regards water. For pre-warning on floods and rainfall, we are dependant on a permanently manned gauging station at Mohebo which is in daily radio contact with Maun.

P. LARKIN

The problem of changes in the distributory patterns was mentioned earlier. In the 1930's, the Boro was not an active river channel - a suggestion was made to block it off to prevent wasting water in that area. If an investment is made in a dam at the end of the Boro, an associated water demand will develop, what if the Boro abandons that channel? Must the Boro be re-opened, or should the investment not be made in the first place?

S. RAADSMA

Our discussions have not included a dam on the Boro; we have considered a dam on the Boteti, the main outfall of the delta. This dam would catch any outflow coming from the Thamalakane. I have also mentioned changes in flow regimes in the past and in the future. The Gomoti is a dying river; it is possible that flows in this river and in the delta will change again. Should this occur and the Gomoti flows into the Thamalakane, the Maun reservoir will catch this outflow without any cost.

MR. SEKWALE

Does seismic activity in the area contribute as an element in the proposed dam construction and how does this affect costs? Are the possible effects of such seismic activities considered in the long term, for example, if the delta were to be tilted and the water reversed its direction of flow.

S. RAADSMA

Seismic activity has been taken into account in the preliminary dam designs. Such activity is strong; two years ago there were 82 very minor tremors in the Maun area and this was considered in the design of that dam. Because of possible liquidation of sands beneath the dam, certain stabilizing features must be incorporated in the design, e.g. the dam must have a wider footing. The cost of such modifications are perhaps in the order of one-quarter to one-eighth of the total dam cost.

In relation to the second part of your question, perhaps the water will run backwards, but all water will flow to some base.

N. HUNTER

For the Master Water Plan, it is important to realise that the Okavango Delta is unique and not only from environmental and ecological aspects but also because it is the one area in Botswana where it is very difficult to disentangle water and land resources. An integrated management plan must be devised which will determine how the area is utilized and how the water is used. I believe this to be the role of the various ministries such as Water Affairs and Local Government and Lands, who must integrate government policies with proper management of the facility. The Okavango Delta accomodates not only irrigation, but also tourism, ecological and environmental concerns and this must be recognised at the outset. The master plan must not only highlight these different facets of the Okavango but also reflect their intricate interdependance.



