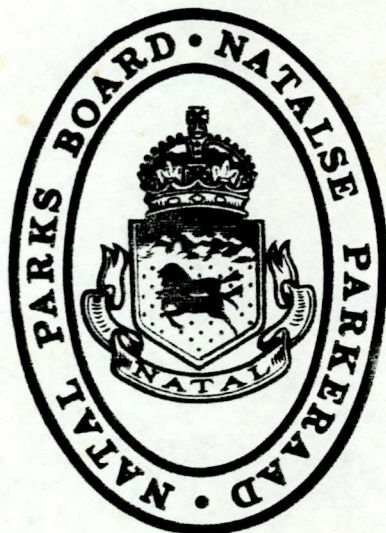


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FLUVIAL PROCESSES IN THE MFOLOZI FLATS AND THE  
CONSEQUENCES FOR ST LUCIA ESTUARY

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ABSTRACT

Cyclone Domoina and associated floods caused considerable change in the study area in January 1984. Investigations were initiated to determine the various system responses to the storm and to identify the natural long-term processes both prior to and after the initiation of sugar cane farming in 1927.

Before 1927 most of the Mfolozi river's sediment load was tied up in the flats and the sediment-free waters reaching the coast kept the combined St Lucia/Mfolozi Estuary mouth open for most of the year. Channelization of the river after 1927 prohibited channel switching and by 1950 the St Lucia/Mfolozi Estuary had become sediment-filled.

During the Domoina flood, a major channel switch occurred depositing a new sand-rich fluvial delta on the flats. The flood strongly emphasized the ability of the flats to retain river borne sediments and the importance of sediment-free flood discharges in scouring and maintaining the Mfolozi and St Lucia estuaries.

INTRODUCTION

The Mfolozi Flats lie between Mtubatuba and the coast and form the coastal plain or receiving basin (Figure 1) of the Mfolozi River (Van Heerden, 1985). Located at the seaward extremity of the Mfolozi Flats is the St Lucia Estuary/Lake system. The Mfolozi Flats constitute the largest coastal flood plain in South Africa and biological productivity is high. In the past, the flats were composed of wetlands which supported large numbers of wild animals and wildfowl while the Mfolozi Estuary was very productive in terms of fish, oysters, shrimp and other such organisms. At present the natural productivity of the area is negligible as it has been replaced by extensive sugar cane plantations. St Lucia is the largest and most productive estuarine system in southern Africa (Day, 1981). The lake and estuary constitute the St Lucia Game Reserve.

St Lucia Estuary originally existed as a shallow connection between the active Mfolozi Estuary and Lake St Lucia. However, sedimentation problems in St Lucia Estuary necessitated the dredging of a separate mouth for the Mfolozi Estuary in the early 1950s. Since then the estuaries have not been permanently linked.

Cyclone Domoina passed over the midlands of Zululand on 30 January 1984 and struck the St Lucia area early on the morning of 31 January (Figure 1). The floods, resulting from the storm, severely damaged farmland in the Mfolozi Flats and forced considerable changes in the Mfolozi and St Lucia Estuaries (Van Heerden, 1984). As a result, studies were initiated in February 1984 to determine the responses of the various systems to the storm and to formulate a management plan

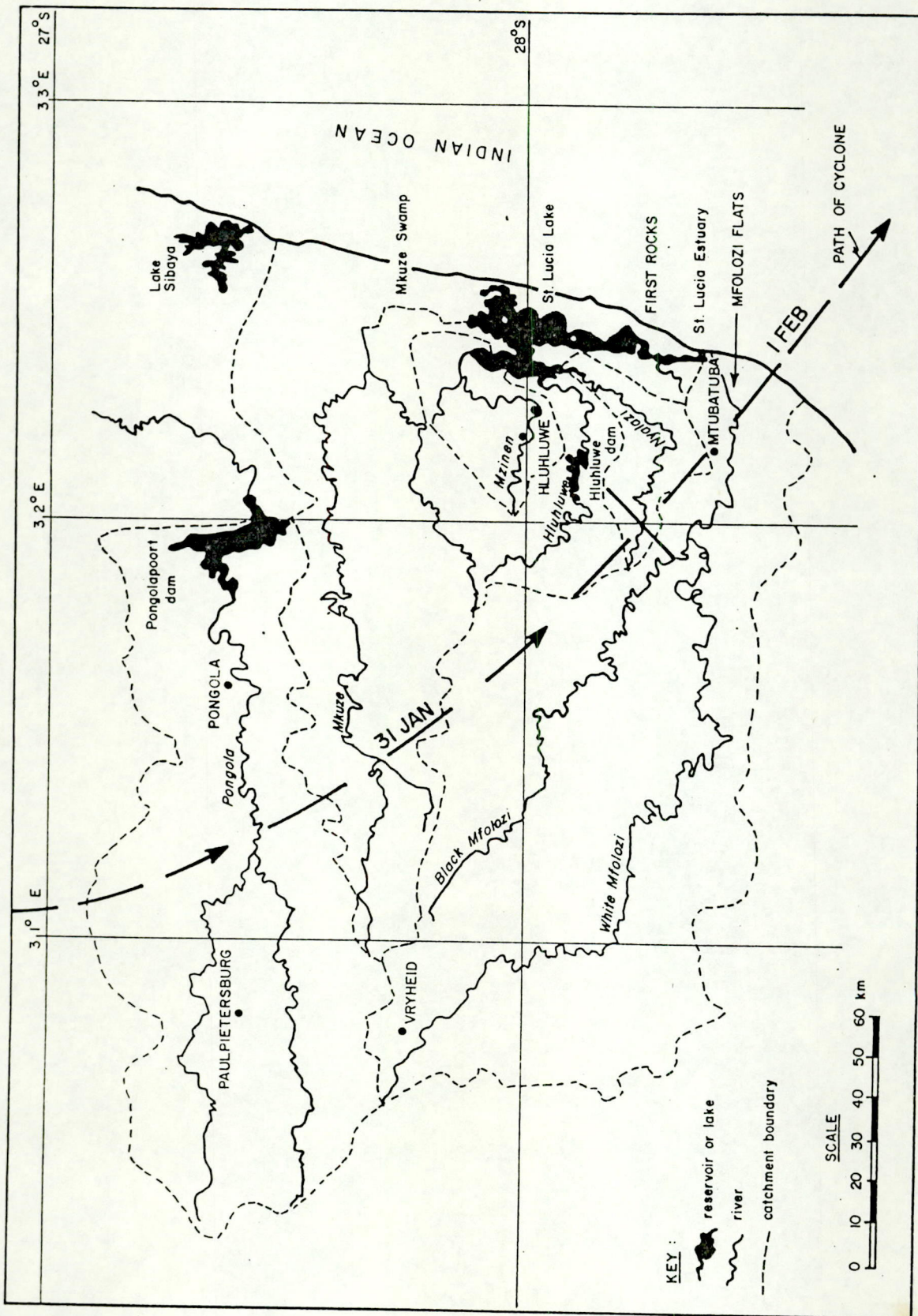


Figure 1. Location of St Lucia Estuary, Zululand.

for St Lucia Estuary with a strong process-response approach. An important part of the work involved deciphering the natural long-term processes. This paper reports on the interactions between the Mfolozi Flats, and the St Lucia and Mfolozi Estuaries as determined for the management plan. The management plan was presented by Van Heerden and Swart (1986).

### METHODOLOGY

#### Literature Review

Aerial photography dating back to 1937 was obtained from the Trigonometrical Survey, Mowbray, Cape Town. This was combined with maps and survey charts of the area produced since 1884 to determine plan-view changes in the morphology of the Mfolozi Flats, and the Mfolozi and St Lucia Estuaries. Historical records dating back to 1576 were examined as well as published and unpublished scientific reports. The above data sources were used in hopes of gaining an insight into the marine and fluvial processes which operated prior to cyclone Domoina.

#### Fluvial Responses to Cyclone Domoina

Aerial photographs of the study area were obtained immediately after the Domoina flood waters receded. Sediment samples were collected at various sites within the flats.

#### Marine Responses to Cyclone Domoina

A hydrographic survey, including echo-sounder and side-scan sonar, was undertaken in July 1984 of the continental shelf, seaward of the two estuary mouths, to a depth of 20 m. Each estuary was also surveyed. These results were then compared with surveys undertaken before January 1984.

### ENVIRONMENTAL FRAMEWORK

#### Climate and Rainfall

Situated between latitudes 27°S and 31°S, Natal has a subtropical coastal and temperate inland climate. Thunderstorms and mid-latitude cyclonic activity contribute to the meteorology. The former predominates in summer (October through March) and the latter in winter (April through September). Precipitation is the most important climatic variable in the present context because of its influence on stream flow and thus sediment load capacity.

Along the southern Zululand coast annual precipitation exceeds 1 250 mm and is associated with almost daily thunderstorms during the summer months. The often intense nature of the rainfall leads to rapid overland flow and to frequent peaks in the stream hydrographs. Winter rainfall, associated with depressions and troughs moving north-east along the coast, is more widespread and not as intense. Nevertheless, when these disturbances are blocked by anticyclonic activity off the Natal coast, continued widespread rainfall may cause extensive

flooding farther inland. Precipitation totals also vary significantly from year to year causing great variability in streamflows, especially in the drier portions of Zululand. There, a succession of low-flow years may have a profound effect on the physical and ecological characteristics of Lake St Lucia (Kriel *et al.*, 1965).

### Tropical Cyclones

Data from South Africa, Madagascar, Mauritius and Reunion revealed that, since 1927, approximately 10 cyclones are generated every year in the tropical regions of the SW Indian Ocean (Dunn, 1984). Of these, four originate in the Mozambique Channel. Since 1950, ten cyclones have caused significant rainfall (in excess of 100 mm) over Natal (Kovacs, 1985), albeit only Domoina traversed South Africa. During Domoina an excess of 600 mm of rain fell over the St Lucia area.

In March 1925 up to 1 200 mm of rain fell in nine days in the Mfolozi catchment (Kovacs, 1985). The ensuing floods were apparently larger than those associated with Domoina (Van Heerden and Swart, 1986). The origin of the storm is not documented but was most likely a tropical cyclone. The tracks of the 10 cyclones observed during the last 35 years suggest that there exists a real possibility of a similar event (in terms of penetration and residence) taking place within a few decades (Dunn, 1984).

### River Discharge

The Mfolozi River has a catchment of approximately 10 000 km<sup>2</sup>. The average annual run-off appears to be between  $393 \times 10^6$  m<sup>3</sup> (Kovacs, 1985) and  $887 \times 10^6$  m<sup>3</sup> (Perry, in prep.). Van Heerden and Swart (1986) found that between October 1921 and September 1975 there were 20 single months in which the discharge was approximately equal to the average annual run-off ( $400 - 900 \times 10^6$  m<sup>3</sup>) and 4 months when the run-off was much larger. The data presented by Van Heerden and Swart (1986) revealed three important features of Mfolozi discharges; firstly, the very erratic discharges of the river; secondly, that large floods are fairly common (24 in 43 years); and thirdly, that floods can occur at any time of the year.

Historically, quantitative examples of peak flood discharges are 15 000 to 22 000 m<sup>3</sup>/s in March 1925, 8 500 m<sup>3</sup>/s in July 1963 and 16 000 m<sup>3</sup>/s during Domoina.

## MFOLOZI FLOOD PLAIN PROCESSES

The sediment made available by the weathering processes on land is not all carried ultimately to seas and lakes. A portion is deposited on land under the influence of fluvial processes. This is especially true for the lower reaches of rivers, where vast flood plains are built from large amounts of fluvial sedimentation. Before discussing sedimentation on the Mfolozi Flats, it is important to review the general concepts of flood plain development.

### Natural Development Processes in Coastal Receiving Basins

The geology, morphology and dominant physical processes of the receiving basin or coastal plain dictate how the fluvial sediment is deposited and the form of these deposits. Narrow, steep-sided coastal plains ensure that most of the river borne sediment is transported to the coast where changes can result in the coastal configuration. Wide, flat coastal plains generally act as sinks for river borne sediment and the coastline configuration is very stable. Extreme floods, however, can create both short-term and long-term changes in the coastline.

In wide, flat coastal flood plains, river gradients are generally low and suspended sediment loads high in comparison with bedloads, and the stream produces a distributary network of meandering channels. In addition, wide coastal flood plains have an inbuilt ability to accept most of the sediment supplied to them by rivers. Build-up occurs as a consequence of differential sedimentation, associated with periodic switching of loci of deposition, as channels switch from one part of the plain to another.

Meander channels on coastal flood plains occupy only a small part of the plain at any one time (Figure 2) and show an organized distribution of channel processes and a clear separation of channel and over-bank environments. Sedimentation is concentrated close to the meander belt and an 'alluvial ridge' is built above the level of the flood plain (Fisk, 1952) (Figure 2). This increasingly unstable situation is periodically relieved by the breaching of a channel bank or levee during floods and the sudden shifting of the meander belt to a new position on the alluvial plain, a process known as 'avulsion'. The new course captures an increasing proportion of the flow and the old meander belt is abandoned.

Subsidence is the second most important mechanism aiding channel switching in coastal fluvial plains. The term "subsidence" refers to the relative rise in sea level and/or the relative lowering of base level in coastal environments and reflects both background and local subsidence mechanisms (Figure 2).

Background subsidence is a regional phenomenon and reflects primarily eustatic rise in sea level and continental downwarping. Local subsidence in flood plains is caused by natural dewatering and compaction of sediments and may be enhanced by human activities.

Swamps and marshes, distant from the meander channel, may not maintain base level due to the sedimentation rate not balancing subsidence. Thus, subsidence aids the creation of topographic lows in inactive parts of fluvial plains and plays a part in the avulsion process.

As natural levee height decreases in a downstream direction on coastal plains, the frequency of switching increases in the same direction. The channel switching process results in the flood plain being built up of juxtapositioned interdigitated sediment lobes (Figure 3).

### Human Influences in Coastal Plains

Human activities can greatly enhance the subsidence rate. Firstly, draining (dewatering) wetlands increases compaction and hence subsidence. Secondly, channelization of rivers and creation of artificial

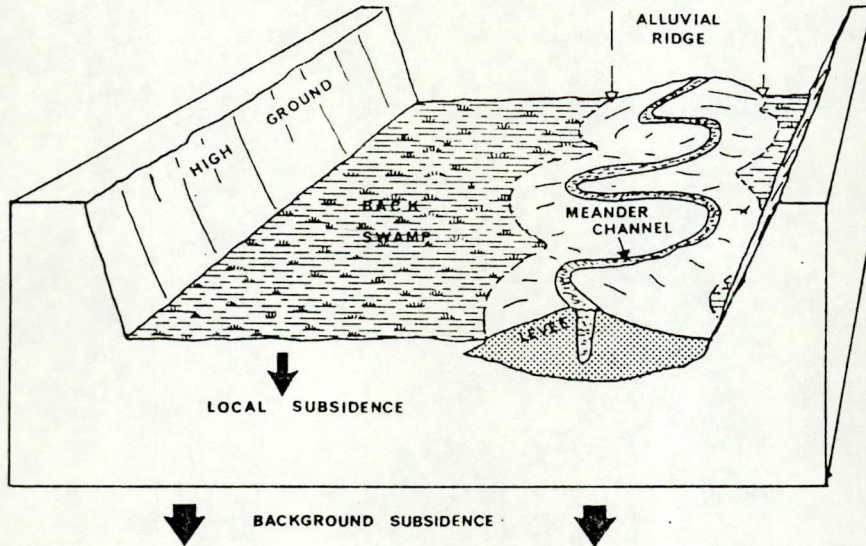


Figure 2. Morphological features of a coastal flood plain.

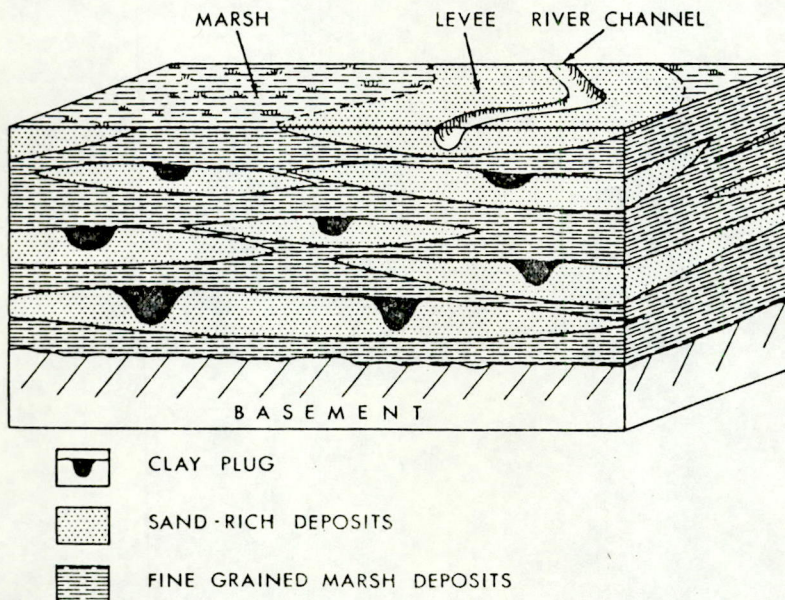


Figure 3. Idealized cross section of a coastal flood plain.

confining levees impedes the distribution of sediment to areas adjacent to the channel. Thus, sedimentation will not balance total subsidence and the lowering of base level will increase. Lastly, if the material used in the artificial levee construction is dredged from the river floor, a situation is created where the local water table is lowered. Such dewatering increases the local subsidence rate.

Although channel switching is a natural process in subsiding coastal fluvial plains it can be restricted by man's activities. Consequently, situations can be created for major, flood-initiated channel switches.

#### Morphology and Natural Depositional Processes of Mfolozi Flats (Pre 1927)

The Mfolozi Flats are apparently underlain by more than 30 metres of relatively fine grained sediments (Orme, 1973), typically deposited from suspension, consisting of silts and clays, and originally having a high water content. Local subsidence due to dewatering and compaction of these sediments is an active process in the Mfolozi Flats and is aided after each flood by the sediment 'loaded' during the flood. The background subsidence, due principally to rise in sea level, is believed to have been 23 cm since 1880 (Barnett, 1984). The total subsidence rate of the surface of Mfolozi Flats is presently not known but in a similar type environment, Atchafalaya River Basin, Louisiana, subsidence rates of 1,3 cm per year have been recorded (Van Heerden, 1983).

Numerous old channel traces are evident on the Mfolozi Flats and indicate that channel switching commonly occurred in the Mfolozi Flats (Figure 4) (Van Heerden, 1984). The aerial photograph data used to compile Figure 4 reveal that the Mfolozi River had occupied its course between points A and B in the upper section of the flats at least since the major flood in 1925 and probably since the late 1800's. The river course was relatively deep and wide with well established confining natural levees. Traces of old crevasse splays or channels displayed in earlier photography (1937) indicate that sedimentation in the upper section occurred through overtopping of the natural levee system (Figure 4) rather than through channel switching. River channel elevation would have progressively increased with each successive flood.

Channel switching was, however, common in the mid section of the flat and appears to have occurred chiefly at two locations (Van Heerden, 1984). Major, fairly long-term upstream diversions occurred in the upper reach of the mid section (Area B, Figure 4) while switching was more common farther downstream (Area D, Figure 4). Using historical maps and photographs, and features such as abundance or lack of tree cover on old levees enables one to infer the chronological order of channel switching. The oldest courses of the Mfolozi in the mid-section of the flat appear to be those marked 1 and 2 in the southern half of the flat. These courses were possibly occupied before the large flood that occurred in 1856 (Kriel et al., 1965).

The earliest known maps of the St Lucia area (1884) reveal that at the time the Mfolozi flowed from point E to point D in the mid-section of the flats (Figure 4) and then flowed in a northerly direction to reach St Lucia Estuary at Honeymoon Bend (Figure 5). Shortly thereafter,

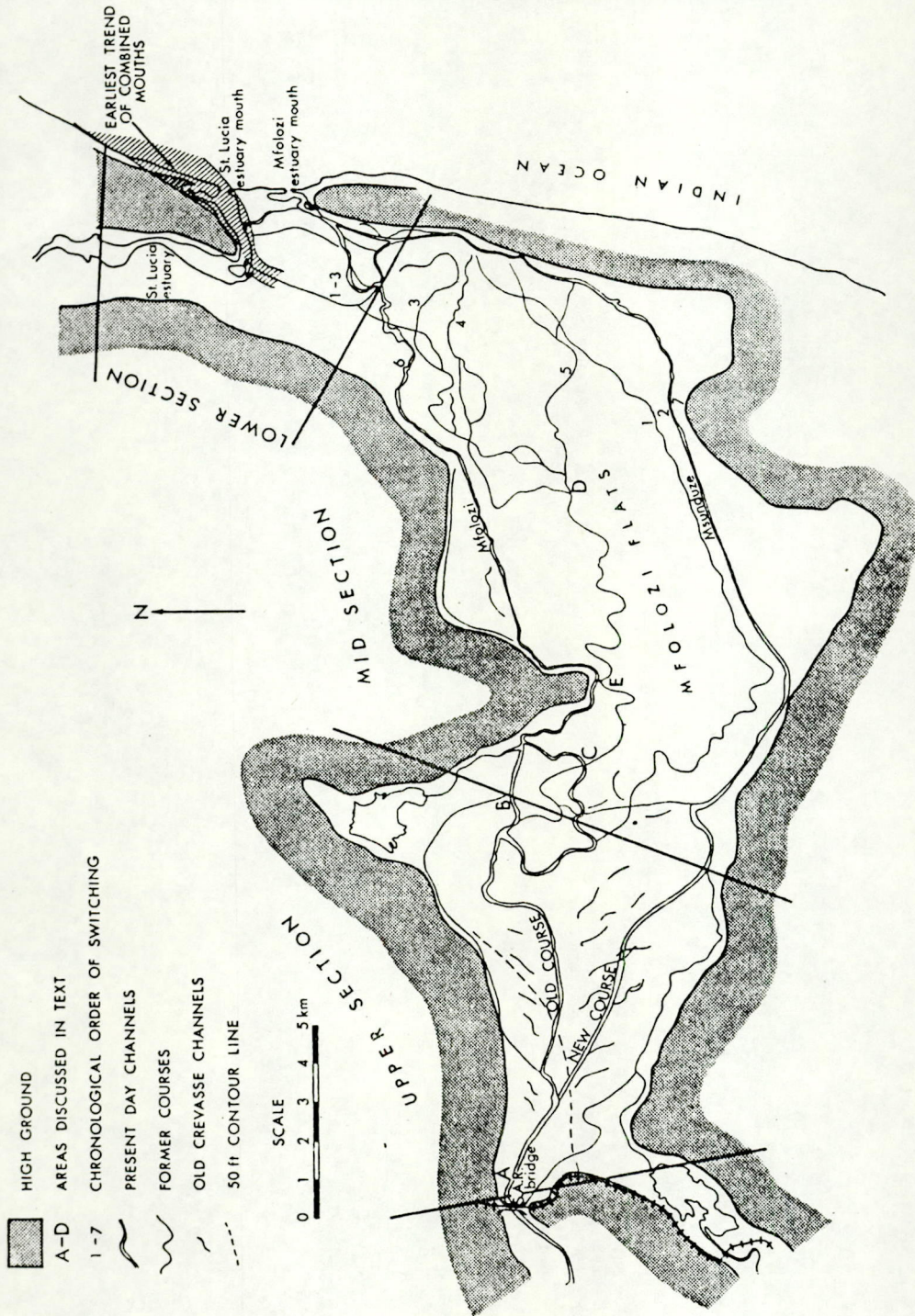


Figure 4. Traces of meander channels on the Mfolozi Flats.

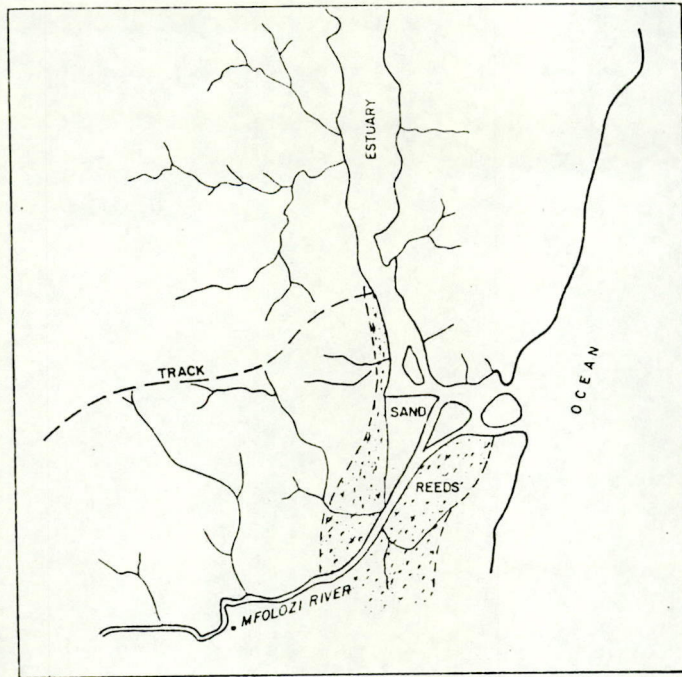


Figure 5. St Lucia Estuary area 1884.

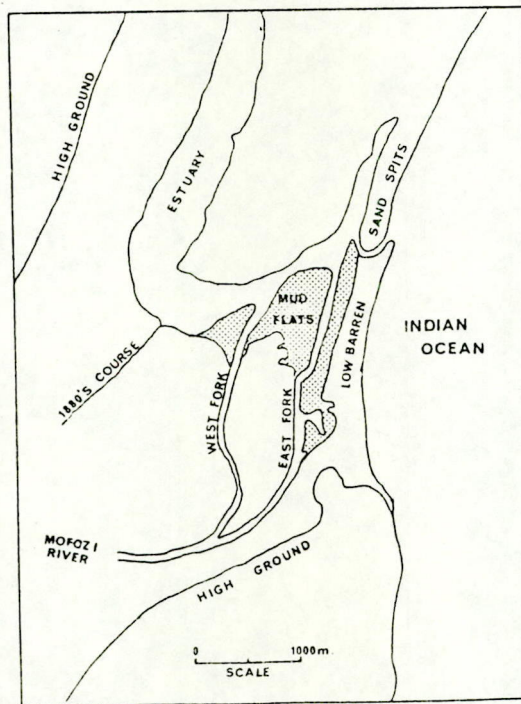


Figure 6. St Lucia Estuary in 1905.

however, it switched to course 3 and then to course 4 (Figure 4) below point D. As a result, in 1905 the Mfolozi entered St Lucia Estuary at a point downstream (seaward) of Honeymoon Bend (Figure 6). Interpretation of the 1937 aerial photographs reveal that, after the large flood in 1925, the Mfolozi River meandered from point B along the most southerly route shown on Figure 4 to point C. From point C to point E, it followed the northerly route shown and then flowed to point D. From here, it took the course marked 5 to the Msunduze River and then joined St Lucia Estuary close to the coast behind a spit complex (Figure 4 and 6). At this time, the river width decreased downstream as did the height of the levees. During the 1925 flood the lower reaches of the Mfolozi River, the Msunduze River and St Lucia Estuary were scoured out as is evident from aerial photographs taken in 1937 (Van Heerden and Swart, 1986).

#### St Lucia and Mfolozi Estuary prior to 1930

Historical records, compiled from Kriel *et al.* (1965) reveal that during the period 1576 to 1927 the combined estuary was open for the greater part of the year. The norm appears to have been for the estuary to close for about three to four months of the year (August to November). During low flow months, fine grained sediments most likely would have been deposited in the mouth area as well as in the lower reaches of the combined estuary, especially if the mouth was closed. High Mfolozi River flows during the wet season would have scoured out the lower reaches of the Mfolozi portion of the combined estuary and the estuary mouth. Overflow from the Mfolozi and rising waters in the Lake system would have increased flows in the lower reaches of the St Lucia arm of the combined estuaries, thus, scouring this system.

It would appear that on a more or less annual basis the whole estuary was scoured open, then closed, followed by some deposition and then opened again. Superimposed on this cycle would have been periods of either longer closure or opening.

#### Modern (post 1930) Mfolozi Flat and St Lucia Estuary Processes

After farming began, the Mfolozi River was shortened and a canal dug between point E in the mid-section of the flats and a large meander in the Msunduze River, near the coast. This new course (Figure 4, Number 6), thus, linked the river directly to a tidal creek offshoot of the Msunduze and considerably shortened the river course to the sea. In addition, the farmers severely restricted channel switching because they lowered the base level of the river as they excavated and used channel bottom sediments to raise the artificial confining levees. Changes in the sedimentation patterns as a result of river channel manipulation are the underlying cause for the ecological stress experienced by St Lucia Estuary following the initiation of farming on the Mfolozi Flats after 1930. Prior to farming the flats accepted most of the river borne sediment and the relatively sediment-free waters reaching the coast kept the then combined systems open and

free of silt. After farming was initiated sediments were transported down the Mfolozi River, directly through the flats to the coast due to the confined, artificially stabilized channel. As a result of this increased sediment supply, both estuaries became heavily silted and estuary mouth closures became common and of longer duration.

Response to channelization appears to have been fairly rapid. In 1932, the mouth was artificially opened for the first time and in 1935 oyster collection, for the Durban markets, was suspended because of "too much silt" (Kriel *et al.*, 1965). In 1936 the first public complaints were made about the deterioration in fishing (Kriel *et al.*, 1965). Mouth closure became more common and the estuary reached a sediment-filled state in 1951. It was only in 1955 that the estuary was finally opened. In the interim, the Mfolozi River was artificially given a separate mouth in 1952. This move, plus the siltation problem prompted the artificial stabilization of the mouth of St Lucia Estuary. Because the Mfolozi River flood and tidal basin scour effect were missing, dredging became a perennial activity.

In addition to restricting channel switching, the farmers drained the wetlands to plant sugar cane. The dewatering of the wetland soils increased the rate of compaction and, hence, subsidence. In general the flats prior to Domoina consisted of a river channel lined by artificially raised banks and surrounded by much lower sugar cane fields.

#### RESPONSES TO CYCLONE DOMOINA

##### Mfolozi Flats

Depositional responses to the Domoina flood were dramatic on the Mfolozi Flats due to an upstream channel switch, in an area where switching seldom occurs (Figure 7). Judging by the amounts and localities of sediment deposition, avulsion must have occurred early in the flood. The sedimentary wedge deposited on the flats during Domoina (Figure 7) is a typical shallow water fluvial delta, displaying the characteristic branching and rejoining of channels around sand-rich lobes (Van Heerden, 1984). The thickness of the "sand" deposited varies between 1 and 2 m (Roberts and Pyke, 1984). Fluvial delta sediments, sampled near the railway bridge in the upper reaches of the flat, consist of fine-to-medium-grained (mean 0,20 mm), well sorted sand (Van Heerden, 1984). Such sediments are usually deposited from suspension as flood waters pass from a confined to unconfined state. In this case, as the flood waters broke out of the confines of the artificially leveed Mfolozi River, they spread out rapidly over the flat with a resultant drop in velocity.

Flood waters would have continued their lateral spreading as they moved down the progressively broadening flat. As a result, a steady longitudinal reduction in velocity occurred such that even finer portions of the sediment load would have been deposited. Spreading of fluvial waters in moving from the confined state and resultant sedimentation usually creates a sediment wedge that thins seaward and exhibits a progressive decrease in grain size. This is the reason that the seaward one-third of the flat was only covered by a few centimetres of silt and clay, although high discharges were experienced.

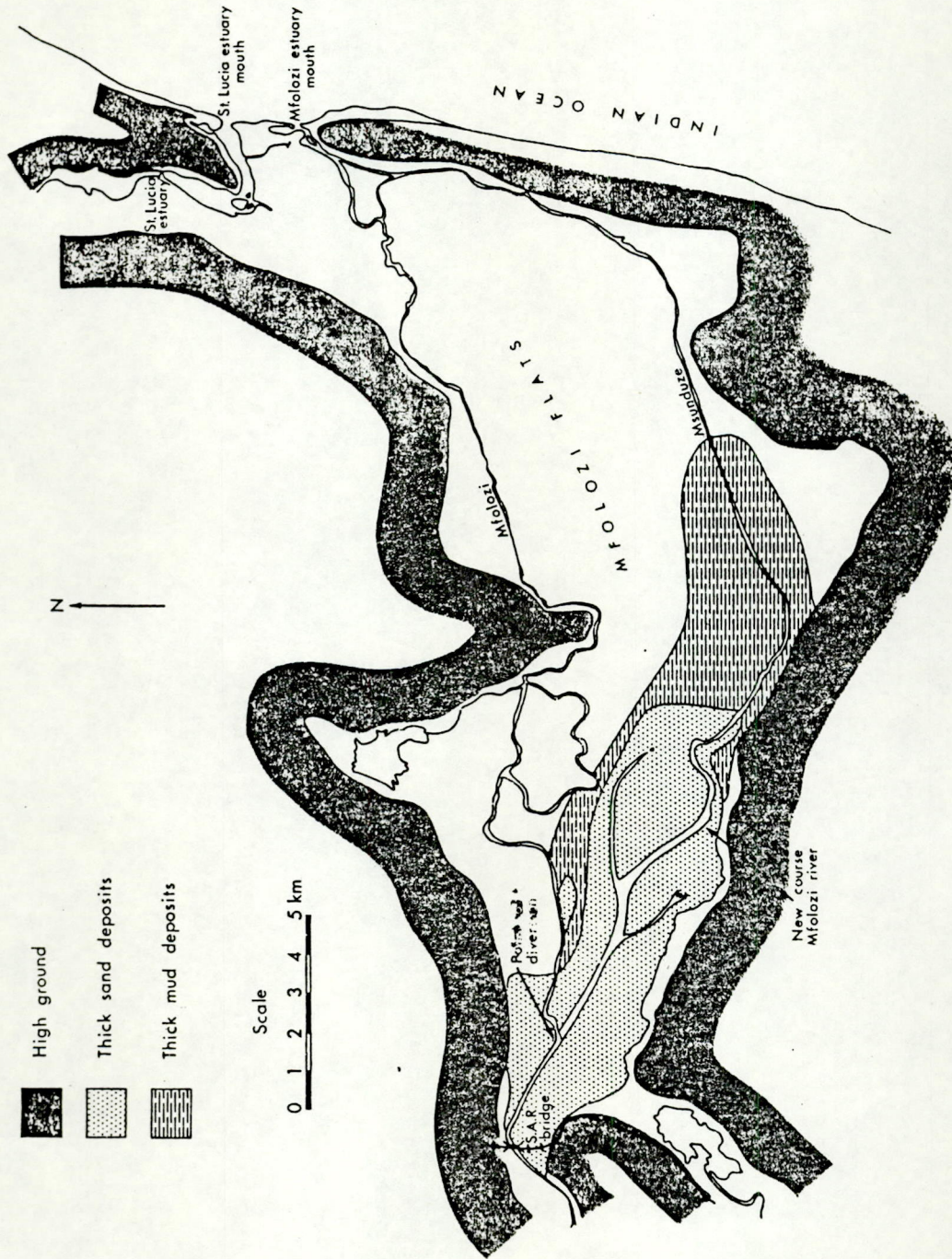


Figure 7. Location of fluvial delta deposited on Mfolozi Flats during the floods associated with Cyclone Domoina.

### St Lucia and Mfolozi Estuaries

The major changes induced by Domoina are clearly revealed by comparing Figures 8a and 8b. Both estuaries had increased dramatically in width, giving the impression that their mouths had been "blown open".

All man-made structures were washed away at the St Lucia Estuary mouth and the estuary assumed a more northerly orientation. As a consequence of most of the Mfolozi's sediment load having been dumped on the flats, the turbulent waters reaching the coast had the ability to entrain vast amounts of sediment previously deposited in the estuaries' mouths. Under the impetus of Mfolozi waters plus waters from a rapidly rising lake system, St Lucia Estuary was scoured out to depths deeper than those present circa 1900 (Van Heerden and Swart, 1986). The average depth of St Lucia estuary was 6 m after the flood as against 1,8 m previously.

The Mfolozi Estuary increased in cross sectional as the southern bank retreated about 300 m because the greatest flood discharge occurred in the Mzunduze River. The relatively sediment-free character of these flood waters ensured that sufficient energy was available to erode and transport the south bank accumulations including sand dunes 50 m high. In addition to bank erosion, the bed of the Mfolozi Estuary was scoured to a mean depth of 6 m considerably deeper than the 1,2 m prior to the flood.

### SEDIMENT AND WATER BUDGETS

The establishment of sediment budgets is an important feature of any quantification of process responses. Unfortunately, budgets are difficult to determine given the data presently available in the literature.

The best estimate of the discharge of the Mfolozi River appears to be  $820 \times 10^6 \text{m}^3$  per annum and that of the Msunduze  $89 \times 10^6 \text{m}^3$ /annum (Chew and Bowen, 1965; Hutchinson, 1976). Orme (1974) suggested a sediment load for the Mfolozi River of  $1,5 \times 10^6 \text{m}^3$ /year. More recently Fleming and Hay (1983) have estimated the sediment load produced in the draining basins of all the rivers north of the Tugela and south of Sordwana Bay, an area dominated by the Mfolozi and Mhlatuze Rivers, as being  $4,243 \times 10^6 \text{m}^3$ /year. The discharge of the Mhlatuze River is apparently  $435 \times 10^6 \text{m}^3$ /year (Chew and Bowen, 1965). If one assumes that the Mfolozi and Mhlatuze rivers carry the same sediment load per cubic metre of water discharged, then the sediment load of the Mfolozi River, using Fleming and Hays (1983) data, can be calculated to be  $2,75 \times 10^6 \text{m}^3$ /year. This estimate is somewhat higher than that made by Orme (1974).

Alluvial valleys can be considered as conduits for sediment transport from the catchment to the receiving basin (Coleman, 1976; Van Heerden, 1985). Assuming that this is the case for the Mfolozi River, it is important to know how much sediment can be deposited in the receiving basin (under natural conditions) and the volume entering the sea for correct management.

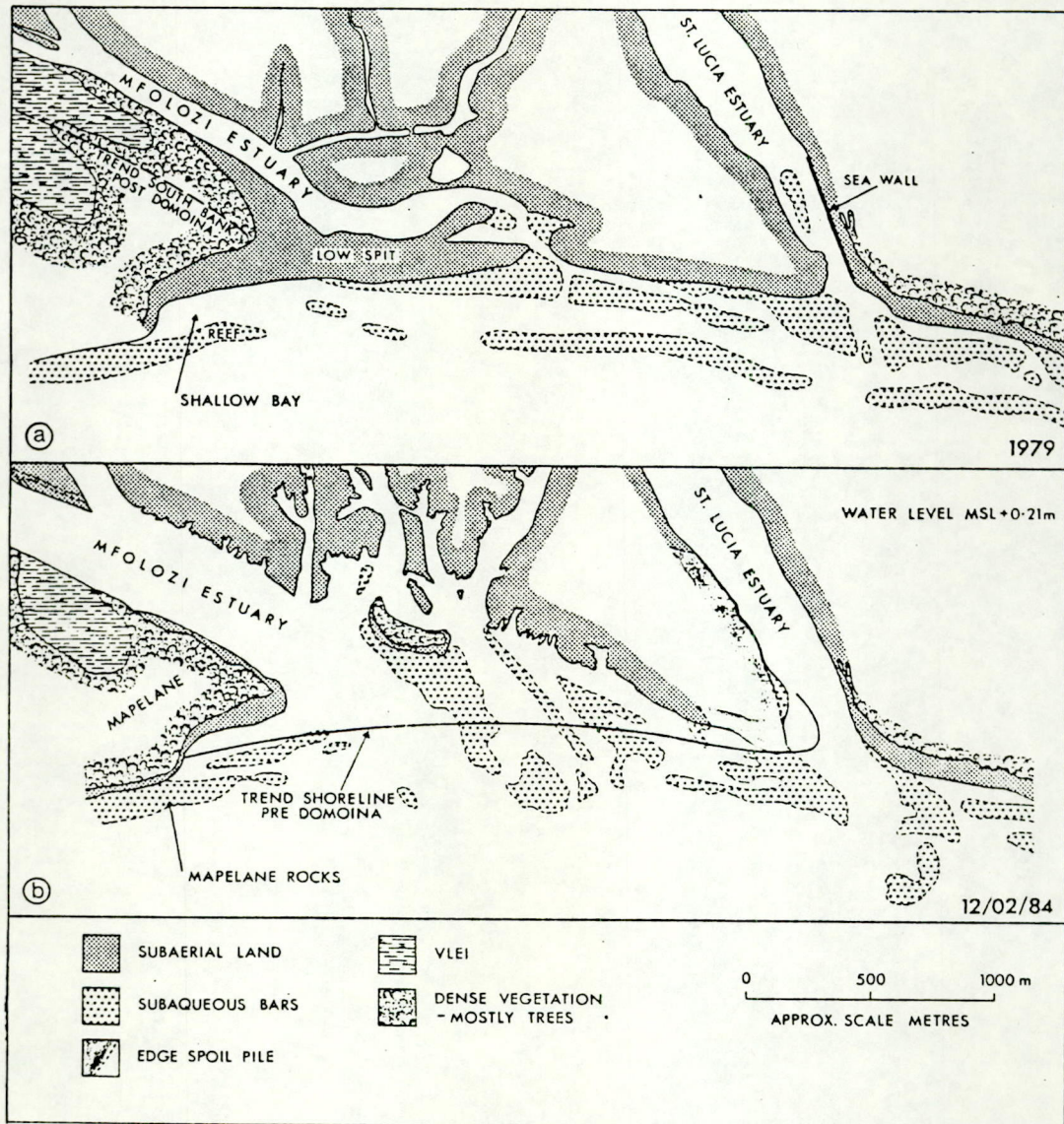


Figure 8. Plan view of St Lucia and Mfolozi Estuaries.

Simple calculations indicate the ability of the coastal flood plain to accept vast volumes of sediment. If the local and background subsidence together equal 1 cm/year for the whole plain, then  $2,4 \times 10^6 \text{m}^3$  of sediment could be deposited annually to maintain base level. This is a substantial amount of potential sedimentation (sink) annually and almost equals the estimates of sediment supplied from the catchment. Therefore, under natural conditions very little sediment would have been transported to the coast. The system broke down once channelization was initiated in 1927 as overbank spillage and flooding, with its associated sedimentation, was prevented.

The floods associated with Cyclone Domoina forced a fairly natural channel switch. Resultant processes strikingly demonstrated the Mfolozi Flat's ability to absorb vast amounts of river-borne sediment. It is estimated that during Cyclone Domoina, approximately  $80 \times 10^6 \text{m}^3$  of sediment was deposited on the Mfolozi Flats. This equals that which could normally have been deposited over 26 years prior to commencement of farming practices.

#### CONCLUSIONS

A literature review combined with field work has resulted in the following conclusions concerning the Mfolozi Flats and the St Lucia and Mfolozi Estuaries.

1. In the natural situation, avulsion was common on the Mfolozi Flats and the majority of river borne sediment entering the flats was deposited before reaching the coast.
2. Farming dictated the artificial channelization of the Mfolozi River. As a result, most river borne sediment passed through the flats and was deposited at the coast, causing the St Lucia system to become severely stressed ecologically.
3. During cyclone Domoina, a major channel switch occurred and vast amounts of sediment were deposited on the Mfolozi Flats. The Mfolozi and St Lucia Estuaries were deeply scoured during the flood. These responses to a flood induced channel switch demonstrated the ability of the flats to retain river borne sediments. Consequently the relatively sediment-free floodwaters were responsible for both the Mfolozi and St Lucia Estuaries being scoured out.
4. Proper management of the Mfolozi Flats in the future could secure the future of the whole Lake St Lucia system.

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