Salt-water intrusion from the Mzingazi River and its effects on adjacent swamp forest at Richards Bay, Zululand, South Africa

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Abstract

Drought conditions in the Richards Bay area coupled with abstraction for domestic and industrial use caused freshwater outflow from Lake Mzingazi to cease in February 1992. This led to the tidal intrusion of saline water from Richards Bay into the Mzingazi River. The extent of the intrusion up the river and into the groundwater was determined and the impact on the adjacent flora recorded. Results showed that saline water penetrated the groundwater for up to 20 m from the river bank and that this had caused the death of a number of swamp forest trees as well as the defoliation of others. Spring tides and particularly a very high equinox tide had further aggravated the situation causing damage to, and the death of, numerous plants in herbaceous swamp areas.

Introduction

Prolonged drought conditions during 1990 and 1991 coupled with daily abstraction of water by the Borough of Richards Bay for domestic and industrial use resulted in a decrease in the level of Lake Mzingazi at Richards Bay (28°49'S, 32°05'E) and a consequent cessation of freshwater outflow over the weir into the Mzingazi River on 02/02/92. Overflow from the weir to the sea is via the Mzingazi River (Fig. 1), then a dredged section of the river known as the Mzingazi Canal and the harbour section of Richards Bay. As a result of the lack of freshwater, the Mzingazi River attained salinities close to that of sea water. Only a small freshwater input occurred, due to seepage from Lake Mzingazi in the vicinity of the weir (Fig. 1). The latter was built some time during 1942/43, raised by 1.75 m in 1945 with subsequent modifications in the 1980s to make more water available for abstraction for domestic and industrial use. At the beginning of 1992 officials of the Borough of Richards Bay noted that portions of the swamp forest and herbaceous marsh in the low-lying land adjacent to the river were showing signs of severe degradation with some trees having died and many others having become defoliated.

The destruction of plant communities as a result of increased water salinities in the Richards Bay area during 1975 to 1977 has previously been reported on by Weisser and Ward (1982). In this case the increase in salinity killed the *Phoenix reclinata/Hibiscus tiliaceus* and *Barringtonia racemosa* communities. This was brought about by the opening of the "new mouth" in the "sanctuary" area of Richards Bay during harbour development, and the associated increases in tidal range and water salinities. Other water-associated tree mortalities along the Zululand coast have been reported by Breen and Hill (1969) and Bruton and Appleton (1975, in Begg 1978). However, both described the death of mangroves as being due to a reduction in the tidal exchange of saltwater into the swamps, the former at the Kosi Estuary and the latter at Lake Mgoboseleni near Sodwana Bay.

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Aims

At the request of the Borough of Richards Bay the Coastal Research Unit of Zululand (CRUZ) conducted an investigation during April and May 1992. This looked at the effects of level changes in the groundwater, salt-water intrusion from the Mzingazi River into the adjacent swamp forest and herbaceous swamp, and the impact of these factors on the environment. This paper is based on results presented in the unpublished report by Cyrus and Martin (1992). The specific objectives of the study were to:

(i) Measure salinity, pH and level of the water table in the study area under varying tidal conditions.
(ii) Determine fluctuations in salinity levels, current velocity, water levels and residence time of salt water over neap and spring tides in the study area.
(iii) Record the plant communities and their dominant species in the study area adjacent to the river, assess the degree of salt-water intrusion into the soil and its effect on the plant life.
(vi) Report on the status of salt-water intrusion in the study area and provide management recommendations for the area related to findings from objectives (i), (ii) and (iii) above.

Study site

The study site lay north of the Richards Bay Harbour and extended from the point where the Mzingazi River is crossed by the Empangeni/Richards Bay road near Meerensee, to the outlet weir on Lake Mzingazi (Fig. 1). A 12-h sampling station was established 950 m downstream from the outflow point. Other sampling points (1 to 8) and the position and number of auger boreholes (A to E) are also shown on Fig. 1.

Methods and materials

Several methods were employed in order to achieve the objectives of the study. These were as follows:

- Surface and bottom salinity, oxygen and temperature, water depth and mid-water current velocity and turbidity were recorded in the study area at regular intervals over a 12-h period during a neap tide on 10/04/92 and a spring tide on 04/05/92.

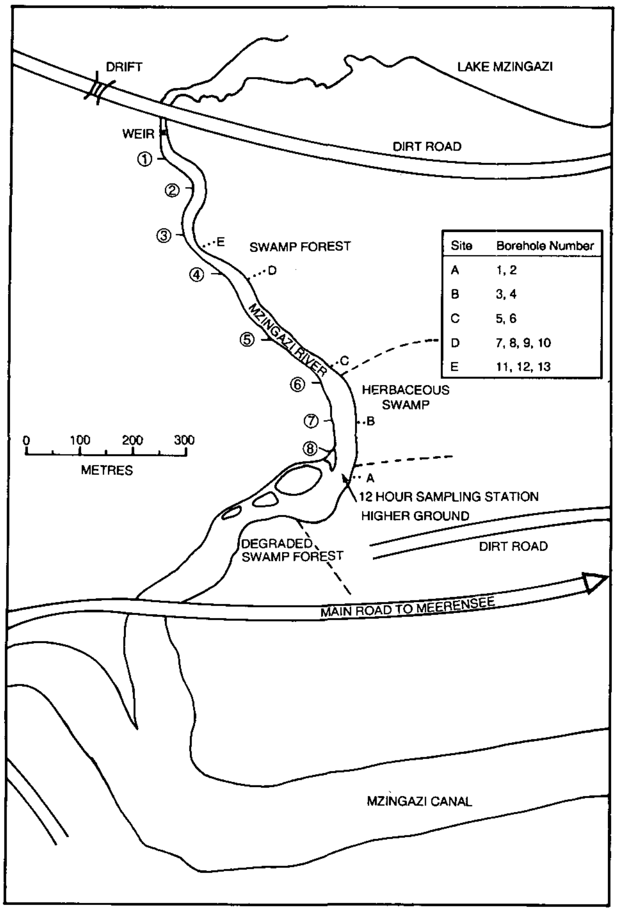

Figure 1
Mzingazi River study area showing position of auger boreholes (A to E), salinity sampling sites (base of weir and 1 to 8) and the location of the 12 h sampling station

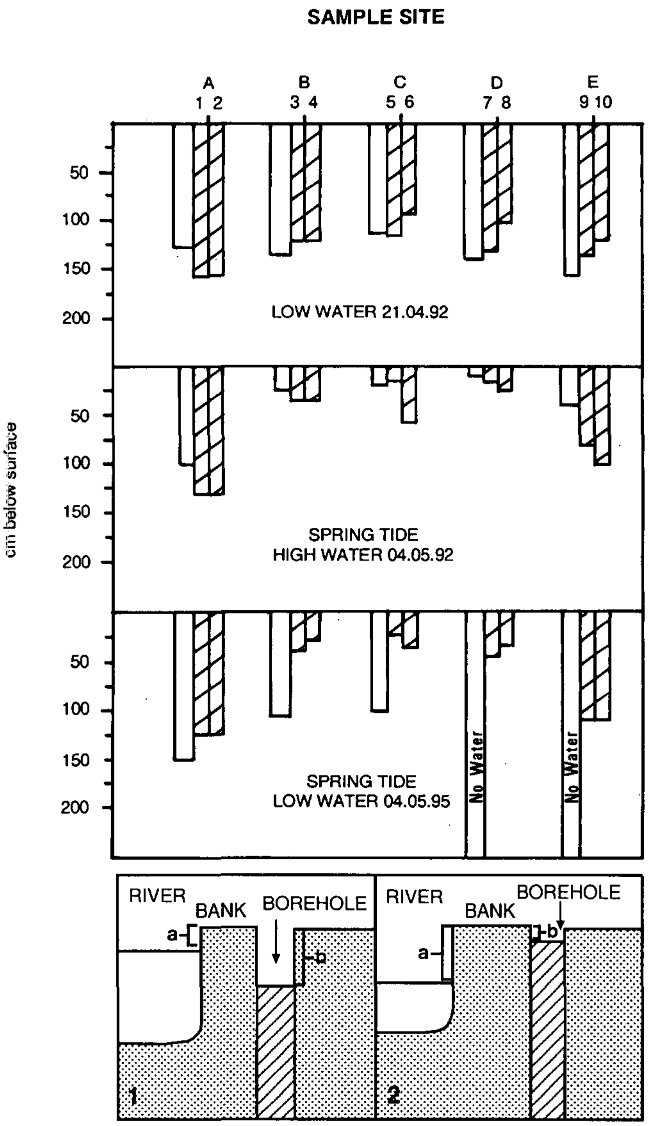

Figure 2
Water table depth in 10 auger boreholes (hatched bars) and level of river water below bank level at five sites (A to E)(open bars), along the Mzingazi River during; low water on a neap tide, high water on a spring tide and low water on a spring tide. Note: When water level in auger borehole is lower than river water level, as illustrated in Diagram I above, conditions exist for saline water to actively intrude into the groundwater.

- Visits were made on 15/04/92 and 28/04/92 to survey the plant species and communities and to identify species vulnerable to impact from potential salt-water intrusion in the study area.
- In order to investigate the effect of changes in the water table on the swamp forest and herbaceous swamp it was necessary to first auger a series of boreholes in the study area. On 21/04/92 five sets of boreholes were sunk to below the depth of the water table along the east bank of the Mzingazi River in the study area (Fig. 1). The holes in each set were spaced at either 5, 10 or 15 m apart (see Table 1 for specific details) in lines at right angles to the river bed. The salinity, pH and water table depth (relative to the height of the river bank) in each hole were measured during a first quarter tidal cycle on 21/04/92 and again over a spring tidal cycle on 04/05/92. At the same time a measure of tidal height was obtained based on the river level in relation to the height of the river bank. Figure 2 illustrates how river level (a) and water table depth (b) were measured. In Fig. 2(1) river level (a) is higher than water table depth (b) and as a result intrusion of river water into the groundwater is able to occur. In Fig. 2(2) river level (a) is lower than groundwater depth (b) thus restricting the intrusion of river water.
- Salinity measurements were taken at nine points along the Mzingazi River (Fig. 1) at high and low water during both spring and neap tides in order to determine the extent of salt-water penetration up river.
- Water salinities were measured in parts per thousand ($^o/_{oo}$) using an American Optics Refractometer. Oxygen in mg/ℓ and temperature in °C were measured with a WTW Model No.96 microprocessor oximeter. Turbidity was measured in nephelometric turbidity units (NTU) with a Hellige direct reading turbidity meter.

TABLE 1
RESULTS OF AUGER BOREHOLE MONITORING DURING HIGH WATER OVER A SPRING TIDE ON 04/05/92 (DIFF.= DIFFERENCE BETWEEN GROUNDWATER DEPTH AND RIVER WATER LEVEL; SAL.= SALINITY IN PARTS PER THOUSAND; MZIN. = MZINGAZI). NOTE: WHEN LEVEL OF RIVER WATER IS HIGHER (DIFF.= +) THAN GROUNDWATER DEPTH, RELATIVE TO BANK HEIGHT, THEN SALINE WATER IS ACTIVELY PENETRATING INTO THE GROUNDWATER

Site	Dist. from river (m)	Ground-water depth (cm)	River water level (cm)	Diff. (cm)	Groundwater		Mzin. River		Time
					Sal. (°/oo)	pH	Sal. (°/oo)	pH	
A1	5	129	96	+33	5	2.2	34	7.5	17:00
A2	10	128	96	+32	2	3.0	34	7.5	17:00
B3	5	34	23	+11	27	3.3	34	7.4	16:52
B4	10	36	23	+13	28	3.3	34	7.4	16:52
C5	5	15	18	- 3	33	6.4	33	7.4	16:42
C6	10	58	18	+40	32	4.0	33	7.4	16:42
D7	5	14	10	+ 4	32	4.2	33	7.2	16:34
D8	10	23	10	+13	31	3.9	33	7.2	16:34
D9	15	37	10	+27	25	3.7	33	7.2	16:30
D10	30	40	38	+ 2	16	3.4	32	6.9	16:30
E11	5	80	38	+42	32	3.7	32	6.9	16:00
E12	10	100	23	+77	· 22	3.4	32	6.9	16:00
E13	30	130	38	+92	1	6.0	32	6.9	16:15

TABLE 2
RESULTS OF AUGER BOREHOLE MONITORING DURING LOW WATER OVER A SPRING TIDE ON 04/05/92. (DIFF.= DIFFERENCE BETWEEN GROUNDWATER DEPTH AND RIVER WATER LEVEL; NMW = NO MEASURABLE WATER IN RIVER; SAL.= SALINITY IN PARTS PER THOUSAND; MZIN. = MZINGAZI). NOTE: WHEN LEVEL OF RIVER WATER IS HIGHER (DIFF.= +) THAN GROUNDWATER DEPTH, RELATIVE TO BANK HEIGHT, THEN SALINE WATER IS ACTIVELY PENETRATING INTO THE GROUNDWATER.

Site	Dist. from river (m)	Ground-water depth (cm)	River water level (cm)	Diff. (cm)	Groundwater		Mzin. River		Time
					Sal. (°/oo)	pH	Sal. (°/oo)	pH	
A1	5	124	153	-29	5	2.3	33	7.2	06:40
A2	10	124	153	-29	1	3.0	33	7.2	07:00
B3	5	41	106	-65	28	3.4	33	7.2	07:15
B4	10	28	106	-78	27	3.7	33	7.2	07:25
C5	5	25	98	-73	32	5.5	33	7.2	07:35
C6	10	36	98	-62	32	4.9	33	7.2	07:40
D7	5	45	NMW	-	32	4.2	33	7.2	09:15
D8	10	30	NMW	-	32	3.9	33	7.2	09:20
E11	5	110	NMW	-	32	3.7	33	7.2	09:45
E12	10	110	NMW	-	24	3.1	33	7.2	09:50

Results

12-hour tidal cycle

The results of sampling over the tidal cycles revealed that minor changes occurred over the 12-h periods. Apart from salinity, no significant differences occurred within the other physical factors, between the top and bottom of the water column, high and low tide or spring and neap tide.

Oxygen levels were slightly lower than would be expected for such a locality (range 3.6 to 5.6 mg/ℓ), and may have been due to the presence of substantial amounts of rotting vegetation in the river. However, oxygen together with temperature (range 20.2 to 27.9°C) and turbidity (range 2.5 to 27.0 NTU) were all within the limits recorded in the upper reaches of small estuaries in Zululand. The water current remained between 0.05 and 0.50 m/s during both spring and neap tides, apart from three occasions when 1.50 (twice) and 3.59 m/s were recorded. Water depth ranged between 2.31 m at spring high and 0.44 m at spring low tide. Salinity levels were, however, very high for an area normally subjected to near freshwater conditions. The values recorded (range 26 to 35 °/oo) were typical of near full sea-water conditions usually associated with tidal areas at the mouths of estuaries.

TABLE 3
RESULTS OF AUGER BOREHOLE MONITORING DURING LOW WATER OVER A NEAP TIDE ON 21/04/92 (DIFF.= DIFFERENCE BETWEEN GROUNDWATER DEPTH AND RIVER WATER LEVEL; SAL.= SALINITY IN PARTS PER THOUSAND; MZIN. = MZINGAZI). NOTE: WHEN LEVEL OF RIVER WATER IS HIGHER (DIFF.= +) THAN GROUNDWATER DEPTH, RELATIVE TO BANK HEIGHT, THEN SALINE WATER IS ACTIVELY PENETRATING INTO THE GROUNDWATER

Site	Dist. from river (m)	Ground-water depth (cm)	River water level (cm)	Diff. (cm)	Groundwater		Mzin. River		Time
					Sal. (°/₀₀)	pH	Sal. (°/₀₀)	pH	
A1	5	156	127	+29	8	2.0	26	6.4	13:47
A2	10	156	127	+29	4	3.5	26	6.4	13:50
B3	5	121	137	-16	22	3.2	33	6.8	14:48
B4	10	120	137	-17	18	3.2	33	6.8	14:52
C5	5	116	118	- 2	34	5.6	32	6.6	14:37
C6	10	93	118	-25	32	3.1	32	6.6	14:30
D7	5	131	136	- 5	32	4.1	26	6.3	14:09
D8	10	103	136	-33	27	4.4	26	6.3	14:01
E11	5	135	155	-20	27	4.0	6	6.3	13:51
E12	10	123	155	-32	5	4.2	6	6.3	13:54

Borehole monitoring

The results of the borehole monitoring are given in Tables 1, 2, and 3, and show that:

- Saline water had in some places intruded into the groundwater of the swamp forest and herbaceous swamp for distances of 20 m or more from the river bank in concentrations deleterious to plant growth (>22°/₀₀)(Table 1 and Fig. 3).
- The water table depth fluctuated with the tide and depended largely on the level of the water in the river bed (Tables 1 and 2). Although the response of the groundwater level in the boreholes to tidal change in the river was direct, a short time lag occurred which may be attributed to soil type and condition, depending on whether it was for example clay or sand.
- The salinity of the Mzingazi River was nearly that of sea water, being only slightly diluted by freshwater seepage from Lake Mzingazi, which itself had stopped overflowing into the river three months prior to the present study.
- The level of the saline river water was frequently higher than the level of the groundwater in the auger boreholes (Fig. 2). Under these conditions saline river water actively intruded into the groundwater (Fig. 2(1)). In some instances saline water had replaced the freshwater altogether (Fig. 3). The reduced groundwater level had been brought about by the ongoing drought and water abstraction from Lake Mzingazi which had resulted in levels remaining very low for extended periods, thus reducing seepage into the groundwater below the lake.
- Intrusion of saline water (salt content >30 °/₀₀) extended, for the most part, up to 10 m away from the river bank. Thereafter, some dilution was noted but the levels of salt in the groundwater, even 30 m from the bank in some cases, remained too high for normal growth (Fig. 3), even of salt-resistant plant species such as *B. racemosa, P. reclinata, H. tiliaceus* and *Phragmites australis* all of which occur in oligohaline areas of South East African Estuaries (Begg, 1984).

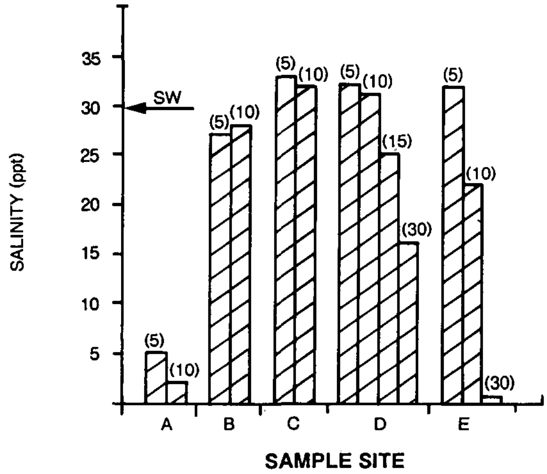

Figure 3
Water salinity (°/₀₀) in auger boreholes adjacent to the Mzingazi River during high spring tide on 04/05/92 (SW = value equivalent to sea water; figures in brackets indicate distance of borehole, at right angles, from river edge; for position of sampling sites see Fig. 1)

- pH measurements (Tables 1, 2 and 3) showed that the groundwater was too acidic for normal plant growth and boreholes with a pH <4 were common. Coincident with low pH was a strong smell of hydrogen sulphide in the water suggesting anaerobic activity which is unsuitable for plant root growth. The production of hydrogen sulphide was a natural event resulting from sulphate reduction which has previously been observed in several local hydromorphic swamp forest soils (pers. obs.). This was probably augmented by salt-water intrusion into the groundwater which resulted in the subsequent reduction of the high sulphate concentrations in the sea water.

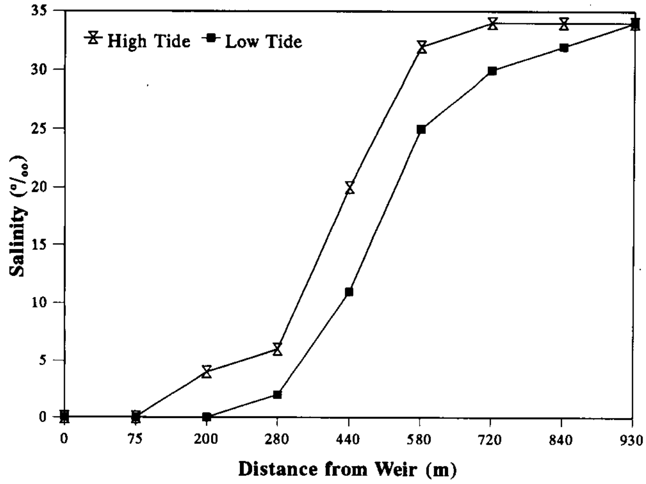

Figure 4
Penetration of saline water up the Mzingazi River towards the outflow weir during high and low neap tides

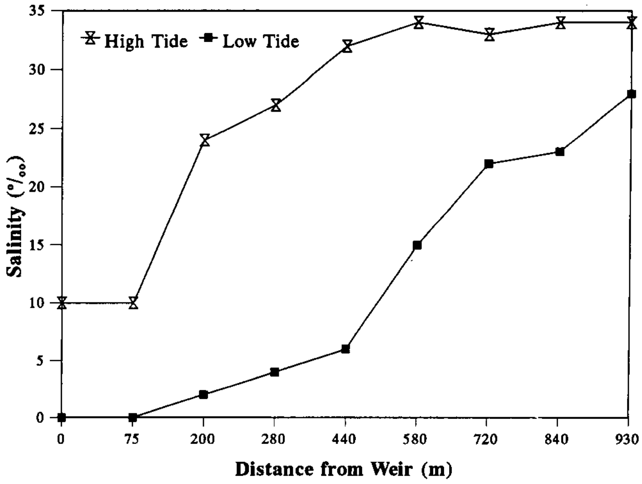

Figure 5
Penetration of saline water up the Mzingazi River towards the outflow weir during high and low spring tides

Salt-water penetration up the Mzingazi River

The extent to which saline water penetrated up the Mzingazi River is shown in Figs. 4 and 5 for high and low water during neap and spring tides. The results indicated that the cessation of freshwater outflow from Lake Mzingazi had enabled saline water, up to 10°/$_{oo}$, to penetrate to the base of the outlet weir over spring high water. Figures 4 and 5 also show that near sea water salinities (>30°/$_{oo}$) extended to within 500 m of the weir on neap tides and penetrated an additional 100m upstream on spring tides. This coupled with a lowered water table allowed salt water right into the heart of the previously freshwater swamp forest.

Plant communities

Freshwater swamp forest was present from the shore of Lake Mzingazi, extending downstream to opposite sampling site No. 6 (Fig. 1). From this point down to the 12-h sampling site the area consisted of herbaceous swamp occupying low-lying areas and drainage lines along old dune slacks. The plant community downstream from this point consisted of degraded freshwater swamp forest.

The different plant communities in the study area and their dominant species are listed in Table 4 which shows that the degraded swamp forest had the higher species richness. In part this could be due to an invasion by swamp herbs, climbing herbs and exotic invaders following the collapse of swamp trees such as *Ficus trichopoda* and *Syzygium cordatum* which had been killed by a previous saline intrusion which occurred in the study area in the early 1980s but for which no data are available (personal observation). In the pristine swamp forest very few herbaceous species were found, due to reduced light penetration and possibly the presence of allelopathic toxins. The latter acts to suppress the growth of other plant species within its surroundings. The estuarine plant communities were restricted to the sand bars present along the river edge, being dominated by the coastal shrub *H. tiliaceus*.

Salt-water intrusion and its impacts

At high spring tides, water overflowed the banks of the Mzingazi River at many points and flooded adjacent low-lying areas of land. This water had a long residence time and in some areas took 5 to 6 h to drain back into the river. Over the high spring tide on 04/05/92 an area extending about 50 m back from the river, between Boreholes 6 and 7 (Fig. 1) had standing surface water with a salinity of 26°/$_{oo}$.

The high water level which was reached on 18/03/92 when an equinox tide occurred was clearly marked by the presence of a dark brown silt band along the culms of the *P. australis* in the study area. This level was a full 200 mm above that of the high water spring tide level of 04/05/92. It clearly indicated that the area inundated by saline waters during the equinox period, only six weeks previously, was substantially larger than that inundated during spring tides over the study period, thus extending the impact further into the swamp.

Salt water had been intruding for some time, via the groundwater, into the peat layer on which the herbaceous swamps and swamp forests were growing. However, this, combined with the equinox-induced flooding of the bank-side herbaceous swamp, had caused the death *en mass* of *Polygonum pulchrum, Thelypteris dentata* and *Ipomoea cairica.* Behind these there were dead *Cyperus latifolius* and *C. papyrus.* Culms of the latter were noted to be triangular in shape indicating a water stress situation. Although flooding may have occurred in the past each year over the two equinox tides, the tidal amplitude in Richards Bay has increased as a result of the dredging of deep channels for the harbour and this could have accentuated the situation.

In the swamp forest, for a distance extending up to 15m from the river bank, nearly all the *F. trichopoda* and *B. racemosa* had lost their leaves. In addition seven large and >20 small *F. trichopoda* were completely dead. Ninety percent of these were situated within 5 m of the river bank. No *B. racemosa* were found dead and in fact all had leaf buds present despite the initial leaf fall.

It was noted that at several places in the swamp forest, where intruding saline water drained from the land by means of eroded gullies, these provided faster drainage, thus reducing residence

TABLE 4
AQUATIC PLANT COMMUNITIES ALONG THE MZINGAZI RIVER (* = EXOTIC INVADERS; + = SALT TOLERANT PLANTS; EC = ESTUARINE COMMUNITY; FHS = FRESHWATER HERBACEOUS SWAMP; FSF = FRESHWATER SWAMP FOREST; DSF = DEGRADED SWAMP FOREST).

Species	Common name	Type of plant	EC	FHS	FSF	DSF
*Melia azedarach**	Syringa	Tree		x		x
Trema orientalis	Pigeonwood	Tree		x		x
Ficus trichopoda	Swamp fig	Tree			x	
Barringtonia racemosa+	Freshwater mangrove	Tree		x	x	x
Macaranga capensis	Swamp poplar	Tree			x	
Voacanga thouarsii	Freshwater frangipani	Tree		x		
Phoenix reclinata+	Wild date palm	Tree			x	x
Protorhus longifolia	Red beech	Tree		x		
Rhus sp.		Shrub	x			
Rauvolfia caffra	Quinine tree	Tree		x		
Syzygium cordatum	Common waterberry	Tree			x	x
Hibiscus tiliaceus+	Swamp hibiscus	Perennial shrub	x			
*Ricinus communis**	Castor-oil plant	Shrub				x
Schinus terrebinthifolia+*	Brazilian pepper	Shrub				x
Ipomoea cairica	Wild morning glory	Perennial Climbing herb		x		x
*Ipomoea congesta**		" "		x		
Canavalia maritima+		" "				x
Cisselampos sp.		" "				x
Smilax kraussiana	Monkey creeper	" "				x
Polygonum pulchrum		Perennial herb		x		
Polygonum sp.		" "		x		
Sarcocornia perenne+	Saltwort	Succulent herb	x			
Stenotaphrum secundatum	Buffalo grass	Perennial grass		x		x
Oryza sp.+	Wild rice	" "				x
Phragmites australis+	Common reed	" "	x	x		x
Hemarthria altissima	Red swamp grass	" "				x
Cyperus papyrus	Papyrus	Perennial sedge		x		x
Cyperus latifolius	Basket sedge	" "		x		x
Cyperus prolifer	Pygmy papyrus	" "				x
Juncus maritimus+	Ncemane rush	" "	x			
Thelypteris dentata	Fern	Fern		x		x
		Total number of species:	**5**	**15**	**5**	**19**

time of standing salt water in the area. At these localities the fig trees appeared to be less affected by the salinities than in other parts of the forest, with most retaining nearly full leaf cover.

Discussion

The effects of salt-water intrusion into the swamp forest along the banks of the Mzingazi River were made conspicuous by the dead trees and wetland plants. Tree mortality from water inundation along the Zululand coast has been described previously by Weisser and Ward (1982) who recorded forest destruction caused by man-induced salt-water inundation in the Richards Bay sanctuary area. The present paper documents the impacts of saline water resulting from a natural phenomena, drought, which was accentuated by man's abstraction of water from Lake Mzingazi.

Salt-water intrusion from the Mzingazi River had evidently started to occur as outflow from the lake decreased, having intensified once freshwater stopped flowing out of Lake Mzingazi on 02/02/92. This took place in three different ways:

- Near sea water ($>30^{o}/_{oo}$) flooded large portions of the study area during equinox tides. Under normal flow conditions water flooding the area, from the Mzingazi Canal, on rising tides would have been diluted by the outflowing freshwater resulting in only slightly brackish conditions, probably $<5^{o}/_{oo}$, being present in the river adjacent to the swamp forest.
- There was regular but less extensive flooding of the study area by saline water on every spring tide.
- As the groundwater level dropped below that reached by the river over high spring tides it was supplemented to an ever-increasing degree by saline water from the river.

The plant community survey of the study area showed that the plants had been affected negatively through flooding by saline water and by salt penetration into the groundwater. The low pH values recorded in the groundwater resulted from the conversion of hydrogen sulphide, derived from the anaerobic decay of plant protein, which produced sulphuric acid when the peat-like soils dried out under the drought conditions. This is a natural phenomenon; however, the combination of low pH with saline water intrusion into the groundwater was lethal to many plants. The death of plants was due to sulphate reduction by bacteria (Green, 1968) during the anaerobic breakdown of plant proteins in the accumulation of swamp forest peat. This natural event has been observed in several coastal swamp forests (personal observation). The H^+ accumulation was probably augmented by salt-water intrusion as the Na^+ replaced H^+ (Hesse, 1971).

The combination of high evaporation rates during late summer with poor drainage of the area would cause a build-up of salt in the groundwater and with time further increase the area affected by salt-water intrusion. The adjacent plant communities would continue to be affected as long as highly salt-laden water was able to penetrate up the Mzingazi River. This could have further implications due to the presence of a number of exotic plant species in the area. If no remedial action were to be taken these invaders could take over, with the Brazilian Pepper *Schinus terrebrinthifolia* possibly forming pure stands of closed thicket while the syringa *Melia azedarach* may replace *F. trichopoda* as a bank liner. In addition regions of the swamp forest may become dominated by the indigenous *B. racemosa* whose seedlings can grow in saline waters of up to 25‰ (personal observation).

A further factor to be considered is that Van Tonder et al. (1986) have stated that, based on tidal heights, once the lake level drops to 1.53 m (=1.5 m a.m.s.l.) below its outflow level, which is situated at 3.03 m a.m.s.l., then saline groundwater will start to intrude towards Lake Mzingazi itself. During May 1992 when the present study was undertaken the lake level was 0.41 m below outflow level (2.62 m a.m.s.l.), but it had dropped to below the 1.53 m mark by the end of April 1993. It then remained below this "critical" level for 23 months reaching its lowest level, 2.195 m below overflow (0.835 m a.m.s.l.) on 17/02/95. Unseasonal late autumn/winter rains brought the level to above the critical 1.53 m below, by mid-April and by the end of November the lake was full and over-topping the outflow and was still doing so on 20 August 1996.

Van Tonder et al. (1986) estimated that should the lake level remain below 1.5 m a.m.s.l., it would take approximately 25 months before saline water enters the lake. It is not known to what extent saline water penetrated towards the lake during the period described above as no data were collected. However, should salt water enter the lake at any time it could have far-reaching implications not only ecologically but also for the expanding town of Richards Bay which utilises the lake as a potable water source.

Recommendations and actions

In order to prevent further saline intrusion taking place in the study area and to remove or dilute the salt from the groundwater, the following recommendations were made to the Borough of Richards Bay upon completion of this study:

- Salt water be excluded from entering the Mzingazi River by means of the construction of a salt-water barrier. The barrier should be placed across the river in the vicinity of the Empangeni/Richards Bay road bridge. The design should make it possible to "flush" out the Mzingazi River water at times, this could be by means of a controlled outlet pipe being placed at the lowest point of the barrier.
- Should a salt-water barrier be constructed, it is both desirable and important that some form of fishway be provided, both at the barrier and at the outflow weir on Lake Mzingazi to allow migration of fish and invertebrates between the lake and the marine environment when the former starts to overflow again. Preliminary results from recent work on the nearby Lake Nhlabane (personal observation) have indicated that the diversity and biomass of the lake fauna, particularly the crustaceans and fish, have been adversely affected by the weir built on that system. The weir constructed at the outlet of Lake Mzingazi has already had a major impact on the fauna of the lake (personal observation) and it is desirable that this should be investigated before the environmental integrity of the lake is placed at risk.
- Once a salt-water barrier has been constructed an investigation should be conducted into the feasibility of diverting some water from Lake Mzingazi into the swamp forest and herbaceous swamp on either side of the Mzingazi River. This water would permeate the water table and serve to gradually dilute the salts deposited by the saline water and return them into the Mzingazi River from which they could be flushed.
- Consideration should be given to decreasing the residence time of salt water which floods into the swamp forest by digging drainage ditches leading into the Mzingazi River. Any ditches dug should be closed and the area rehabilitated once the situation returns to normal.
- The number of auger boreholes used in the current study should be increased and the progression of the salt intrusion in the area monitored through this extended system of boreholes. The levels of salt in the groundwater should be measured on a regular basis to give prior warning of possible saline intrusion into Lake Mzingazi itself. As an important prerequisite to monitoring the possible progression of salt-water intrusion, it is imperative that the difference in height, based on mean sea level, between the lake outflow and that reached during spring high tides and equinox high tides in the Mzingazi River be established. The monitoring programme should be continued once the salt-water barrier is in place in order to determine the effectiveness of the desalination of the ground water.
- Due to the possibility of saline water intruding into the lake itself, hydrological studies of the area should be initiated to obtain a more accurate indication of the likelihood of such an event occurring.

The reaction of the Borough of Richards Bay to these recommendations was to construct an earth-walled salt-water barrier at the recommended position on the Mzingazi River. However, this only incorporated a few outflow pipes near the top of the wall aimed at preventing overtopping and thus erosion of the barrier. No pipes were installed lower down in the wall to allow for flushing of the upstream waters. Furthermore no monitoring studies were initiated and the area was left with the section of the Mzingazi River above the road bridge (Fig. 1) being inundated due to the presence of the barrier. Additional hydrological studies of the area were, however, commissioned and this work is still under way. The drought continued until April 1995 when unseasonal rains resulted in the lake filling to capacity by the end of November 1995.

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