DOCUMENT NO. 653

ST LUCIA DOCUMENT COLLECTION

Author HUTCHISON I P G

Title THE HYDROLOGY OF THE ST LUCIA SYSTEM

Source

Source 1976 PROC. ST LUCIA SCIENTIFIC ADVISORY COUNCIL WORKSHOP:CHARTER'S CREEK: FEB. 1976

Keywords

Keywords HYDROLOGY,LAKE*CATCHMENTS*WATER=LEVELS*SALINITIES*

653

THE HYDROLOGY OF THE ST.LUCIA SYSTEM

I.P.G. Hutchison
University of the Witwatersrand

THE HYDROLOGY OF THE ST. LUCIA SYSTEM

I.P.G. Hutchison
B.Sc.(Eng.)(UCT), G.D.E.(Rand)
Research Fellow, Hydrological Research Unit,
University of the Witwatersrand, Johannesburg

ABSTRACT

On an average annual basis the water budget of Lake St. Lucia is: river inflow 300 x $10^6 m^3$, and direct rainfall 270 x $10^6 m^3$; net outflow by estuary to the sea 170 x $10^6 m^3$ and 400 x $10^6 m^3$ by evaporation. Whereas the evaporation is continuous the rainfall and riverflow are intermittent and so the salinity regime is adversely affected; on the average 70 x $10^6 m^3$ of sea water enters the lake annually. As more and more riverflow is diverted for use in the catchments commanded by the lake the salinity position is increasingly aggravated. It has been shown by numerical simulations of the system that deterioration can be ascribed almost exclusively to diminution of fresh water inflows through agricultural and forestry developments in the catchments. Dredging of the estuary has lowered the mean level of the lake and narrowed the extreme fluctuations, but has had little effect on the salinity regime.

THE HYDROLOGY OF THE ST. LUCIA SYSTEM

INTRODUCTION

The aim of the paper is to present to the reader a general picture of the water and salt circulation patterns in the Lake St. Lucia system as they are today and as they have been over the past half century. The results presented have been abstracted from a series of publications[1→6] in which the outcome of research carried out in the Hydrological Research Unit of the University of the Witwatersrand was reported to its sponsors, namely the Department of Building Services of the Natal Provincial Administration.

Briefly, Lake St. Lucia is a large shallow body of water, 300 km^2 in area averaging one metre in depth, situated on the coastal plain of Zululand (see Figure 1). Fresh water enters the lake by direct rainfall and by inflow of the rivers Mkuze, Mzinene, Hluhluwe, Nyalazi and Mpate, and seepage from the lake's eastern shore, and leaves by way of evaporation and at times through the estuary to the sea. The estuary is a long, relatively narrow and shallow channel (20 km by 100 m to 500 m by an average of 1 m deep) (see Figure 2).

Fresh water deficits, i.e. excess of evaporation over direct rainfall and river inflow, are compensated for by entry of sea water through the estuary. The lake experiences alternating periods of fresh water deficit (during which salt is brought into the system from the sea) and fresh water surplus (when some of the salt is flushed out to sea). Lake salinity therefore varies in response to these fluctuations of the hydrological cycle. Fluctuations of water level are less violent than those of salinity and depend primarily on the geometry of the estuary which in turn controls the rate at which sea water can enter or lake water can escape the system.

Because of the stochastic nature of the fluctuations, the behaviour of the system must be studied over a period of about 50 years so

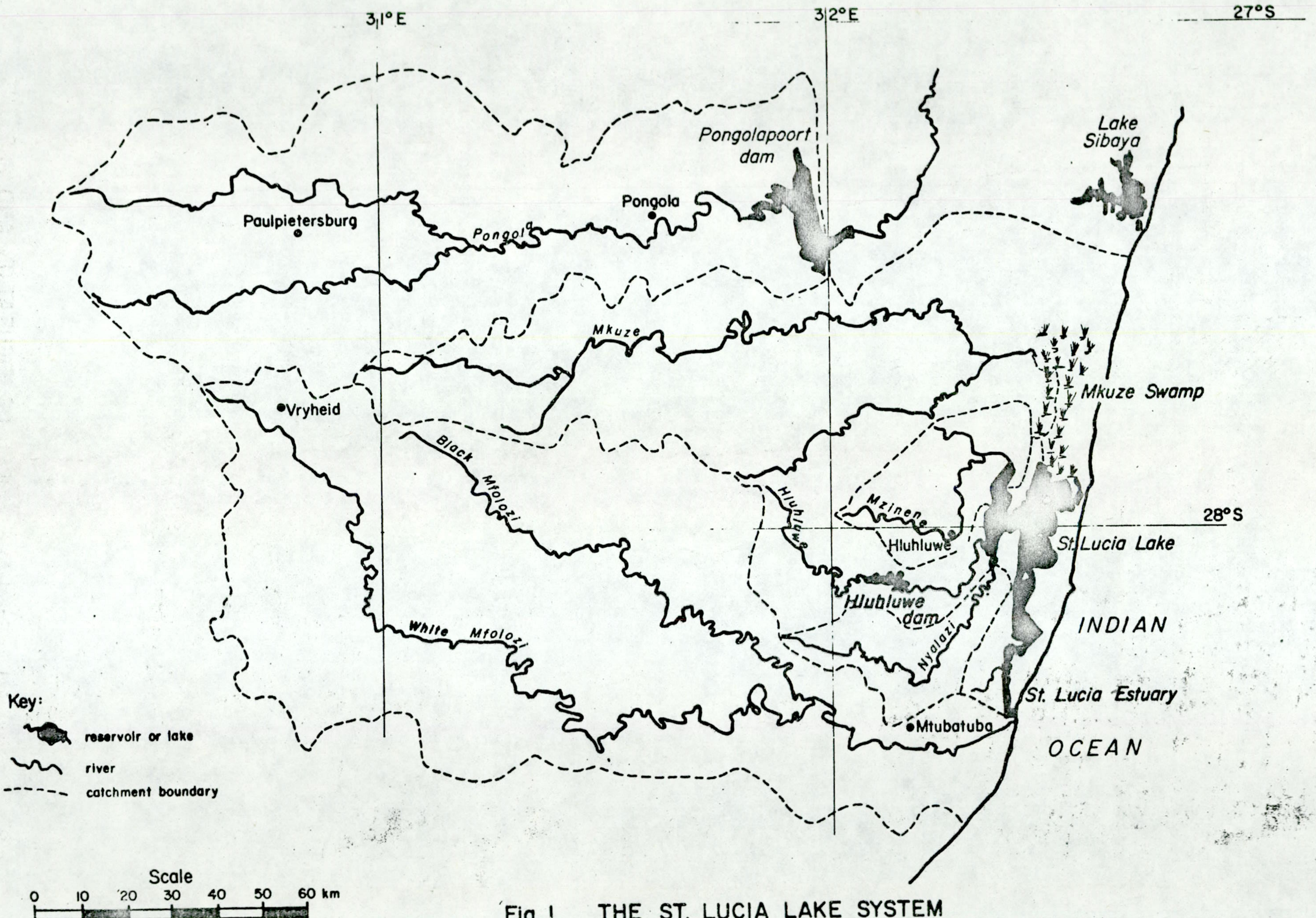

Fig. I THE ST. LUCIA LAKE SYSTEM

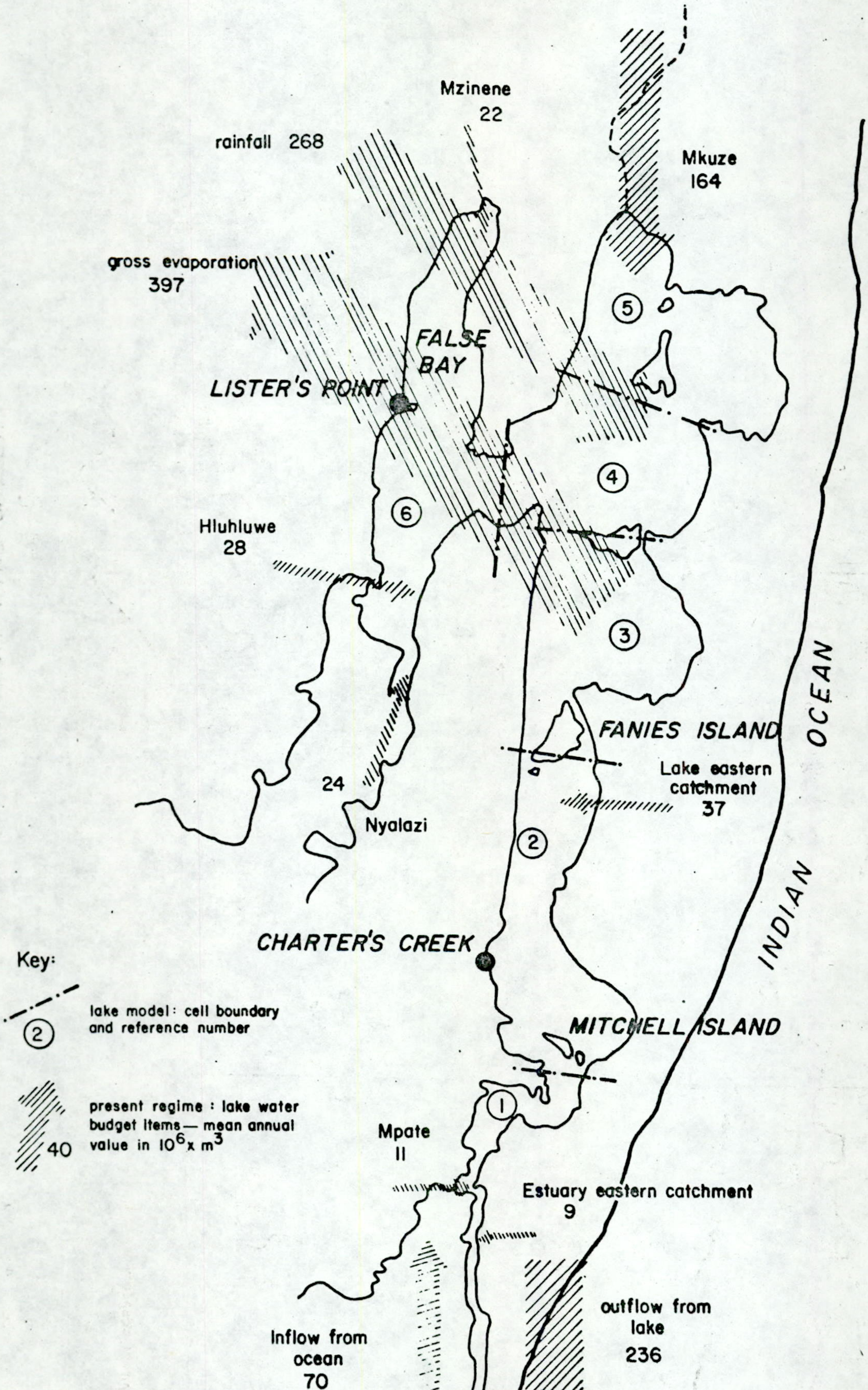

Fig. 2 ST. LUCIA LAKE: LAKE MODEL CONFIGURATION AND PRESENT WATER BUDGET

as to ensure that the effects of a representative series of droughts and floods can be examined. As field observations of some of the parameters covering the long period were lacking it was necessary to develop a series of interconnected models to simulate streamflow, tidal flows in the estuary and water and salt regimes in the lake. These models were calibrated over the relatively short periods for which concurrent observations were available and were then used to simulate a half-century of lake behaviour. Any changes to the system, such as increasing upstream irrigation abstractions or implementation of measures to improve the salinity regime, could then also be simulated.

CATCHMENT RUNOFF

The flows of rivers feeding the lake have been measured only for relatively short periods and at few stations, located generally some distance from the edge of the lake. A monthly rainfall: runoff model developed at the HRU was used to generate 54 years of runoff (1918 - 1971) into the lake. Abstractions and losses of water in the catchment through irrigation, afforestation and damming were accounted for in this model. As the Mkuze is intercepted by a vast swamp at the head of the lake, a separate model, admittedly a fairly simple one, had to be set up and calibrated for routing the flow through the Mkuze swamp into the lake. Details of the foregoing work are reported in reference 1 and the results are summarized in Table 1.

Given at the foot of Table 1 are the runoffs also of the Pongola and Mfolozi as these rivers may have a role to play in the measures to improve conditions at St. Lucia. "Virgin conditions" are assumed to be those that existed in the early 1900s before man's activities became significant. "Present conditions" would be those of the late 1960s, early 1970s.

Evidently the influence of irrigation and afforestation has been to reduce the mean annual runoff to the lake by roughly 20% to 295 x $10^6 m^3$. The estimate is admittedly somewhat crude because of the paucity of data.

Table 1 : Mean annual runoff to the St. Lucia system ($10^6 m^3$)

Catchment	Virgin condition	Present condition	Losses		
			Total	Irrigation (incl. dams)	Afforestation
Mkuze (into lake)	194	164	30	30	-
Mzinene	24	22	2	2	-
Hluhluwe	49	28	21	21	-
Nyalazi	32	24	8	2	6
Mpate	16	11	5	-	5
Estuary eastern catchment	11	9	2	-	2
Lake eastern catchment	38	37	1	-	1
Total into lake/estuary system	364	295	69	55	14
Mfolozi (at mouth)	746	729	17	17	-
Pongola (at Pongolapoort dam)	1070	1070	-	-	-

Averages can be rather misleading unless supported by indications of the distribution. Statistical analyses indicate that, of the 54 years of runoff generated, 39 years (i.e. 72% of the total time) had annual totals below the mean of $295 \times 10^6 m^3$. Drought sequence analyses[6] reveal the following :-

(i) During 20 years out of 100, on the average, the total inflow to the lake over a <u>two</u>-year period will drop to $220 \times 10^6 m^3$ (i.e. $110 \times 10^6 m^3$/year)

(ii) Once in half a century, the total inflow to the lake over a <u>two</u>-year period will be as low as $60 \times 10^6 m^3$ (i.e. $30 \times 10^6 m^3$/year) and over a <u>five</u>-year period $320 \times 10^6 m^3$ (i.e. $64 \times 10^6 m^3$/year)

Thus, although normally annual inflow of river water is approximately equivalent to the mean lake volume, it falls to but a fraction of the volume during drought.

RAINFALL AND EVAPORATION

The mean annual precipitation on the lake is 890 mm, varying from 1200 mm at the estuary mouth (or St. Lucia township) to approximately 625 mm at Lister's Point (on the north-western lake shore).

Mean annual gross evaporation for the lake as a whole is 1325 mm, varying from 1250 mm along the south-eastern shores to 1430 mm along the western shores of False Bay. Evaporation values are based on Symons pan observations and a pan factor of 0,9, adopted on the basis of lake model calibrations. Mean annual net evaporation varies from a minimum of practically zero at the south-eastern extremity of the lake to about 800 mm along the western shore of False Bay.

Combination of evaporation and rainfall values with average water surface areas of the lake yields mean values of gross evaporation loss as $397 \times 10^6 m^3$ and of rainfall contribution as $268 \times 10^6 m^3$.

LAKE AND ESTUARY MODELLING

Models have been developed for simulating water and salt circulations in the lake. The estuary model simulates one-dimensional tidal flow and salinity dispersion between the ocean and the southern end of the lake at Mitchell Island (see Figure 2). The model was calibrated by comparison of calculated with measured water levels, discharges and salinities. By averaging the simulated discharge over a tidal cycle it is possible to calculate the net exchange of water between the lake and the sea for specified lake level, estuary and estuary mouth geometry and mean sea level. These results provide the boundary conditions for the lake model, discussion of which follows.

The lake model envisages the lake as comprising six cells as depicted in Figure 2. Since friction losses in the lake are negligible[4] it may safely be assumed that water levels are always equal in all cells. Water and salt are transferred monthly in the model from one cell to another in response to monthly inputs of riverflow and outputs of net evaporation (i.e. gross evaporation minus rainfall) and in response to the monthly volume of sea water entering or leaving via cell 1.

This model was calibrated by comparison of calculated with measured lake levels and cell salinities. Figure 3 shows the degree of agreement achieved.

PRESENT AND PAST LAKE REGIMES

Before discussion of the model simulations that will reflect the lake regimes, two important points need emphasis :

(a) as the aim of the modelling was to study water level and the salinity regimes it was necessary to select for simulation a stationary situation, that is, the hydrological input should not exhibit a trend and there should be no change with time in the geometry of the lake or estuary

(b) although one way of depicting the regime of lake level and salinities would be simply to plot simulated lake levels and salinities on a time basis over a long period, the result would be extremely cumbersome and quantitative information would not be readily discernible. Accordingly the following statistical parameters were evaluated from the simulation traces:

  (i) means, minima, maxima and standard deviations

  (ii) duration curves; in effect, compression of a simulated trace into a single curve relating water level or salinity to percentage time that the variable was equalled or exceeded.

With the generated hydrologies for virgin and developed conditions of the catchment as input, model simulations were performed both for the undredged estuary (as surveyed in 1961) and the present geometry (as surveyed in 1971). For all simulations the estuary mouth was assumed to be continuously open and in good condition. In Table 2 the state of the system for each run is indicated as well as the results of the simulations. Figure 4 illustrates the duration curves associated with these runs.

The simulated virgin lake levels and salinities (i.e. undredged estuary and virgin runoff) and those associated with the present conditions (present estuary and runoff) are plotted in Figure 5.

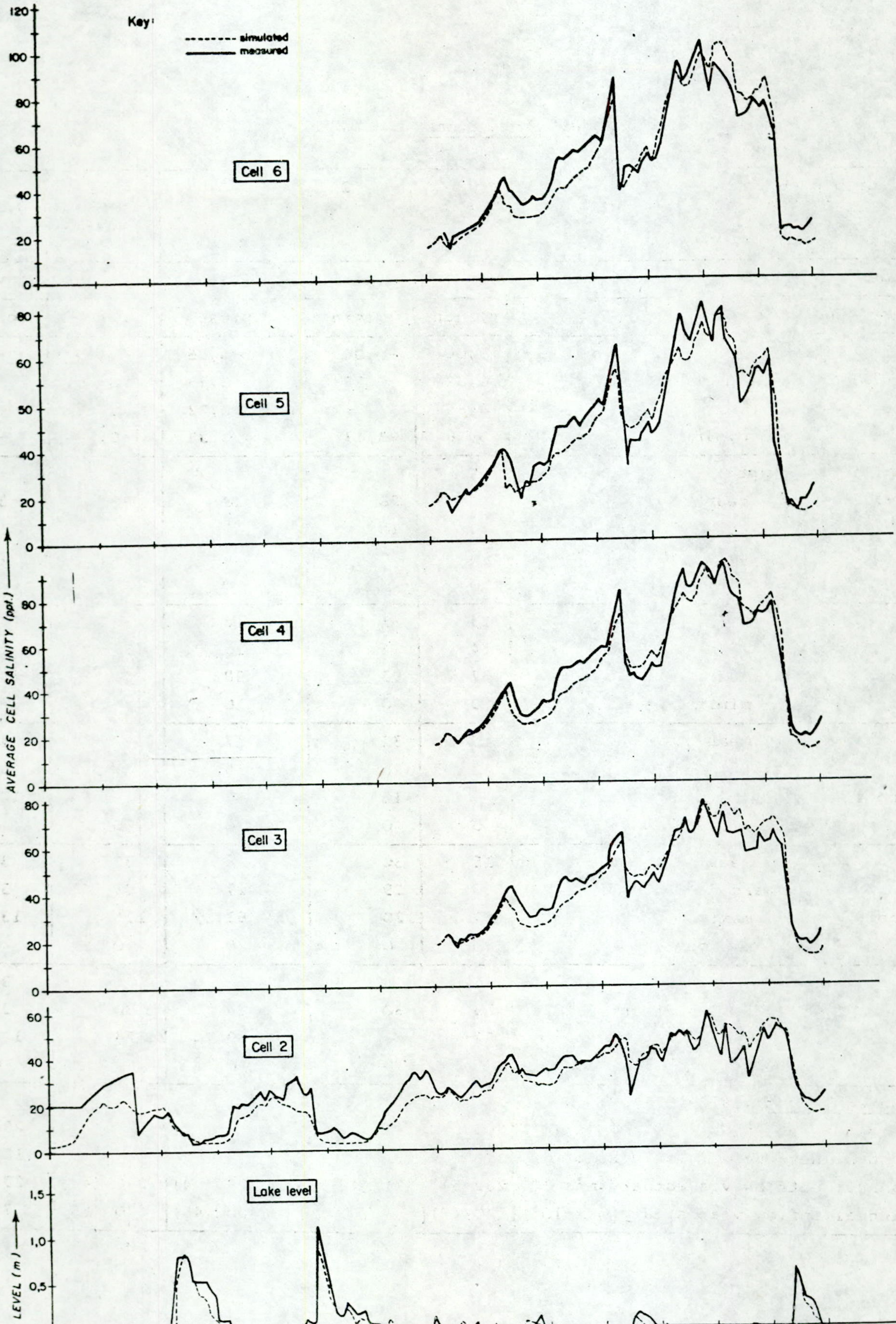

Fig. 3 LAKE ST. LUCIA: COMPARISON OF SIMULATED WITH MEASURED WATER LEVELS AND SALINITIES

Table 2 : Results of lake model simulations

Simulation number and description		1 virgin regime	2	3	4 present regime	5 0,1 m silt
catchment condition		virgin	developed	virgin	developed	developed
estuary condition		virgin	virgin	present	present	present
lake level (m)	mean	0,00	-0,06	-0,06	-0,09	-0,09
(1922-71)	standard deviation	0,32	0,32	0,28	0,28	0,28
	July 1963	0,86	0,78	0,72	0,66	0,66
	minimum	-0,38	-0,43	-0,33	-0,35	-0,35
cell salinity - ppt						
(1922-71)	mean	18	28	19	28	30
	standard deviation	12	15	13	16	17
cell no.2	maximum	45	70	46	68	71
	minimum	O	O	O	O	O
	mean	16	31	18	32	34
	standard deviation	14	24	15	24	26
cell no.3	maximum	57	93	58	95	104
	minimum	O	O	O	O	O
	mean	15	32	17	33	35
	standard deviation	15	28	16	28	31
cell no.4	maximum	64	115	66	110	123
	minimum	O	O	O	O	O
	mean	15	32	16	33	35
	standard deviation	15	29	17	29	32
cell no.5	maximum	67	120	69	115	130
	minimum	O	O	O	O	O
	mean	15	34	16	35	37
	standard deviation	15	30	16	30	34
cell no.6	maximum	67	129	69	124	140
	minimum	O	O	O	O	O
lake water budget (1918-1971)						
total mean annual river inflow ($m^3 \times 10^6$)		364	295	364	295	295
mean annual net evaporation ($m^3 \times 10^6$)		135	132	130	129	129
mean annual outflow via estuary ($m^3 \times 10^6$)		269 (55)*	221 (43)	284 (54)	236 (44)	236 (44)
mean annual inflow via estuary ($m^3 \times 10^6$)		40 (45)	59 (57)	50 (46)	70 (56)	70 (56)

* The figures in brackets are percentages of time inflow or outflow occurs

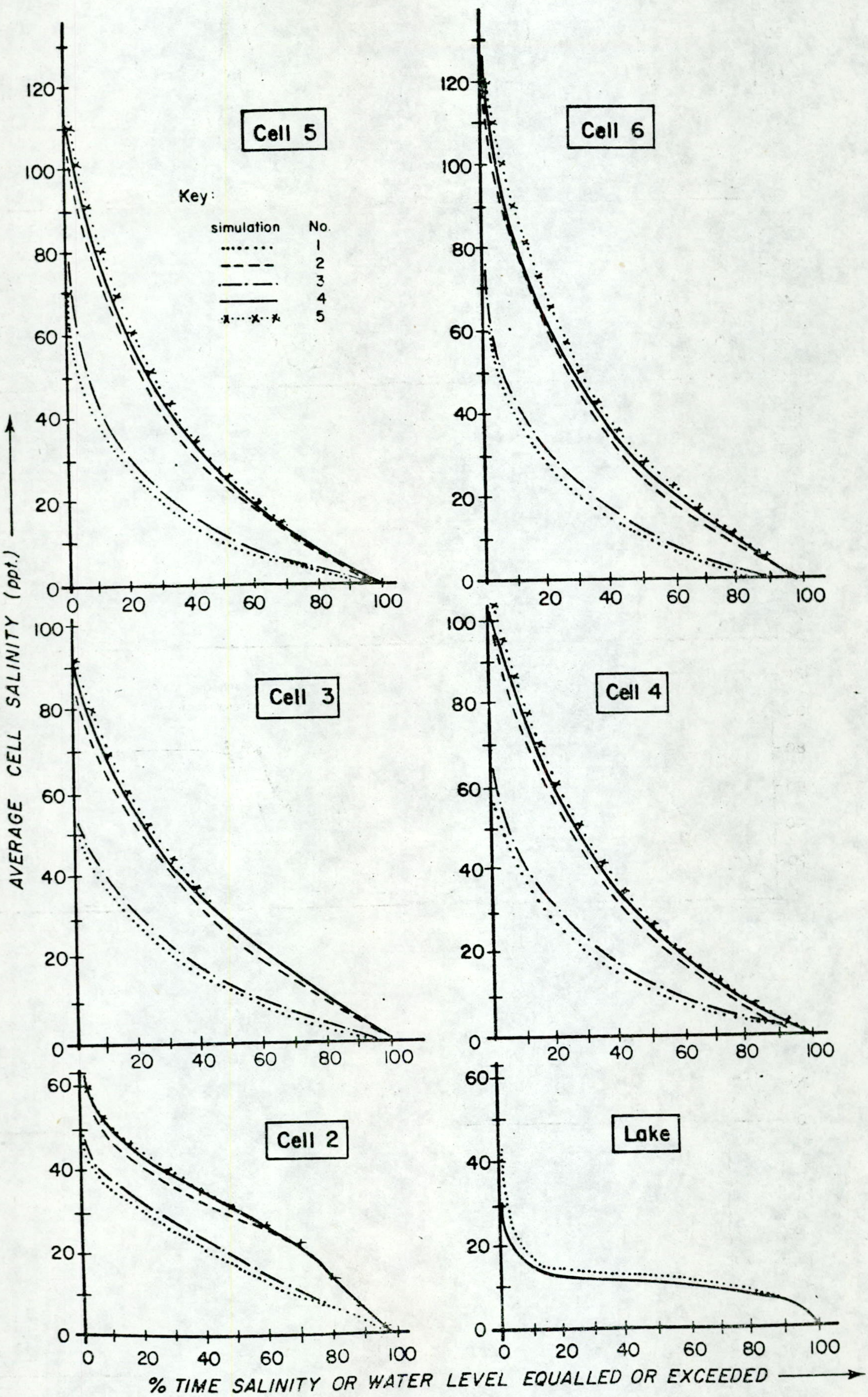

Fig. 4 SIMULATED SALINITY & WATER LEVEL DURATION CURVES

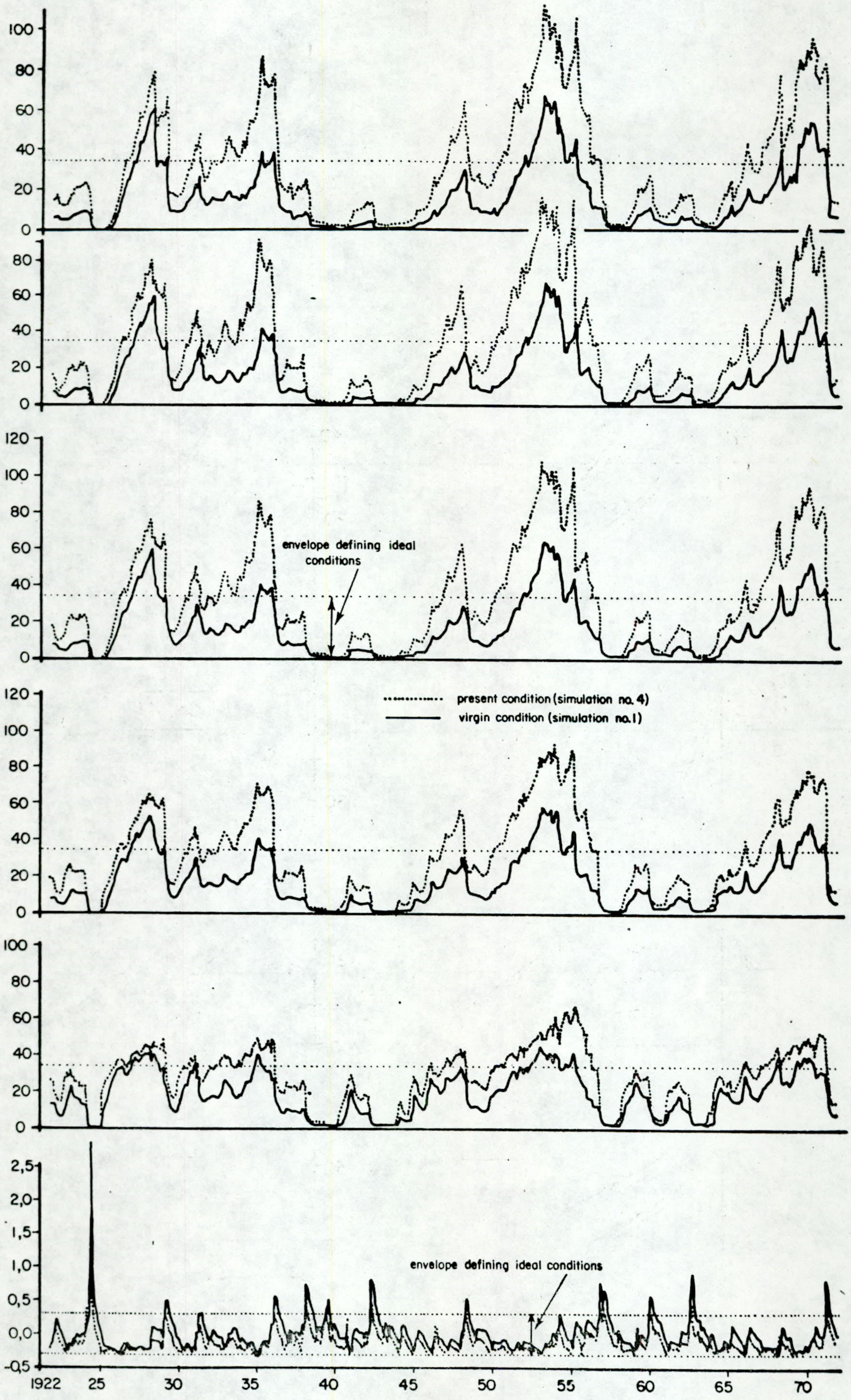

Fig. 5. SIMULATED LAKE LEVELS AND SALINITIES FOR VIRGIN AND PRESENT CONDITIONS

Prior to 1952, it will be recalled, the Mfolozi and the estuary had a common mouth but to simulate accurately the effect of entry of Mfolozi water to the lake under these conditions would require complex two-dimensional tidal modelling of the estuary mouth area. This was beyond the scope of the project. Nevertheless, the one-dimensional simulations performed indicated that provided a combined mouth was continuously open its effect on lake salinity was small.

On the question of silting, indications are that the present annual silt accumulation in the swamp and lake system is roughly $2 \times 10^6 m^3$. Determination of the age of lake bed deposits indicates that the rate of sediment accumulation over the last 15 000 years has been between 2 and 5 mm per year. To discern the effects of sedimentation in the lake, it will be noticed in Table 2 and Figure 4 that an additional model simulation was performed (run No. 5); it was assumed that during the 50-year period 0,10 m of silt had been deposited evenly over the entire lake bottom.

CONCLUSIONS

From scrutiny of Table 2 and the curves in Figure 4 the following important conclusions may be drawn :-

Generally: The water level regime of the lake is controlled primarily by the geometry of the estuary channel. The greater the capacity of the channel the lower the mean level of the lake and the smaller the standard deviation; extremes of low and high are narrowed. The salinity regime is mainly dependent on the fresh water supply to the system and is therefore little affected by the estuary channel geometry.

Specifically:

(1) There occurred in the virgin system extended periods during which lake salinity exceeded 35 ppt. Figure 4 shows that cell 6 (False Bay) experienced salinities exceeding 35 ppt for roughly 12% of the time while the monthly maximum in the 50-year period was 67 ppt.

(2) The sole significant cause of the present occurrences of extreme salinity conditions is the reduction of runoff to

the lake, ascribable to developments, such as irrigation, afforestation and dam construction. The percentage time salinity exceeds 35 ppt in cell 6 rose to 40% and the 50-year maximum value to 124 ppt.

(3) The effect of dredging the estuary on the salinity regime is minimal. Increasing the cross-section of the estuary by dredging tends to raise the average salinity slightly and to narrow the extremes.

(4) The present long-term average lake level is -0,09 m ECD (Estuary chart datum), i.e. 0,17 m above the mean sea level of -0,26 m.

(5) A 0,1 m sediment accumulation on the lake bottom will tend to increase average salinities by about 2 ppt, but the 50-year monthly maximum increases by 16 ppt in the northern lake reaches.

CITED REFERENCES

1. HUTCHISON, I.P.G., PITMAN, W.V. Climatology and hydrology of the St. Lucia lake system. St. Lucia lake research report, Vol. 1, Natal Provincial Administration, Hydrological Research Unit, 1973.

2. HUTCHISON, I.P.G. St. Lucia lake and estuary - hydrographic data. St. Lucia lake research report, Vol. 2, Natal Provincial Administration, Hydrological Research Unit, 1974

3. HUTCHISON, I.P.G. Mathematical models for simulating one-dimensional tidal propagation and dispersion in the St.Lucia estuary. St. Lucia lake research report, Vol. 3, Natal Provincial Administration, Hydrological Research Unit, 1974.

(4) HUTCHISON, I.P.G. Mathematical models for simulating monthly water levels and salinities in Lake St. Lucia. St. Lucia lake research report, Vol. 4, Natal Provincial Administration, Hydrological Research Unit, 1975.

(5) WEISS, H.W., HUTCHISON, I.P.G., MIDGLEY, D.C. The proposed Mfolozi river/St. Lucia estuary link. Report to Natal Provincial Administration, Dept. of Civil Engineering, University of the Witwatersrand, Oct. 1975.

(6) HUTCHISON, I.P.G. St. Lucia lake - development of mathematical models and evaluation of ameliorative measures. St. Lucia lake research report, Vol. 5 (final), Natal Provincial Administration, Hydrological Research Unit, 1976.