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671

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POSSIBLE REMEDIAL MEASURES

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ABSTRACT

With the aid of a simulation model the effects of various proposals to improve conditions at Lake St. Lucia were tested against a set of criteria associated with a supposedly "ideal" state of health or the simulated "virgin" state.

Significant improvements are shown to be achievable by diverting fresh water from the Mfolozi or Pongola river, or by drastically altering the geometry of the lake, or by interfering with the Mkuze swamp (possibly destroying the ecosystem in the process).

The suggestion is that the next step is to determine the costs of the more promising ameliorative measures and to compare costs with improvements achievable. Decision should be taken on implementation only after thorough examination of the environmental impact of the least-cost measures.

A plea is made for the establishment of a dynamic lake management programme to meet the conflicts that are bound to arise as developmental pressures increase.

INTRODUCTION

About five years ago Professor D.C. Midgley was invited to serve on the St. Lucia Scientific Advisory Council and asked to assist with studies aimed at improving the lake regime. He recommended that the system be mathematically modelled and offered to have the modelling undertaken in the Hydrological Research Unit under his direction provided that the required field work - surveys and data-collection - be undertaken by other agencies. The offer was taken up by the Natal Provincial Administration and the author was charged with the task of building the model. The system to be modelled is depicted in Figure 1.

Because of difficulties in retaining suitable staff and in concluding satisfactory contracts or commissions for the execution of the field work, there were delays in acquiring sufficient information for calibrating the models. Nevertheless, the models have been set up and calibrated to a degree sufficient to permit comparative assessments to be made of various possible measures aimed at improving the lake regime. The results are reported in full in the HRU St. Lucia research report series, the final volume of which is No. 5[1] now in press.

This paper summarizes the results of the final report in regard to appraisal of alternative remedial measures. The aim is not to offer a least-cost engineering design but merely to illustrate the probable physical interactions with the system of the various possible measures. A final design can be attempted only after the economic, ecologic, social and institutional aspects have been probed.

Evaluation or appraisal was accomplished by simulating the effects of the various measures on water levels and salinities within the modelled lake system. All simulations were performed for the period 1918 to 1971, this being the coverage of the majority of rainfall records, which formed the basis of the hydrological models.

It is convenient at the outset to define a basis for appraisal in the form of a set of criteria for what might be termed a "healthy state" for the lake.

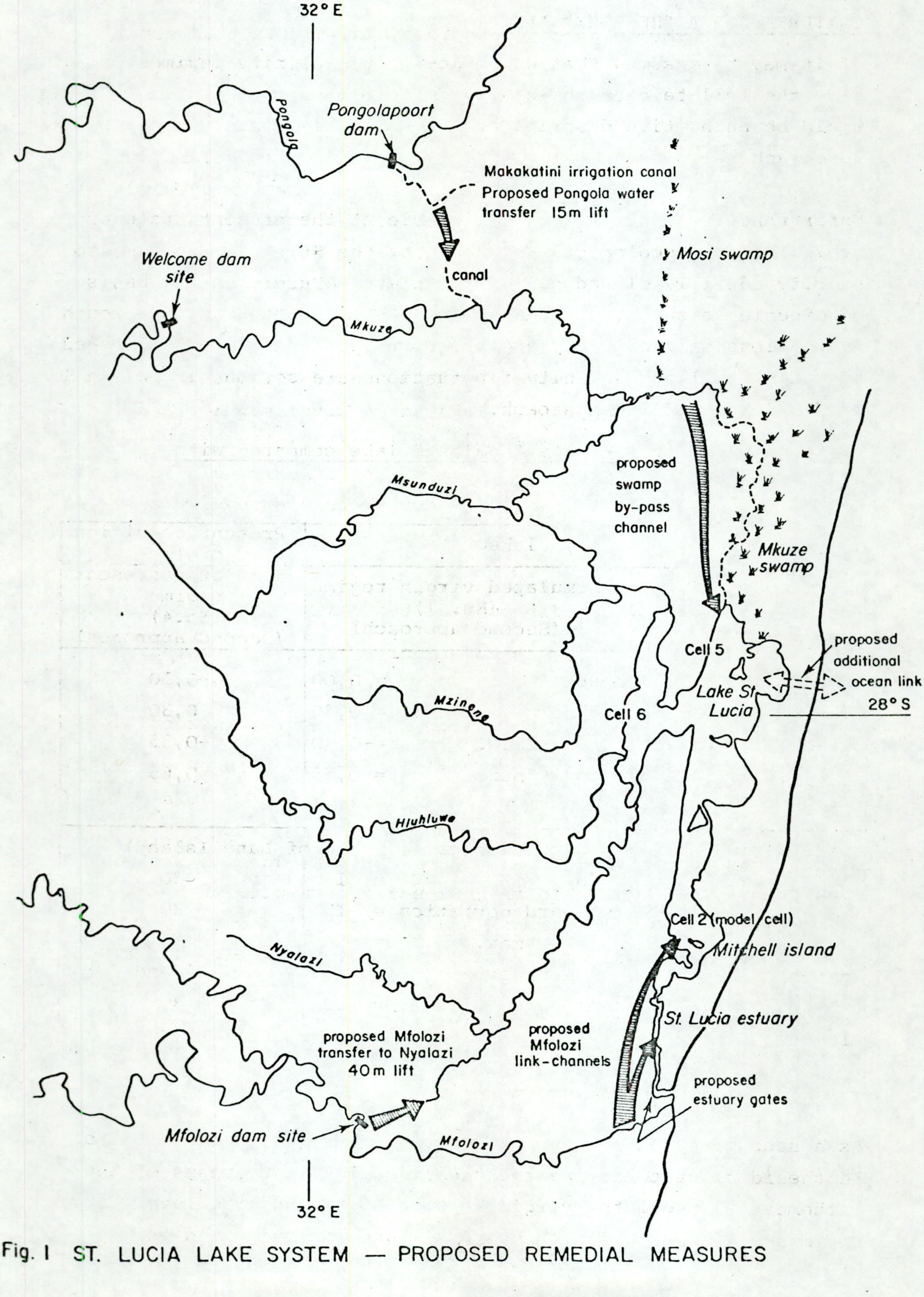

Fig. I ST. LUCIA LAKE SYSTEM — PROPOSED REMEDIAL MEASURES

CRITERIA FOR A "HEALTHY" LAKE

If it may be assumed that water level and salinity regimes provide the tell-tale of the state of the ecosystem suitable criteria would be quantitive descriptions of allowable fluctuations in lake level and salinity.

Unfortunately it has not been possible at the present state of biological and ecological knowledge of the St. Lucia system, to specify ideal level and salinity regimes. Purely on the basis of experience and intuition, biologists have set down some rough indications of the ideal, and the corresponding allowable ranges of water level and salinity fluctuations are set out in column 1 of Table 1 - first approach.

Table 1 : Criteria for a "healthy" lake compared with present conditions

"Healthy" lake		Present condition of lake
Defined ideal conditions (First approach)	Simulated virgin regime (No. 1) (Second approach)	Simulated present regime (No.4) (Second approach)
Lake level (m): Not less than -0,3 m and not greater than 0,3 for any appreciable length of time	mean = 0,00	-0,10
	standard deviation = 0,30	0,30
	50-year min. =-0,40	-0,35
	max. = 0,85	0,65
Lake salinity (ppt): Generally not higher than 35 ppt throughout the lake and not higher than 40 ppt for any appreciable length of time	Southern lake (south of Lane Island)	
	mean = 15	30
	standard deviation = 15	20
	50-year max. = 50	80
	Northern lake (north of Lane Island)	
	mean = 15	35
	standard deviation = 15	30
	50-year max. = 65	115

As a second approach, one might assume the virgin condition to be the ideal or to define the "healthy" lake. By means of the mathematical model the virgin lake salinity and lake level regimes can be established by simulation, as explained in reference 1, viz. virgin hydrology, undredged (1961) estuary geometry, mouth continuously open and in good condition, and effect of combined Mfolozi/estuary mouth negligible.

Quantification of this approach yields different criteria for the northern and southern sectors of the lake. See column 2 of Table 1 (second approach). The results of the model simulation of present conditions according to the second approach criteria are shown in the third column of Table 1.

Of course, it is not necessarily true that the condition or regime of the lake during the early part of the present century was ideal, or healthy. As neither approach is entirely satisfactory both sets of criteria should be employed and judgment of the merits of a particular measure under test should be based on comparisons with both sets of criteria.

AMELIORATIVE MEASURES

Possible measures to improve lake conditions are categorized as:

(i) those involving manipulation of fresh water supplies to the lake

(ii) those involving the supply of sea water to the lake and

(iii) those affecting possible changes to the geometry of the lake.

In Table 2 some of the most feasible ameliorative measures are listed and described with the results of tests in respect of the Charter's Creek cell (No. 2), the Mkuze mouth cell (No. 5) and the False Bay cell (No. 6). Descriptions of the ameliorative measures are supplemented by the information given in Figure 1. For the sake of clarity in presentation the results for other cells have been omitted. Figure 2 illustrates the corresponding salinity duration curves, again for cells 2, 5 and 6. Detailed results of the simulations performed appear in reference 1.

The ameliorative measures are set out in Table 2 and discussed hereafter.

TABLE 2 : REMEDIAL MEASURES - SIMULATION RESULTS

Remedial category	Do nothing	Fresh water									Sea water			Lake geometry	"Healthy" lake	
		Regulation of Mkuze flow	Increase of present yield			Importation of water										
Simulation description and run number		By reservoir at Welcome draft = 7 x $10^6 m^3$/month	Mkuze swamp area reduced by 50%	Mkuze swamp area reduced by 100%	Swamp by-pass channel capacity = 10 m^3/s	10 x $10^6 m^3$/month from Pongola into Mkuze swamp	Transferred from Mfolozi via link channel: Into estuary at 8 km	Transferred from Mfolozi via link channel: Into lake at Makakatana	Transferred from Mfolozi via link channel: From dam into False Bay 10 x $10^6 m^3$/month	Gate in present estuary	Additional Selley's lakes' estuary	Pumping sea water at Selley's lakes capacity 20 m^3/s	Lake area reduced by 50%	Simulated virgin conditions	ideal conditions
	4	12	14	15	16	19	22	24	30	34	36	39	43		
Lake level (m)															
mean	-0,09	-0,09	-0,07	-0,05	-0,08	-0,04	-0,07	-0,01	-0,03	0,13	-0,18	0,00	-0,07	0,00	≯0,30
st. dev.	0,28	0,27	0,28	0,28	0,27	0,28	0,27	0,27	0,27	0,38	0,14	0,26	0,27	0,30	
max. (July 63)	0,66	0,65	0,72	0,84	0,61	0,71	0,66	0,69	0,69	1,20	0,34	0,69	0,69	-0,40	≮-0,30
min.	-0,35	-0,35	-0,34	-0,33	-0,33	-0,32	-0,33	-0,31	-0,25	-0,35	-0,28	-0,20	-0,27	0,85	
Cell salinity (ppt)															
South: cell 2 mean	28	30	23	15	24	13	15	6	9	22	32	33	18	15	
st.dev.	16	15	14	11	13	10	9	5	8	15	9	18	11	15	
max.	68	65	53	39	51	36	38	25	28	60	47	75	40	50	
min.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
North: cell 5 mean	33	34	20	10	22	8	18	9	5	25	36	33	15	15	≯40
st. dev.	29	28	19	9	18	8	15	7	5	24	16	17	14	15	
max.	115	111	83	38	75	32	64	33	19	93	69	73	53	65	
min.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
North: cell 6 mean	35	36	22	11	24	9	19	9	4	26	38	36	15	15	
st. dev.	30	28	20	11	20	9	16	8	4	25	19	20	14	15	
max.	124	119	89	43	87	35	69	35	13	95	80	81	53	65	
min.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Lake water budget															
Mean annual value ($10^6 m^3$)															
Total river inflow	295	283	332	373	308	407	295	295	415	295	295	295	295		
Net evaporation	129	129	130	130	129	131	129	133	131	146	128	130	85		
St.Lucia estuary: outflow	236(44)	222(42)*	260(51)	282(60)	233(50)	308(65)	245(40)	374(72)	303(71)	187(14)	50(12)	333(98)	253(53)		
St.Lucia estuary: inflow	70(56)	67(58)	57(49)	38(40)	54(50)	32(35)	79(60)	22(28)	19(29)	41(33)	131(88)	0(2)	42(47)		
Selley's estuary: outflow	-	-	-	-	-	-	-	-	-	-	260(84)	-	-		
Selley's estuary: inflow	-	-	-	-	-	-	-	-	-	-	11(16)	-	-		
Pumped sea water	-	-	-	-	-	-	-	-	-	-	-	168(27)	-		

* Figures in brackets indicate percentage of time flow occurs.

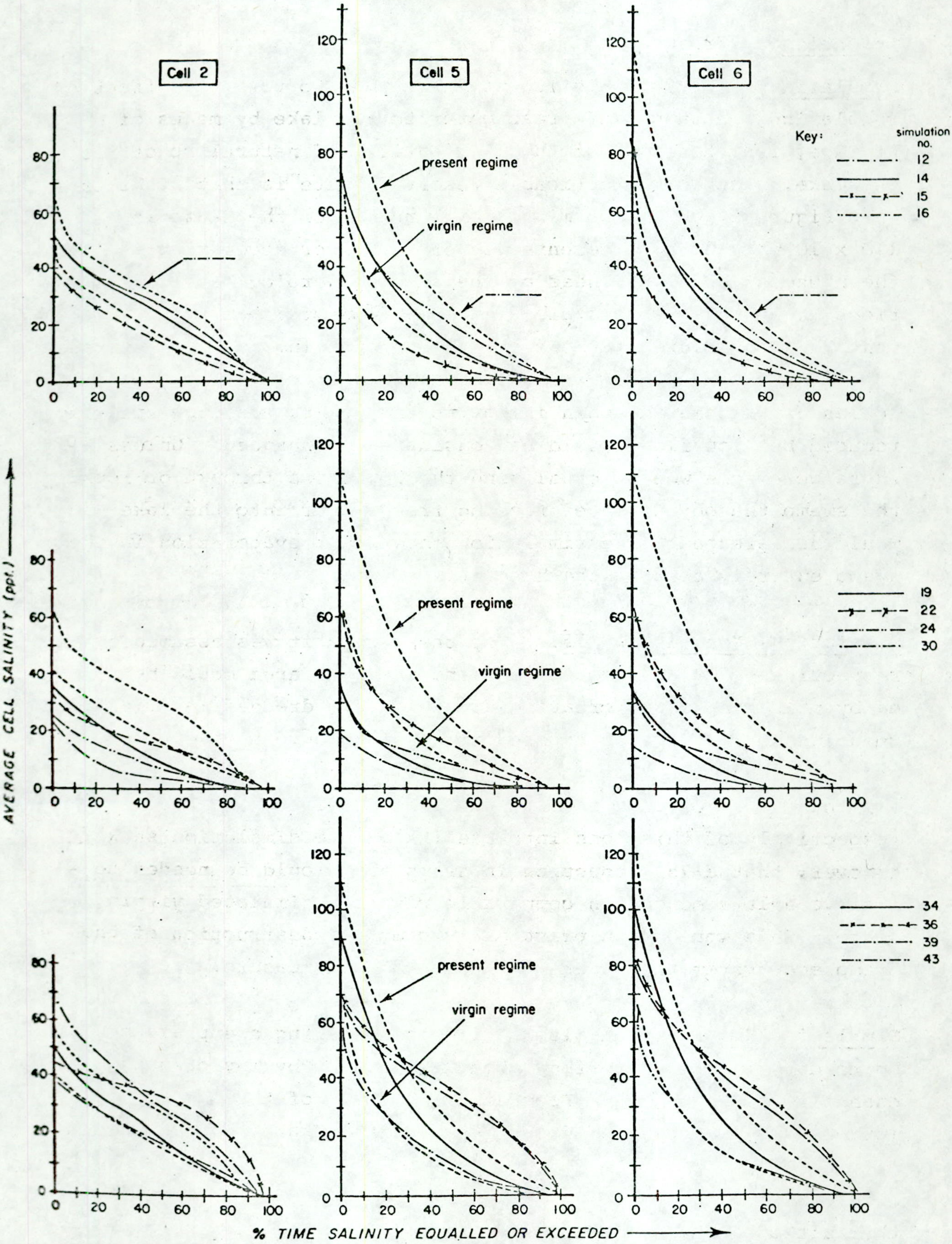

Fig. 2 SALINITY DURATION CURVES BASED ON VARIOUS SIMULATIONS

Injection of fresh water

Simulation No. 12. This run was performed to test the effect of regulating the supply of fresh water to the lake by means of storage, i.e. to even out the fluctuations of natural runoff to the lake. The only practicable reservoir site is that at Welcome (see Figure 1) where the mean annual runoff of the Mkuze is 140 x $10^6 m^3$, which represents 78% of the river's contribution to the Mkuze swamp at the head of the lake. Hydrological calculations showed that to sustain a minimum flow of 7 x $10^6 m^3$ per month, with failure not more often than once in 25 years, storage capacity of 170 x $10^6 m^3$ would be needed. Because of evaporation losses at Welcome the mean inflow to the swamps would be slightly reduced but low flows would be considerably enhanced. Unless there were some way of canalizing the low flows through or round the swamp the objective of feeding fresh water into the lake would be defeated; the simulation shows that evaporation in the swamp entirely absorbs the benefit.

Simulations Nos. 14 and 15. For these runs it was assumed that respectively 50% and 100% reductions in swamp area could be achieved by poldering, viz. creating dry land from dredged material, thus reducing the water area exposed to evaporation. Mean annual net evaporation from the swamp at present averages roughly 80 x $10^6 m^3$ and the effect of this measure would be to divert 50% and 100% respectively of this loss into the lake. The simulation shows, however, that a 75% reduction in swamp area would be needed to achieve a lake condition comparable with the simulated virgin state. This would mean practically complete destruction of the swamp eco-system - clearly an unacceptable measure!

Simulation No. 16. An alternative to poldering swamp areas would be to divert Mkuze riverflow around the swamp by way of a by-pass channel (see Figure 1). From an examination of the duration curve (cumulative frequency of discharge) for the Mkuze, a channel capacity of 10 m^3/s was selected for trial. With all flows up to 10 m^3/s in the Mkuze diverted direct to the lake Figure 2 shows that although there is a significant improvement, the performance of the system still does not come up to that under the virgin condition. Furthermore, the effect of this loss of water to the swamp is quite severe; the water level is reduced on the average by 0,5 m and in the extreme by 1,0 m.

Simulation No. 19. This simulation was aimed at testing the effect of transferring to the Mkuze swamp 10 x $10^6 m^3$ of water per month (120 x $10^6 m^3$ per annum) from the proposed Makatini flats irrigation scheme by tapping the canal from the Pongolapoort dam (see Figure 1). As may be seen, a substantial improvement is possible and the criteria for the ideal state can be satisfied.

Simulations Nos. 22, 24 and 30. Water from the Mfolozi can be fed into the estuary or into the southern part of the lake by way of a link-channel[2] or into False Bay from a dam in the Mfolozi feeding into the Nyalazi (see Figure 1). The simulations show that if the Mfolozi channel were to enter the estuary anywhere between points 8 and 16 km from the mouth the effect on lake salinity would be the same. On average water would enter the lake at the rate of 47 x $10^6 m^3$ per annum. If the link-channel could be extended up into the lake proper the quantity diverted would jump to 190 x $10^6 m^3$. The effects of links with Mfolozi are highly favourable. For instance, that with outfall in the estuary 8 km from the mouth satisfies the virgin state criterion while the other schemes tested bring the lake to the ideal state.

Regulation of sea water supply

Simulation No. 34. This run was performed to test the effectiveness of a gated structure in the estuary. To prevent flood water from escaping to the sea, the gates were closed whenever the lake level was between 0,0 m and 0,7 m. The simulation shows that an improvement can be achieved and that the operating rule can be optimized. It shows, too, that the gates might have to be closed for about 75% of the time, implying that a biological lock would be essential to allow unimpeded migration of marine organisms.

Simulation No. 36. An additional ocean link in the Selley's lakes area would prevent salinities in this northern part of the lake from rising to quite such high extremes but the improvement is clearly not significant enough to warrant the enormous expense that would be involved. The general average lake salinity would, of course, rise.

Simulation No. 39. Instead of constructing a second estuary in the north, pumps could be installed at Selley's lakes to inject sea water into the system whenever necessary. For this simulation, pumps of capacity 20 m^3/s were assumed to operate whenever the lake level dropped below -0,09 m, i.e. the level at which sea water starts flowing into the lake along the existing estuary. As may be seen the effect on lake salinity is similar to that for a Selley's estuary.

Lake geometry

Simulation No. 43. This simulation was performed to test the effect of reducing the area of the lake by 50% while maintaining the original volume of 300 x $10^6 m^3$. The net evaporation loss from the system would be markedly reduced (see Table 2) and the criteria for the virgin state would be satisfied. Such a scheme, however, would involve the shifting of approximately 150 x $10^6 m^3$ of material - a formidable engineering undertaking!

CONCLUSIONS AND RECOMMENDATIONS

The remedial measures that effect significant improvements to the salinity regime are clearly those involving the injection of fresh water to the system from either the Pongola or the Mfolozi, or those involving substantial alterations to the flow regime of the Mkuze or to the geometry of the lake.

The following steps are recommended :

(1) With the help of these preliminary appraisals of possible ameliorative measures discussed herein and described in detail in reference 1, a range of ameliorative measures, all of which produce (in different degree) some improvement in lake salinity regime, should be designed and costed. Costs should be plotted against "state of health" of the lake as shown in Figure 3.

Only when the results of investigations have been presented in a form such as Figure 3 and when the environmental effects of the most promising measures have been thoroughly examined should decisions be taken by the relevant authorities as to which measures should be implemented.

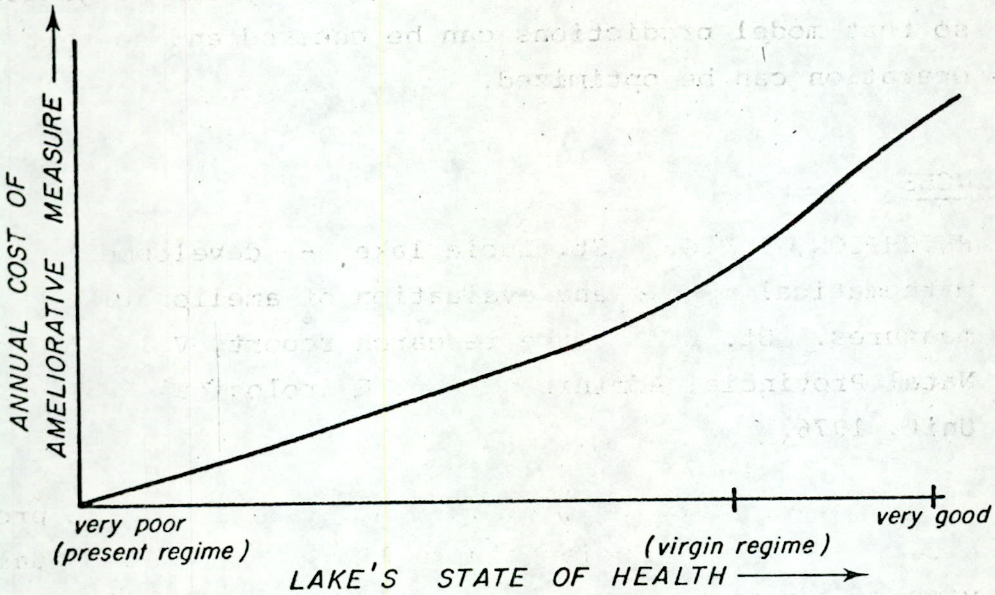

Fig. 3 COST OF ACHIEVING DIFFERENT DEGREES OF IMPROVEMENT IN LAKE REGIME

(2) In view of the fact that conditions in the St. Lucia system must be expected to change as future developmental pressures increase, it is imperative that a dynamic lake management programme be instituted. There should be a continuous feed-back to lake management of data pertaining to the physical state of the system (lake level and salinity, river runoff and silt yield) as well as information concerning envisaged water resource developments in the catchment of the lake. This requires regular contact with those agencies (central and local government and farmers' associations) involved with the development of the region. It must be possible to anticipate any adverse changes and to take timeous steps to ensure satisfactory behaviour of the lake system.

(3) Research should be undertaken with the object of improving knowledge of the water balance in the Mkuze swamp and of the rate of silting of the lake and the swamp.

(4) Any ameliorative measure that is implemented should be carefully monitored so that its efficacy can be judged, so that model predictions can be checked and so that operation can be optimized.

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