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ST. LUCIA LAKE - MATHEMATICAL MODEL

HYDROLOGICAL RESEARCH UNIT REPORT NO. 2 - MARCH 1971

The lake mass balance model has now been developed to the stage where simulations are sufficiently representative of prototype behaviour to warrant comparative analyses of the various schemes aimed at improving lake salinity conditions. Figures (1) and (2) demonstrate the degree of correspondence between salinities and water levels as measured in the lake and those predicted by the model.

I. GENERAL INFORMATION

(a) Stable lake levels, volumes and surface areas under various conditions. ('Stable' refers to the lake water level at which no in- or outflow occurs via the narrows through tidal influence).

Condition	Surface area km^2	Volume mill. m^3	Reduced level m
Narrows undredged	335	351	4.05
Narrows dredged	322	308	3.93
Lake with the whol of False Bay filled in:			
Narrows undredged	268	278	4.05
Narrows dredged	267	243	3.93

(b) Mean monthly catchment runoff into the lake (from all the rivers and the eastern shores)

Runoff in mill. m^3

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Tot.
Virgin Runoff	16.8	26.0	38.7	46.9	53.0	125.0	44.4	21.2	14.4	22.7	6.1	7.6	423
Affected Runoff	13.5	20.1	32.2	37.0	42.6	106.1	37.3	17.8	11.3	19.1	5.1	6.4	349
Difference	3.3	5.9	6.5	9.9	10.4	18.9	7.1	3.4	3.1	3.6	1.0	1.2	74

II. SUMMARY OF RESULTS FROM THE COMPARATIVE ANALYSES

(a) Virgin runoff and undredged Narrows.

Long-term mean lake salinity = 12.1 ppt (parts per thousand). The frequency distribution of the monthly salinities is shown on figure (3). The figure reveals that, on the average, salinity is below 10 parts per thousand for 6 months of the year.

To complete the picture of salinity in the lake the severity and frequency of occurrence of high salinities of various durations must be determined. To simplify the outline of the comparative analyses that follow only one duration, viz. 6 months, and two average frequencies of occurrence, viz. once every 2 years and once every 20 years, are considered. The following shorthand notations have been adopted:

S_2 = average salinity during a 6-month period occurring, on the average, once every 2 years. (i.e. Normal dry conditions).

S_{20} = as above except that the event occurs, on the average, once every 20 years. (i.e. Severe drought conditions).

For the above case S_2 = 12 ppt S_{20} = 37 ppt.

As these conditions closely resemble what was once the 'normal' lake behaviour, the complete frequency duration analysis of lake salinities has been included in this report and is to be found on figure (6). The influence of the Umfolozi has not yet been included in the lake model. As a result the salinities shown on figure (6) are probably slightly more severe than the actual normal values. Nevertheless the figure should provide botanists and zoologists with some basis for estimating 'standard' frequency-duration curves of lake salinity. To be deemed reasonably successful, any remedial scheme that may be finally adopted would, on simulation, have to generate a lake salinity history conforming to this standard.

(b) Affected runoff and undredged Narrows.

Long-term mean lake salinity = 18.0 ppt.

S_2 = 18 ppt; increase due to runoff decrease = 6 ppt

S_{20} = 53 ppt; " " " " " = 16 ppt.

Analysis reveals that during drought periods the lake water levels would be decreased by about 3 cm. (This value gains significance when one realises that the average depth of the lake is only of the order of 100 cm).

(c) Affected runoff and dredged Narrows.

Long-term mean lake salinity = 22.1 ppt.

S_2 = 23 ppt; further increase due to dredging = 5 ppt

S_{20} = 58 ppt; " " " " " = 5 ppt.

The average lake level would be decreased through lowering of the stable lake level. During drought periods, however, the lake levels are improved by about 12 cm. This effect however does not lead to decreased salinity values as the total salt content of a lake associated with a dredged estuary is higher than that when the estuary is not dredged.

Condition (c) above corresponds to that of the lake as at present. In the following sections various remedial measures are evaluated:

(d) Mkuze swamp bypass canal. (Capacity either 200 cusec or 400 cusec - figures for the latter size are bracketed below).

Long-term mean lake salinity = 20.3 (19.9) ppt.

S_2 = 21 (20) ppt; improvement = 2 (3) ppt

S_{20} = 54 (54) ppt; " = 4 (4) ppt.

There is no significant change in the lake levels. These diversion canals would reduce the average supply of Mkuze water to the swamp by 24% (31%). The effect of the altered time-flow sequence into the swamp is difficult to judge at this stage as the storage capacity of the swamp is not yet known.

(e) Seawater pumping schemes.

Pump capacities of 20 and 50 mill.m^3/month operating under various rules were considered. Although the schemes investigated had not been optimized (to secure lowest salinities for given pump capacity) the results do indicate the general effects of this type of scheme.

Long term mean lake salinities varied from 21 to 18 ppt.

S_2 values varied from 22 to 23 ppt

S_{20} " " " 49 " 58 ppt

Figure (4) indicates that while this type of scheme is effective in decreasing severe drought salinity in the lake (also shown by the S_2 and S_{20} figure above), it does so at the expense of slightly increasing the values of the above-average salinities that have a higher frequency. Lake water levels during drought periods would be improved by as much as 10 cm.

(f) Reduction in size of lake.
Two alternative schemes were investigated. The first was merely a 10% reduction in surface area, keeping the volume unchanged. The second (salinity values and levels are bracketed below) was abandonment of False Bay as part of the system, i.e. a more extreme version of the first measure. (The latter scheme has an additional advantage, viz. that the abandoned portion has a higher average net evaporation than the rest of the lake - 600 mm as compared to 420 mm). The general aim of this type of scheme is to approach the original ratio of average annual inflow to lake volume.

Long-term mean lake salinity = 18.8 (15.7) ppt.

S_2 = 19 (17) ppt

S_{20} = 50 (43) ppt.

The water levels in the lake during a drought period would be improved by 2 - 3 cm (4 cm).

(g) Lock systems.
The basic aim would be to retain some of the flood waters and to reduce the influx of sea water to the lake by means of gates in the Narrows. Several model runs were executed under various gate operating rules. As for section (e) above, optimization has not yet been effected. The results do, however, indicate the magnitude of the improvements to be expected.

For a particular operating rule (see figure (5)) the results were as follows.

S_2 = 16ppt

During drought years lake levels were decreased by about 20 cm. (This results from cutting down the amount of sea water entering the system).

It must be emphasized, however, that the gates had to be kept closed for about 50% of the time.

(h) Water from the Pongola.
Model runs to test the effect of supplying additional fresh water have not yet been executed. The order of magnitude of the additional volume of fresh water required can be gauged, however, from the fact that there is a deficit of 74 mill.m^3 per annum (28 500 morgen feet) resulting from water usage in the catchment. This figure is considerably lower than the 49 000 morgen feet arrived at in the Commission's report. Their figure was based on attempts to keep the average lake salinity below 35 ppt; this endeavour however would be tantamount to an improvement on 'normal' lake behaviour. An average annual supply of 74 mill.m^3 would merely offset the effect of reduced catchment runoff.

This type of scheme is in effect comparable with the virgin runoff/dredged Narrows case; figures for the latter are given below:
Long-term average lake salinity = 16.6 ppt.
S_2 = 18 ppt
S_{20} = 45 ppt.

Change in lake levels during drought periods would not be significant.

(i) Diversion of the Umfolozi.
Model runs for this measure have not yet been attempted. The effects, however, would obviously be advantageous. Determination of the optimum position at which these waters should enter the lake system involves detailed studies of water and salt circulation within the lake and estuary; the programmes require further development before any meaningful results can be obtained.

III. CONCLUSIONS

The causes of the present condition at the Lake are basically twofold:

1. reduction of river runoff into the Lake and
2. dredging of the Narrows.

Gradual silting up of the lake has also had a deleterious effect. To regain the former balance of the forces of nature one has to reverse the effects of the two main processes.

As far as point 1) is concerned one should think in terms of a smaller lake rather than of importing additional supplies of fresh water. There are two very good reasons for this:

i) with increased demands on our water resources the value will rise

ii) with increased upstream utilization the quantities to be imported will increase.

To retain the advantages of easy access that have resulted from dredging the Narrows (point (2)) one should contemplate construction of a flow control device such as a controlled constriction.

IV. FURTHER RESEARCH

1. A study of detailed circulations of water and salt within the lake is in hand. An important aspect of the model associated with this study will be checking the validity of the mass balance model from which the results outlined above have emerged.

2. A study of silt movements within the system is envisaged.

3. A more detailed study of the Mkuze swamp in order to evaluate its storage capacity and its ability to attenuate floods is also needed.

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