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NATURAL ISOTOPE STUDIES IN LAKE ST LUCIA

REPORT TO

THE LAKE ST LUCIA SCIENTIFIC ADVISORY COUNCIL

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1. INTRODUCTION

The stable isotopes oxygen-18 (^{18}O) and deuterium (D or ^{2}H) are present in small concentrations in all natural waters as the molecules $H_2{}^{18}O$ and $HD^{16}O$. Since the physical behaviour of these molecules is slightly different from that of the normal $H_2{}^{16}O$ molecules, their concentrations vary in waters of different origin.

In sea water the abundance of the isotopes is very constant, the ratios $^{18}O/^{16}O$ and D/H being 1.98 ppt and 160 ppm respectively. For convenience, abundance ratios are reported relative to standard Mean Ocean Water (SMOW-standard) and expressed as δ-values in permil. Negative δ-values indicate that the sample contains less of the heavy isotope than the standard ocean water and positive values vice versa.

In addition to these stable isotopes, natural surface waters contain small amounts of the radioactive hydrogen isotope, tritium (T or ^{3}H). The tritium content of a sample is expressed in Tritium Units (T.U.), where 1 T.U. represents a T/H ratio of 10^{-18}.

2. APPLICATION TO SURFACE WATER STUDIES

2.1 Water budget of a lake

In establishing the water balance of a lake there are usually several unknown or only imperfectly known quantities in the generalized equation:

$$P-E+I-D=\Delta V,$$

P = Precipitation

E = Evaporation

I = Inflow-

D = Discharge

Since large quantities are subtracted from each other, a relatively small error in any one of the components is considerably magnified. In the case of Lake St Lucia the main unknown quantity is the inflow which is comprised of surface run-off, river inflow and ground water seepage:

$$I=S+R+G.$$

Measurement of the stable isotope abundance in the different components of the balance equation provides an additional independent equation for the heavy isotopic molecules so that, in principle, one more unknown quantity can be determined

2.2 Degree of Evaporation

The lighter isotopic molecule, $H_2{}^{16}O$, evaporates faster than the heavier ones so that the heavy isotopes are concentrated in the remaining liquid. This enrichment continues up to a maximum value which is determined by the atmospheric water vapour (humidity). By comparing the increase in the concentration of the heavy isotopes in a pan with the increase in a dam or lake the rate of evaporation can be deduced. This can be done with an accuracy of a few percent and provides a method of determining the dam-to-pan ratio where this is not possible by other means.

2.3 Stable Isotopes as Fresh Water Tracer

Since the isotopic content of the lake water is markedly different from that of the river run-off and the ground water, the natural isotopes can be used to trace the movement of fresh water entering the lake. Whereas an artificial tracer inserted at a specific point shows the movement of a localized water mass at a specific time, the natural isotopic tracers give the average movement integrated over a longer period. They can thus, for instance, be used to detect areas where ground water enters the lake along the eastern shore, or where water from the swamps seeps in along the northern shore. In the course of time the isotopic content of the fresh water increases by evaporation and becomes indistinguishable from the lake water.

2.4 Tritium as Sea Water Tracer

The entry of sea water into the lake can be detected by means of natural tritium. The surface water of the southern oceans has a low tritium content as compared with precipitation and run-off on the continent. The tritium content in the lake and estuary can thus provide a minimum value for the fraction of sea water present and can be used to trace sea water in its passage into the lake. In the course of time the tritium content of the sea water in the lake will increase by isotopic exchange with the atmosphere and become identical with the fresh water in the lake. Tritium thus only traces a fesh inflow from the sea.

2.5 Use of Tritium to Determine the Recharge Rate on the Eastern Shores Area

The amount of subsurface water entering the lake along the eastern shore constitutes an important quantity in the water budget of the lake. This quantity is equal to the amount of precipitation that infiltrates into the sand over the appropriate surface area of the land tongue between lake and sea and can be measured by means of natural tritium. The method of determining the recharge rate is as follows: Water samples are collected at various depths under the surface at selected points and the natural tritium profile is measured. Recent increases in the tritium content of rain due to nuclear weapon tests allow the infiltrated water to be dated and thus give a quantitative estimate of the average recharge rate.

3. RESULTS

Since June 1970 monthly samples have been collected from the Lake St Lucia area for isotope analysis. Samples were taken of precipitation, ground water, lake water, ocean water and the rivers. The data obtained from the analysis of these samples serve mainly to build up background knowledge on the distribution of the isotopes deuterium, oxygen-18 and tritium in the area. The sampling stations are as follows:

1. Lister Point: rain and lake water
2. Charter's Creek: rain and lake water
3. Essengeni: lake water
4. Old Jetty: ground water
5. Sengwane: ground water
6. Mission Rocks: ocean water
7. Bengazi Pan: pan water
8. Umfolozi River: river water
9. Mkuzi Swamps: river water.

The localities of the sampling points are shown in fig. 1.

3.1 Water budget

There is a general qualitative correspondence between the salinity and the oxygen-18 content of the lake water at Charter's Creek and Lister Point. Deviations from a linear relationship between the two quantities is due to their different behaviour during simultaneous evaporation and addition

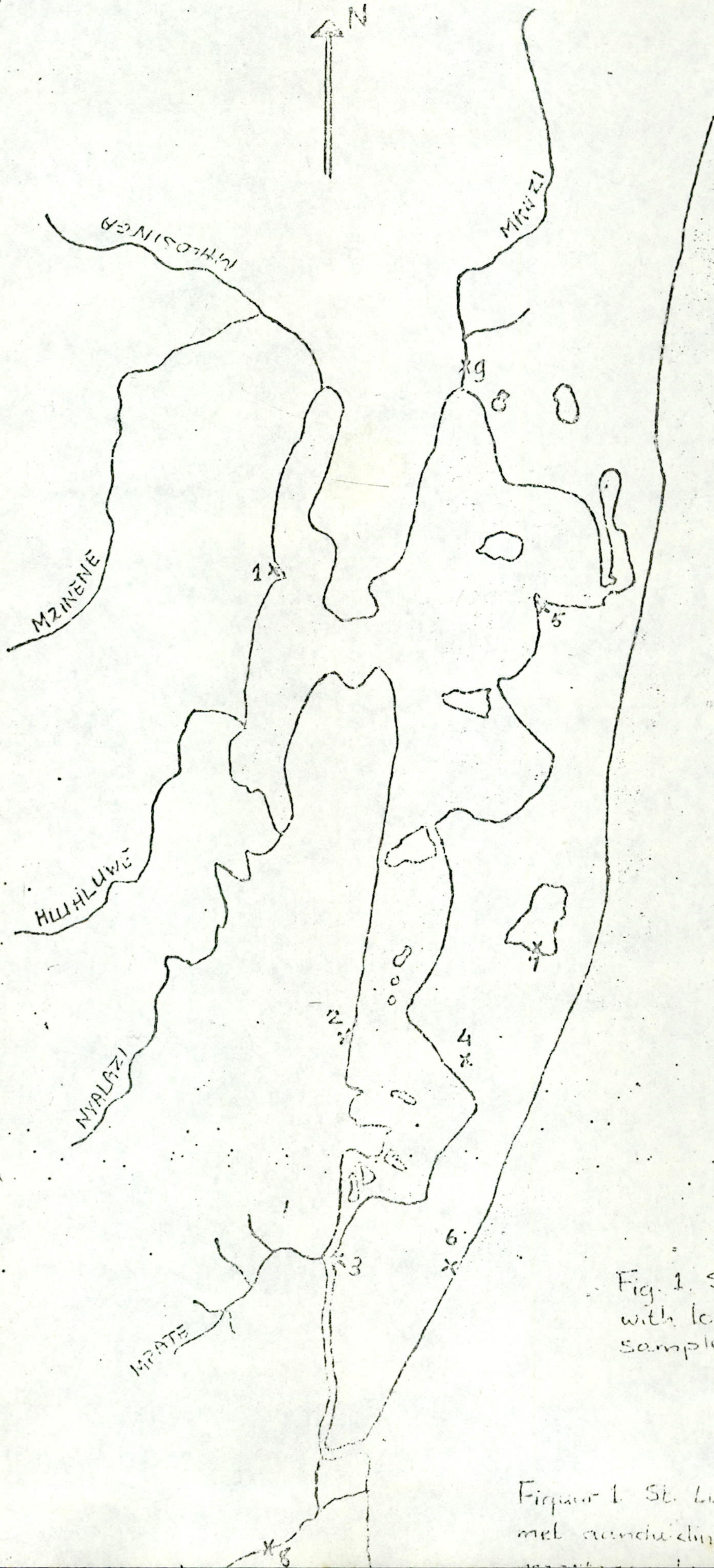

Fig. 1. St. Lucia lake with locations of sample points.

Figuur 1. St. Luciameer met aanduiding van

+5
0
-5
δ18
‰
100 ppt
50
↑ salinity
Lister Point
Charter's Creek
Mkuzi Swamps
Essengeni
Salinity
oxygen-18
7/70
1/71
1/72

Figure 2

of fresh water. In several instances the reduction in the oxygen-18 content is greater than can be expected from the contribution of oxygen-18 difficient precipitation - indicating addition of run-off to the lake. No calculations can, however, be made with only two lake water stations. With sufficient data it seems probable that quantitative information on the water balance could be obtained. In one instance - in May 1971 - when the salinity at Essengeni and Charter's Creek increased while the oxygen-18 content decreased a considerable influx of sea water is suspected.

Measurements show that the ground water in the Eastern Shores Area has the same oxygen-18 content as the river water so that no distinction can be made between these two sources in water balance calculations for the oxygen-18 isotope.

3.2 Degree of Evaporation

During most of the time since June 1970 the oxygen-18 content of the lake was high and close to the maximum value attainable. When this is the case the evaporation cannot be determined by the method proposed in par. 2.2. The method could, however, be applied at times when fresh water influx has reduced the oxygen-18 content, as was the case, for instance, in November 1970 and, especially, in March 1972. To determine the dam-to-pan ratio it would be necessary to install a floating tray of water for comparison.

3.3 Oxygen-18 as a Fresh Water Tracer

During January/February 1972 the lake received a large amount of fresh water from excessive precipitation and run-off. On 9 February and again on 29 February series of samples were collected at a number of points in the lake. At the time the oxygen-18 content of the lake had already been decreased from an approximately uniform value, $\delta=+2.0‰$ on 1 January 1972 to an average value of $\delta=-0.4‰$ on 9 February and $\delta=-0.9‰$ on 29 February. Most of this decrease was due to the addition of oxygen-18 difficient precipitation, but the inflow of river water can clearly be seen too. The oxygen-18 values on these two dates are shown in Figures 3 and 4. The main influence of fresh water on 9 February is seen south of the Mkuzi River, while the area around Sengwane shows the least influence (positive δ-values). Near Dead Tree Bay and Old Jetty along the Eastern shore there is also more fresh water than on the western bank.

3.4 Tritium as Sea Water Tracer

The tritium content of some representative samples was measured to test its use as a tracer for sea water entering the lake. The results are shown in table 1. The tritium content of rain water in the area is about 20 T.U. (tritium units) and that of sea water is about 2 T.U.

	Locality	Date	Tritium Content
Ground water	Old Jetty	1/12/70	15.4 ± 0.9 T.U.
	Old Jetty	1/4/71	11.1 ± 1.0 T.U.
Ocean water	Mission Rocks	1/12/70	2.1 ± 0.6 T.U.
Lake water	Essengeni	1/12/70	6.6 ± 0.6 T.U.
	Essengeni	1/4/71	8.1 ± 0.6 T.U.
	Charter's Creek	1/12/70	10.9 ± 0.9 T.U.
	Charter's Creek	1/4/71	11.2 ± 0.9 T.U.
	Lister Point	1/12/70	17.7 ± 1.2 T.U.

The lake water samples have a tritium content intermediate between that of fresh water and sea water. The low values found at Essengeni slow clearly that sea water was entering the

9 Feb 1972

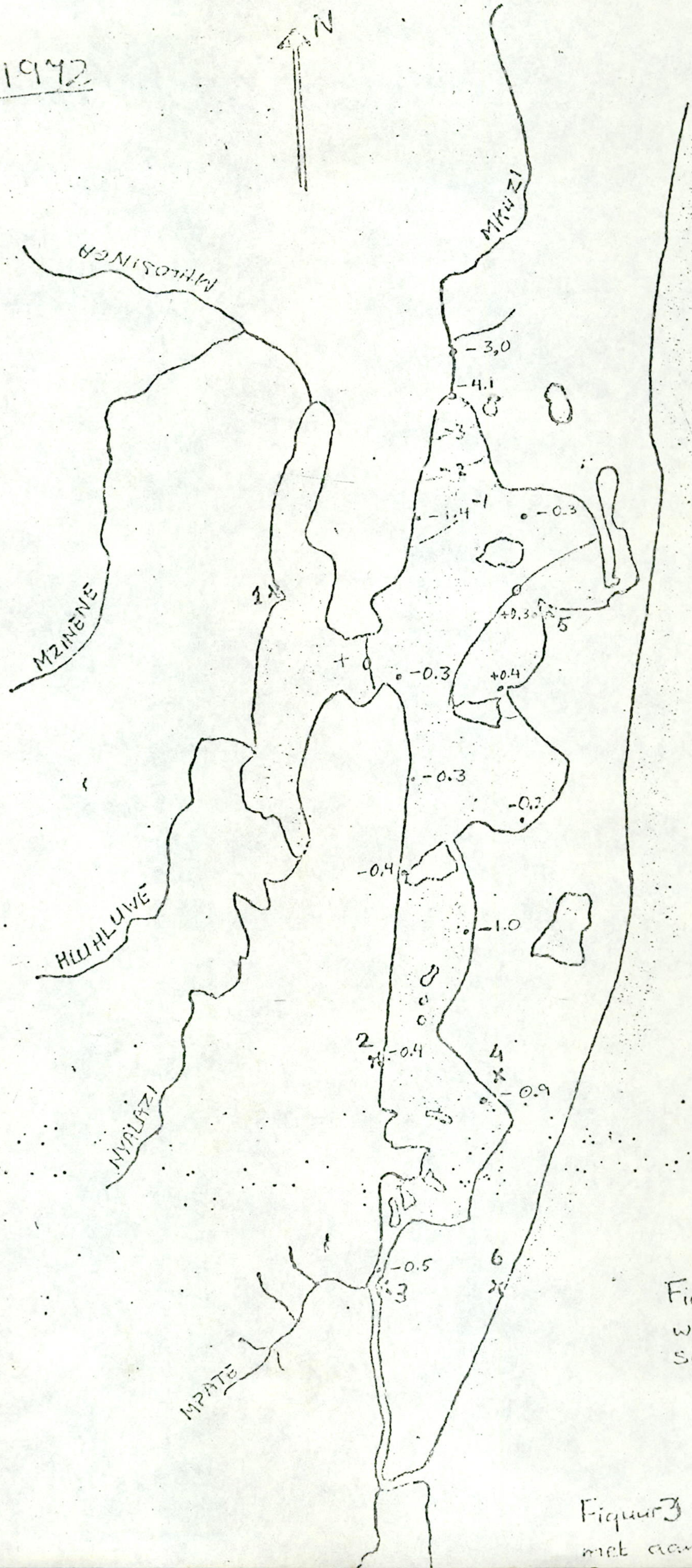

Fig. 3. St. Luci with location sample point

Figuur 3 St Luciam met aanduiding van

lake in November 1970 and March 1971. The effect of the sea water could still be detected at Charter's Creek, but not at Lister Point. The results show that the entry of sea water could reliably be detected by regular sampling at, for instance, Essengeni. Quantitative estimates could also be made.

3.5 Recharge Rate on the Eastern Shores

The relatively high tritium content of the ground water entering the lake at Old Jetty (Table 1) show that tritium could successfully be used to measure the rate of recharge on the eastern shores. Samples should be collected at various depths during drilling operations in the area.

4. SUMMARY

Measurements of the oxygen-18 content in the lake clearly show the extent of evaporation that took place in 1970 and 1971. It seems probable that the isotope could be used to distinguish whether an increase in salinity is due to evaporation or to the influx of sea water. The rate of evaporation could also be determined when the lake is relatively fresh.

The influx of fresh water from the Mkuzi river could be traced after the floods of February 1972. The degree of detail obtained is dependent on the number of samples collected.

The tritium content of the lake water can be used to trace the entry of sea water into the lake. This method provides a value for the inflow averaged over a period of weeks which is in contrast to the result obtained from artificial tracers.