A STUDY OF PHOSPHORUS DYNAMICS IN THE MAIN BASIN OF SWARTVLEI SEPTEMBER → DECEMBER 1980

Project Report
Part II of M.Sc. Limnology

M.J. Silberbauer
Rhodes University
January 1981.

CONTENTS

I. INTRODUCTION

Phosphorus is an especially scarce element in the aquatic environment, yet it is of vital importance to living organisms: the pyrophosphate bond is the basis of biochemical energy transfer, and phosphate groups make up the backbone of the nucleic acids (Wetzel, 1975). An understanding of phosphorus movements and transformations is thus essential to a study of the biological functioning of a lake. The present report describes a study of phosphorus dynamics in Swartvlei, a lake with an extremely low pelagic primary production rate, in the order of 0,15 $gC.m^{-2}.d^{-1}$ (Robarts, 1973; Howard-Williams and Allanson, 1978). The littoral phosphorus dynamics of Swartvlei have been discussed in some detail (Howard-Williams, 1977; Howard-Williams and Allanson, 1978), and what follows is an attempt to quantify the changes in phosphorus concentration occurring in the deeper parts of the lake, which comprise some 57% of the total area.

A. THE LAKE AND SURROUNDINGS

Swartvlei is a small, brackish, brown-water lake. It lies in a cryptodepression about 3 km from the sea on the southern Cape coast (34°00'S 22°45'E), and is intermittently connected to the sea by a 7 km long estuarine channel (Figure 1). Swartvlei is not an estuary, in that it does not have a permanent connection with the sea permitting free tidal interchange (Schubel and Pritchard, 1971). At irregular periods, a sand-bar blocks off the mouth of the estuary, which then technically becomes part of a coastal lagoon comprising the lake and the channel. The sand-bar is breached, either by overtopping or artificial cutting, when heavy rains have filled the lake to about 2,0 m above geodetic mean sea level (GMSL, South African mean). When the lake is in the open phase, the surface lies at about 0,65 m above

GMSL and the mean depth is 5,45 m.

Three main rivers flow into the lake: the Wolwe, the Hoëkraal and the Karatara. They drain a 340 km^2 catchment and supply an estimated 66.10^6 $m^3.2^{-1}$ of water to the lake (CSIR, 1978 in Howard-Williams and Allanson, 1978). The catchment consists of uncultivated mountain slopes, forestry plantations and agricultural areas. The water in all three rivers is acidic (pH range 4→7) and deeply stained with humic materials. The total phosphorus concentration is in the order of 10 $\mu g.\ell^{-1}$ (Dept. Water Affairs/Forestry/Environment Data Bank, Pretoria), which implies a loading of < 0,1 g $P.m^{-2}.a^{-1}$. Abnormal flow and organic debris after heavy rain may increase the loading figure: Howard-Williams and Allanson (1978) report a 'flood' phosphorus concentration of 42 $\mu g.\ell^{-1}$.

B. ECTOGENIC MEROMIXIS

The lake becomes meromictic at irregular intervals, as a result of two outside influences (Robarts and Allanson, 1977):

1. Strong inflows of saline water occur at spring tides, when the bar at the mouth of the estuary is open. This water sinks to the bottom of the lake as a dense layer, which causes marked resistance to vertical mixing (cf. Hutchinson, 1957: 777-779). The inflow of sea water is impeded by resistance to flow in the estuarine channel, the constriction of the channel by a railway bridge and embankment, and the presence of large, shallow sandbanks in the southern, seaward end of the lake (Figures 2 and 10; Moes, 1976). This aspect is discussed further in IIC and IVC.

2. Heavy rains in the catchment and river floods result in fresh water spreading over the surface of the lake and mixing with the upper

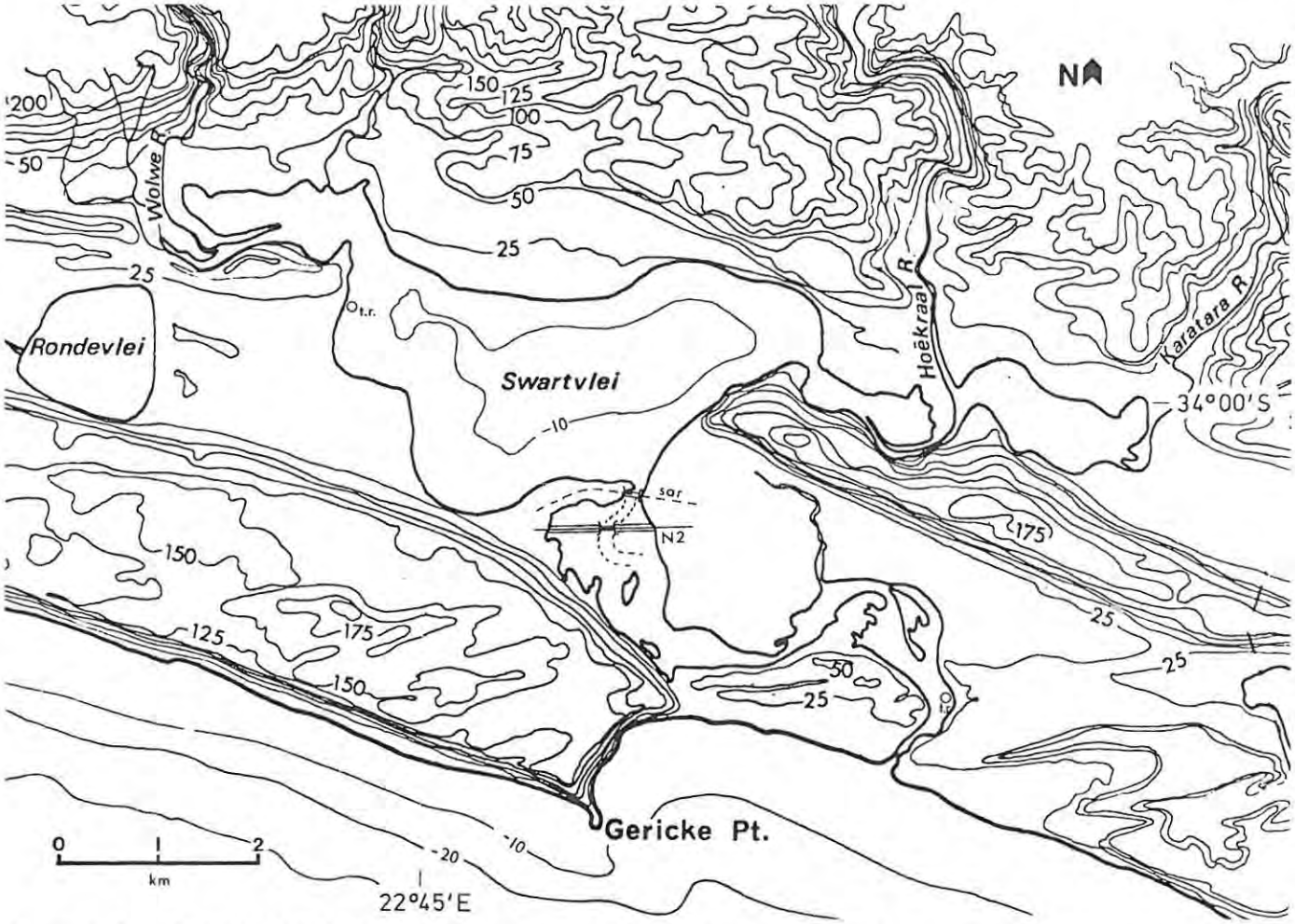

Figure 1. Swartvlei bathymetry and surrounding topography.
sar = Railway
N2 = National road
o t.r. = A. Ott water level recorder
(Reproduced, with modifications, from *Relief and bathymetry of the Wilderness lakes and embayment*, monochrome contour map held at the Institute for Freshwater Studies, Swartvlei).

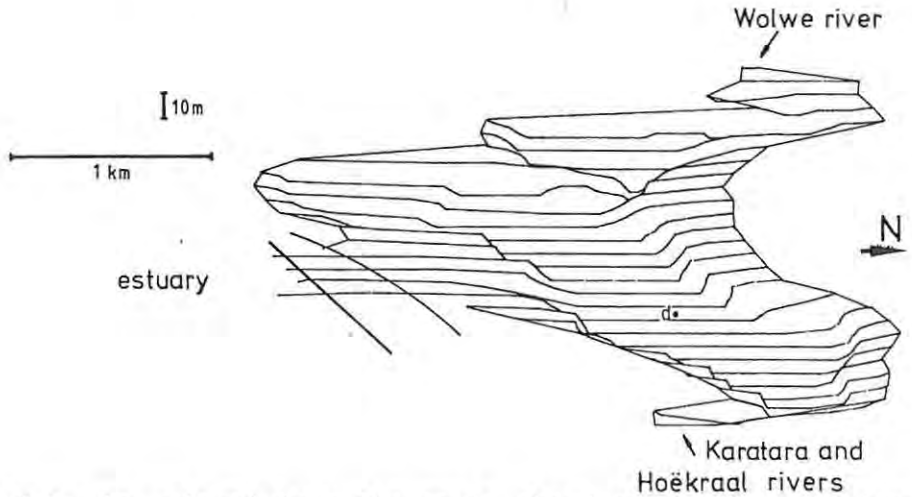

Figure 2. Swartvlei basin, viewed from the east, showing sampling station d. This projection does not allow for perspective, and is a series of linear interpolations between contours at 2 m intervals. The profiles are 200 m apart. (Drawn with the aid of the subroutine HIDE, written by Prof. P. Terry, Department of Computer Science, Rhodes University).

layers of water.

These are both forms of ectogenic meromixis, and the lake may be thought of as an open meromictic system, because of the constant inflow to the mixolimnion (Hutchinson, 1957; Kimmel, Gersberg, Paulson, Axler and Goldman, 1978). Meromixis is liable to breakdown by wind-induced circulation, and Howard-Williams and Allanson (1978) have discussed this in detail. They calculated the total stability of Swartvlei by the method of Walker (1974) and compared the stability with the amount of wind stress. When the estuary is closed and there is little runoff from the catchment, the lake becomes a closed meromictic system. This is not stable and is eventually completely mixed by the prevailing westerly and south-easterly winds.

This study is an effort to determine how periodic meromixis affects the transfer of phosphorus across the sediment-water interface; to ascertain - with the aid of laboratory core systems - the extent to which the sediment can act as a phosphorus source for the overlying water; and to bring the different facets of phosphorus cycling together in the form of a conceptual and computer simulation model.

II. METHODS

A. LAKE SAMPLING

Station d (Figure 2) had already been established as physically and chemically representative of the main basin of Swartvlei (Howard-Williams and Allanson, 1978), and it was used as the sampling station for this study. It was sampled at approximately weekly intervals. Water samples for phosphorus analysis were collected with an acrylic

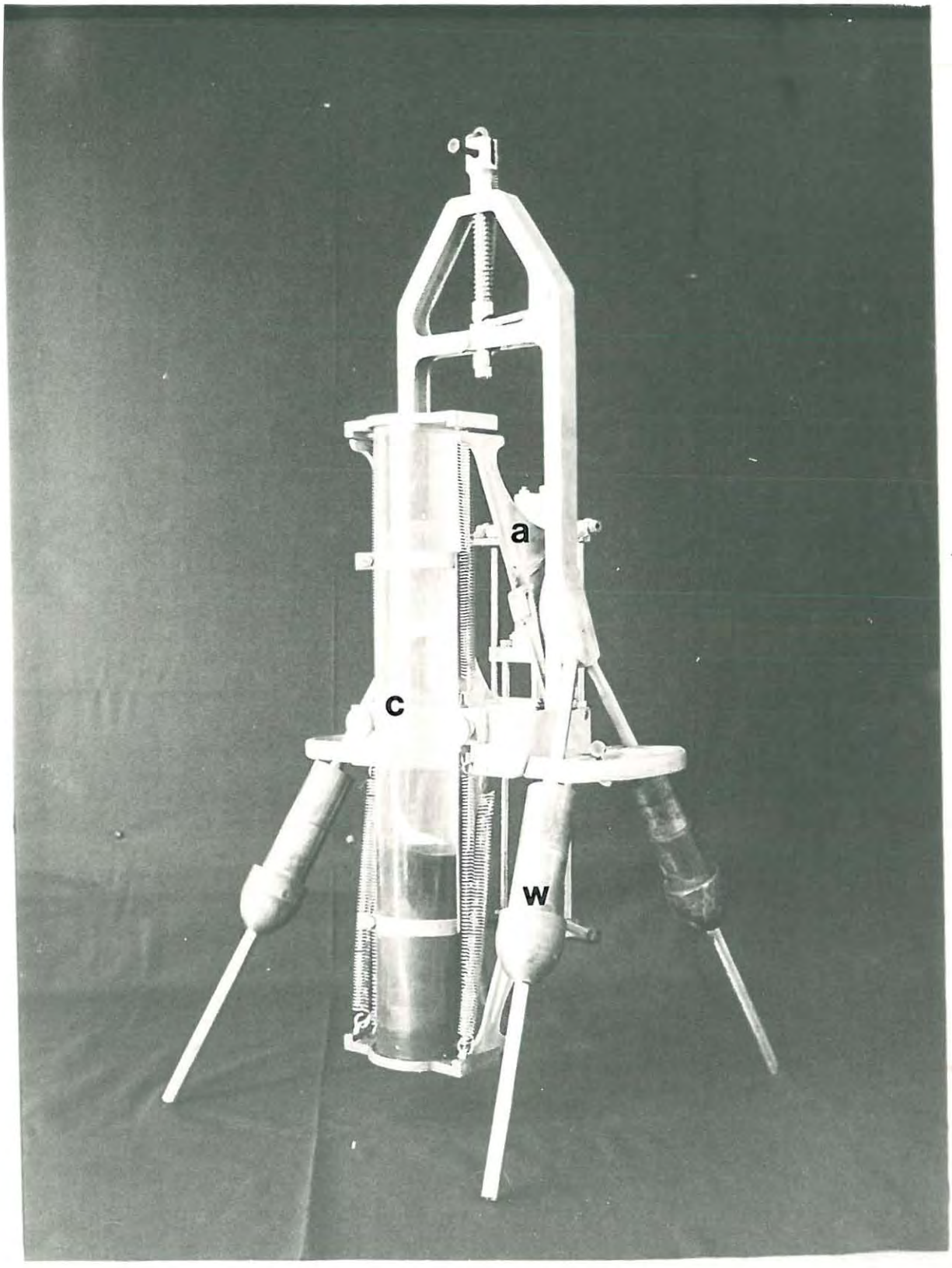

Figure 3. This Jenkin corer was used to sample the sediment and overlying water. The acrylic coring tube (c) and weighted legs (w) are shown. The closing-arms (a) are prevented from closing rapidly (and disturbing the sediment) by a dashpot (partially obscured in this photograph).

('Perspex') Ruttner bottle, and taken to the laboratory in PVC containers. For investigation of the sediment-water interface, a Jenkin corer (Mortimer, 1942; 1971 and Figure 3) fitted with glass or acrylic tubes (70 mm ø, 500 m long) was used. The corer is designed to collect an intact column of sediment (~20 cm deep) and the overlying water, with a minimum of disturbance. Normally, two cores were taken. The water 2 cm to 15 cm above the sediment of the first was partitioned between a PVC bottle (for phosphorus analysis) and two glass-stoppered bottles (for iron(II) and H_2S). The other core was kept sealed for electrode potential measurement.

Oxygen concentrations in the lake were measured directly, using a combined oxygen probe and thermistor (Yellowstone Springs Instruments S1B). This unit read to within ± 0,1 $mg.\ell^{-1}$ in a zero oxygen calibration solution (Radiometer, Copenhagen) and agreed with the Winkler oxygen method to ± 0,3 at 6,8 $mgO_2.\ell^{-1}$ (Taylor, 1981). Salinity was determined with an American optical refractometer which was accurate to ± 1‰ (± 1 g salt.kg $water^{-1}$) when checked against distilled water and a standard sodium chloride solution. Salinity and temperature were used to calculate actual density as described by Knudsen (1901). His equations are listed in Appendix A.

B. LABORATORY CORE EXPERIMENT

1. Setting up the cores

This experiment was designed along the lines of that conducted by Mortimer (1941, 1971) and many others since (see Golterman, 1977).

On 6 December 1980, three Jenkin cores were collected at station d. They are designated columns I, II and III. They were placed in a blacked-out water bath (Figure 4) which stabilized temperatures in the

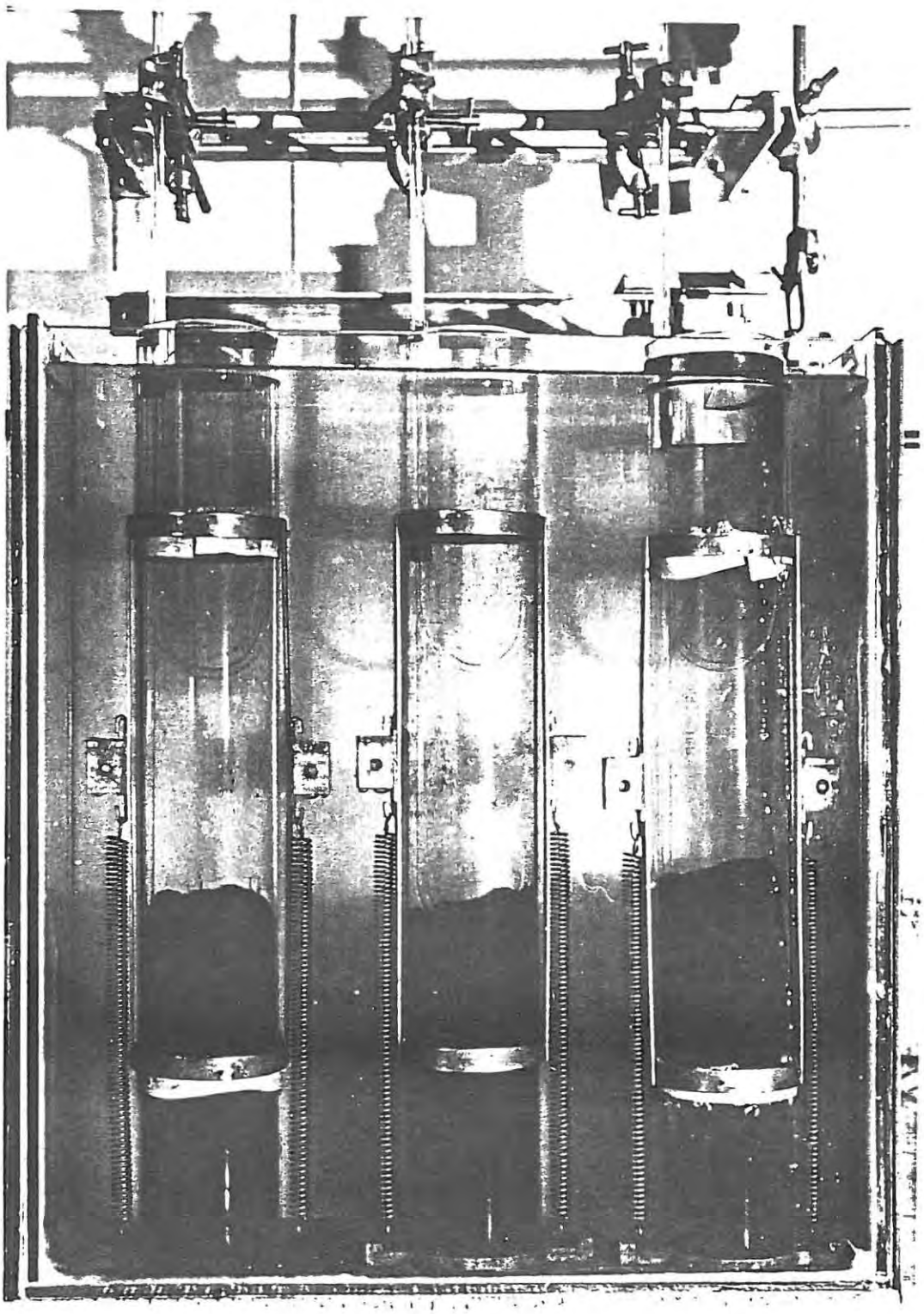

Figure 4. The laboratory core experiment, with water-bath covers removed. The upper 500 mℓ of water in columns I (left) and III (right) was replaced with lower-salinity water to simulate meromixis. The central column (II) was left undisturbed. The J-shaped tubes, suspended in the overlying water and in the sediment, assisted in sampling (cf. text: II.B.2).

range 20→25°C (3 to 8°C higher than the lake bottom temperature) and helped to seal the bottom covers of the cores. Saline lake water was used in the water bath to minimize diffusion or osmosis effects at the bottom covers.

To simulate meromixis, the top 500 mℓ of water was removed from columns I and III, and was replaced with a mixture of station d bottom water and Karatara River water. The final salinity of the upper layer was 8°/$_{oo}$.

Column II was kept unchanged, and was intended to represent a completely mixed water column. It became evident that the bottom layer was not going to be sufficiently aerated, even if the system was unstratified, and on the 11th day of the experiment all the water in column II was replaced with aerated station d bottom water (collected at the same time as the cores).

In order to represent the effect of estuarine water inflow to the lake, water of salinity 32°/$_{oo}$ - collected in the middle reaches of the estuary - was diluted with distilled water to 20°/$_{oo}$. The bottom water of column I was replaced with this water on the 13th day of the experiment. The columns were open to the air and there was free exchange of oxygen with the water surface. The system is represented diagrammatically at the top of Figure 9.

2. Sampling

A glass syringe fitted with a length of 3 mm ø PVC tubing was used to draw samples from the upper and lower water layers. To reduce disturbance of the system, J-shaped 6 mm ø lengths of glass tubing were permanently fixed in the columns - serving as guides for the PVC tubing - with the bottom of the J at the level to be sampled.

Samples for iron(II), H_2S and soluble reactive phosphorus analysis. were filtered through 0,45 µm cellulose nitrate membrane filters immediately after collection. This was done with an in-line 25 mm Ø Sartorius syringe filter, which caused little exposure to air. It was necessary to pre-wash membrane filters in 10% H_2SO_4 and distilled water before filtration of SRP samples. The total sample volume drawn was limited to a maximum of 50 mℓ per layer per day. This volume was replenished from stocks at equilibrium with the atmosphere.

A siphon consisting of a weighted piece of 0,6 mm ø Tygon tubing was set up in each Jenkin column. The siphon inlet was 1 cm above the sediment-water interface. The tubing fed water via an acrylic manifold block to an oxygen flow cell (Figure 5) in which was mounted a Radiometer (Copenhagen) oxygen electrode. Flow was controlled with a system of pinchcocks. The procedure followed for measuring oxygen concentration was as follows:

(a) Air-saturated, deionized water was flushed through the flow cell until a steady reading was obtained on the oxygen meter.

(b) The meter was adjusted for temperature and barometric pressure.

(c) Water was allowed to flow from one of the Jenkin columns for 5 min (about 15 mℓ). This allowed sufficient time for the electrode to respond to low oxygen concentrations. (A recycling system with a peristaltic pump was envisaged, but was never developed).

(d) The flow cell was rinsed and the electrode recalibrated as in (a).

(e) Finally, oxygen readings were converted from percentage saturation to $mgO_2.\ell^{-1}$, and corrected for temperature and salinity with the nomogram in Strickland and Parsons (1968).

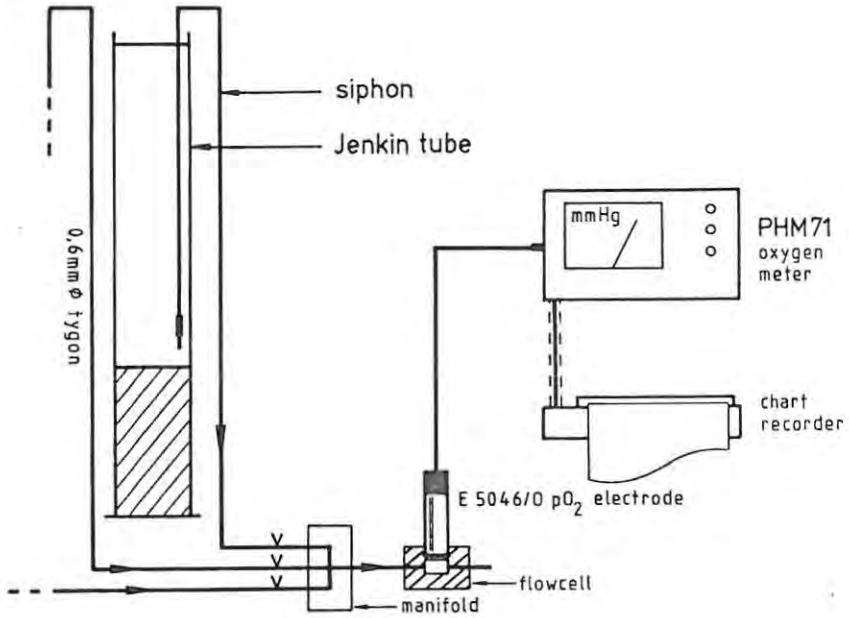

Figure 5. The apparatus used for measuring oxygen concentrations in the laboratory core experiment.

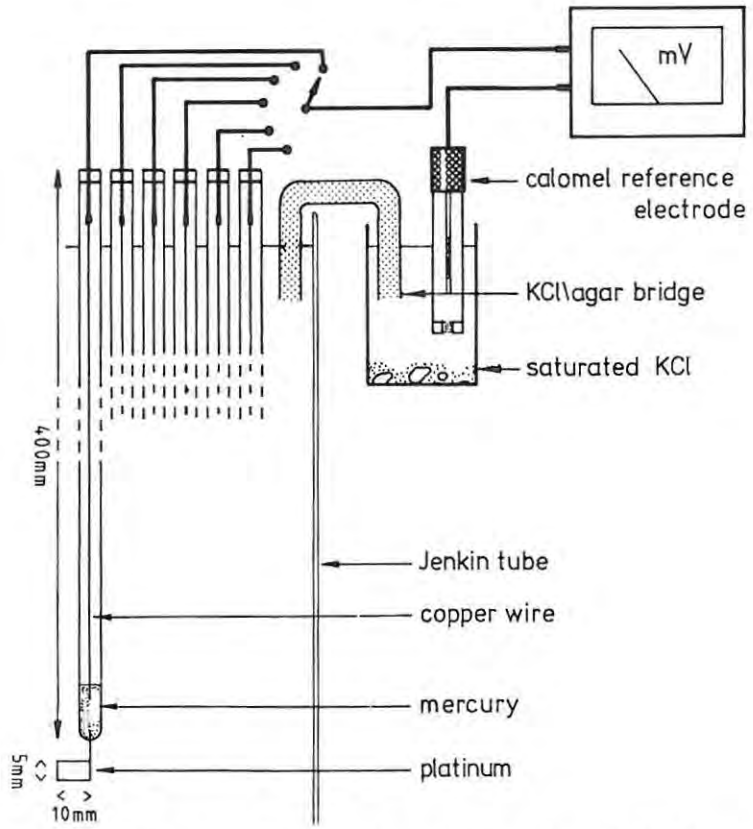

Figure 6. The electrode array and millivolt meter (Beckman) used to measure electrode potentials in core samples. Only one of the six platinum electrodes is shown in detail.

C. SPRING TIDE INFLOW

The connection between Swartvlei lake and estuary is shown in detail in Figure 10. For the purposes of this report, the railway bridge in the Figure is taken to be the actual outlet of the lake.

In order to determine the magnitude of sea water inflow to Swartvlei, the salinity of inflowing and outflowing water during a spring tide was observed over a 12h period on 21 December. Samples were collected for phosphorus determination and the water current speed was measured using a rotor-type sensor (Hydro Products, California). The rotor unit was secured to an aluminium frame and installed at the bottom of the main channel under the railway bridge. The changes in water level near the estuary mouth and in Swartvlei were obtained from recorders (A. Ott) belonging to the Cape Provincial Administration (marked in Figure 2 as t.r.). Water levels at the bridge were measured to an arbitrary datum and then corrected to actual levels by comparison with the results of Moes (1976) and the survey of Kluger (1975). The latter survey was used, in conjunction with personal observations, to determine the channel cross-section at the bridge.

D. CHEMICAL ANALYSES

Analytical grade reagents were used (E. Merck, May and Baker and BDH). Distilled water was prepared from rainwater in a Büchi single still, and stored in PVC containers. The soluble reactive phosphorus content of this water was less than 0,5 $\mu g.\ell^{-1}$, and the total phosphorus was less than 3 $\mu g.\ell^{-1}$.

1. Phosphorus

Two phosphorus components were distinguished: total phosphorus (TP)

and soluble reactive phosphorus (SRP). The term SRP is used to indicate the concentration of phosphorus obtained by the sampling and analytical methods used, implying that these methods may not give a true estimate of the actual orthophosphate phosphorus, or $PO_4^{\equiv}$ as P concentration (Rigler, 1973).

(a) SRP analysis

(i) Lake water

SRP was determined by a revised method of Mackereth, Heron and Talling (1978), supplied by B.R. Allanson (personal communication). This method is a variant of the commonly-used reaction of phosphate with molybdate in the presence of the reducing agents, ascorbic acid and antimony (III). The coloured complex formed is reduced molybdoantimonyl phosphoric acid, and the ratio $[H^+]/[MoO_4^{\equiv}]$ is selected for optimal colour development (Murphy and Riley, 1962; Going and Eisenreich, 1974). The absorbance was measured in 4 cm cells at 882 nm in a Shimadzu 4-decimal spectrophotometer (Kyoto, Japan). There is no published reference for the SRP method as used, so it is described in detail in Appendix B.

Calibration curves were constructed in the $0 \rightarrow 10$ µg $P.\ell^{-1}$ and $0 \rightarrow 100$ µg $P.\ell^{-1}$ ranges, with four replicates of each standard. At the low range the standard error was 4%, and at the high range, 2%. The limit of detection was 0,5 µg$.\ell^{-1}$.

Because of the low P concentrations found in Swartvlei, contamination of samples was a problem. Strict cleanliness of sample bottles and glassware had to be observed, and the acid-washing and storage procedures of Mackereth, Heron and Talling (1978) were followed.

SRP analysis was normally done on the day of sampling. If it was

necessary to keep samples overnight, they were refrigerated. Immediate analysis was found to be essential when the water redox potential was low, because rapid precipitation of dissolved material occurred.

Samples were filtered through pre-rinsed 47 mm ø Gelman 0,45 µm membrane filters. A consistently low filter blank was obtained (< 0,5 $\mu g.\ell^{-1}$). The SRP concentration of three replicate subsamples of the filtrate was determined. If the water was highly stained, it was necessary to include a colour blank, to which all reagents except molybdate were added.

(ii) Core interstitial water

For determination of interstitial SRP, the overlying water was siphoned from a Jenkin core sample and the surface 2 cm layer of sediment was scraped off into a centrifuge tube. The sediment was spun down (10 min, desk-top centrifuge, half speed) and the SRP of the supernatant was determined after filtration and dilution.

(b) TP analysis

(i) Water samples

Unfiltered samples were used for total phosphate analysis, which was done in triplicate. Samples were acidified (pH ≅ 1) and digested with solid potassium persulphate (14 $g.\ell^{-1}$) in covered glass reagent bottles for 30 min at a pressure of 100 ± 20 kPa (∿ 15 $lb.in^{-2}$, domestic pressure cooker). The samples were cooled, and P was determined by the SRP method already described.

The standards for calibration of the TP method were subjected to the same treatment as the samples. Two calibration curves were drawn

up: 0 → 50 µg $P.\ell^{-1}$ and 0 → 500 µg $P.\ell^{-1}$. The standard error was 5% in the low range and 2% in the high range. However, greater variations occurred on occasions, possibly as a result of water loss during digestion. A revision of the procedure is necessary.

(ii) Core sample

An estimate of the total amount of phosphorus in the upper layers of the sediment was required. A single core sample was used, although a detailed durvey would require samples across at least one transect (Frevert, 1979). A sediment core taken at station d on 26 September 1980 was frozen, the overlying ice was discarded and the sediment portion was sliced into 2 cm discs with a hacksaw. The discs were dried in an oven (105°C) and ground to a fine powder.

Approximately 10 mg of powdered sediment was weighed accurately (to 0,1 mg) and was then digested in 30 mℓ water under the conditions described above for TP determination. This type of method provides an indication of the amount of extractable phosphorus per mass of sediment (Aspila, Agemian and Chau, 1967; Twinch, 1980). A further point to bear in mind is that the method of drying meant that a certain amount of salt was included in the sediment (∿ 18 mg salt per mℓ of water).

2. Iron(II)

Samples for iron(II) analysis were filtered through a 0,45 µm membrane filter (in-line), avoiding excessive aeration. The samples were then acidified (pH 4,7) and a colour reagent, 2,2'-bipyridine, was added (Mackereth, Heron and Talling, 1978). The absorbance of the resulting $[Fe\ (bipyridine)_3^{++}]$ complex was read at 520 nm (Shimadzu). Interference from humic materials was a problem, so colour blanks

were required. These were buffered samples with water added in place of the bipyridine.

3. Hydrogen sulphide

The H_2S concentration in water samples was determined by the *N*,*N*'-diethyl-*p*-phenylenediamine + iron(III) method (Strickland and Parsons, 1968; Mackereth, Heron and Talling, 1978). No anaerobic centrifugation facilities were available, and H_2S was very quickly lost (even from bottles with ground-glass stoppers), so samples were filtered (0,45 μm) and the reagents added at the sampling site.

E. ELECTRODE POTENTIALS

1. Electrodes

An electrode array was assembled after the design of Mortimer (1942, 1971). Each electrode consisted of a 10 × 5 mm platinum foil 'flag' welded to a 15 mm length of platinum wire. The wire was embedded in one end of a 6 mm × 400 mm glass tube, and was connected to a copper conductor by means of a drop of mercury (Figure 6). The six electrodes were fixed side-by-side so that the flags would be at the following mean depths (sediment-water interface = 0 mm): +20, +3, -3, -8, -14, -19 mm. The side-by-side arrangement caused less disturbance to the sediment-water interface than the bundling method used by Mortimer (1942, 1971).

A calomel reference electrode was used, either immersed in the same solution as the platinum electrodes, or connected to the solution via a saturated-KCℓ/3%-agar bridge. The reference and platinum electrodes were connected to a pH-millivolt meter (Beckman SS-2) as shown in Figure 6. Readings are expressed as E_h, uncorrected for pH.

2. Cleaning

The method finally adopted for cleaning the platinum electrodes was immersion in hot concentrated nitric acid, followed by brief exposure to red heat in a bunsen flame. The electrodes were rinsed in distilled water after this treatment. The procedure was followed every time the electrodes were used. It was necessary to keep the period of immersion in nitric acid very short to prevent damage to the copper conductors, caused by leakage at the Pt-glass seal.

3. Variation

In oxygenated water, the individual electrodes showed E_h values ranging from 400 to 500 mV, and the variation between electrodes was often greater than this. An attempt to correlate E_h and $[O_2]$ in the lake was unsuccessful. This problem has been discussed by Hayes, Reid and Cameron (1958), Morris and Stumm (1967), Doyle (1968a,b), Whitfield (1969) and Mortimer (1971), and it is agreed that the greatest discrepancies occur where there is lack of poise, i.e. low amounts of strongly reducing or oxidizing agents. In highly reduced mud, results are in much closer agreement.

4. Operation

The electrodes were clamped to a retort stand mounted on a laboratory jack, which permitted very slow adjustment of the electrode height. This was essential in order to avoid disrupting the sediment-water interface. Despite the precautions taken, visible alteration of the sediment surface in the laboratory experimental cores occurred when electrodes were removed.

After the electrodes had been lowered into a core sample, they were left in position for at least 1h, to allow the measured E_h to

stabilize. A possible reason for this E_h drift has been put forward by Doyle (1968b): initially, iron in the water or sediment coats the platinum with a hydrous iron(III) oxide film, which causes a high E_h reading at the voltmeter. The iron(III) is subsequently reduced at a slow rate, and, eventually, an electrode potential is reached which is representative of the oxidation-reduction state around the electrode.

III. RESULTS

A. MONITORING OF STATION d

1. General conditions

Changes in density and oxygen concentration are shown in Figure 7(a). During the period of study, 18 September 1980 to 1 January 1981, the lake changed from the closed phase and complete mixing (a uniform salinity of 18°/$_{oo}$) to the open phase and meromixis (surface salinity 12°/$_{oo}$, bottom salinity 18°/$_{oo}$). The surface temperature rose from 18°C to 26°C and the bottom temperature from 15°C to 18°C. Surface pH was fairly constant, between 7,7 and 8,0, except on 3 December when it dropped to 7,4 after high river discharge. Bottom pH values were between 7,2 and 7,3, except at the start of the programme, when the pH was 7,4.

The electrode potential results obtained over the last three weeks of the project are shown in Figure 7(b), and rainfall figures are represented in Figure 7(c).

2. Chemistry

The total phosphorus values obtained at station d have been plotted

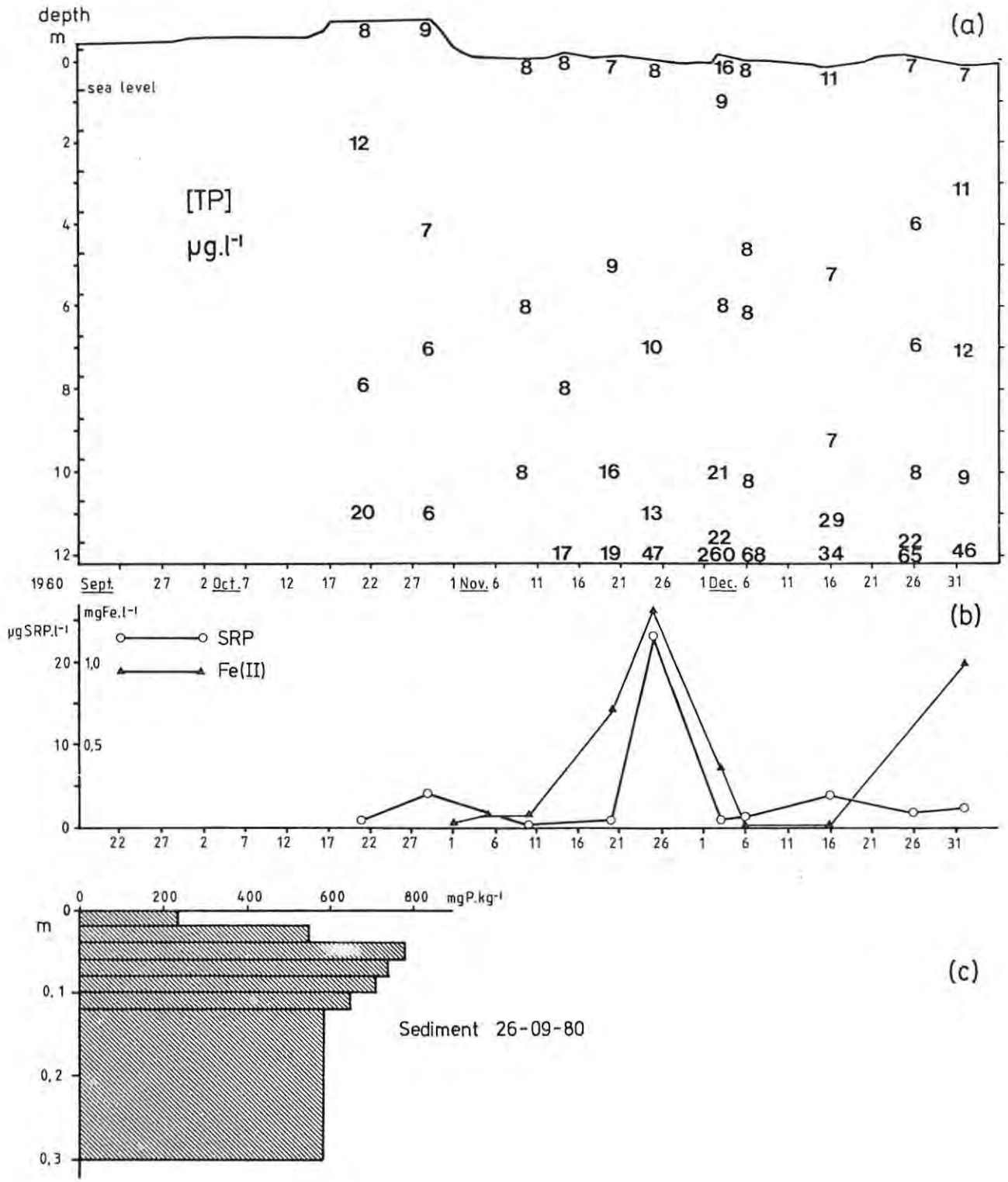

Figure 8. (a) Spot concentrations of total phosphorus in Swartvlei at station d, September to December 1980.

(b) Soluble reactive phosphorus and iron(II) concentrations above the sediment at station d, with the same time scale as (a).

(c) Total phosphorus extracted from a core sample (26 September) by oxidation and digestion at pH≅1, 100 kPa, 30 min.

as spot concentrations in Figure 8(a), on the same scale as Figure 7(a), as isopleths would be uninformative. Soluble reactive phosphorus concentrations in the water column were normally less than 1 μg $P.\ell^{-1}$, except on 3 December when 2 μg $P.\ell^{-1}$ was recorded at the surface after abnormal river inflow. SRP and iron(II) concentrations at 5 cm above the sediment-water interface are given in Figure 8(b), and the sediment core total (extractable) phosphorus results appear in Figure 8(c). It should be noted that, when the top 2 cm sediment layer was first centrifuged, and the saline supernatant discarded, a TP concentration of 830 mg $P.kg\ sediment^{-1}$ was obtained. Figure 8(c) applies to uncentrifuged samples, and is in agreement with the result of 250 $mg.kg^{-1}$ obtained by Howard-Williams (1977) for the upper 5 cm of sediment, using the wet ashing procedure of Golterman and Clymo (1969).

B. THE EXPERIMENTAL CORES

The results of the laboratory sediment-water exchange experiment are shown in Figure 9. TP in the upper water layer, as well as TP, SRP and iron (II) in the lower water layer, are plotted to the same time scale as Figures 7 and 8. Electrode potential isopleths at the sediment-water interface are drawn to the same scale as Figure 7(b). Table 1 shows the final interstitial SRP concentrations, measured when the experiment was dismantled.

Table 1: SRP concentrations (μg $P.\ell^{-1}$) in the interstitial water of the upper 2 cm of sediment, on day 26 of the sediment-water exchange experiment.

	column		
	I ($-O_2$)	II ($+O_2$)	III ($-O_2$)
SRP	56	23	138

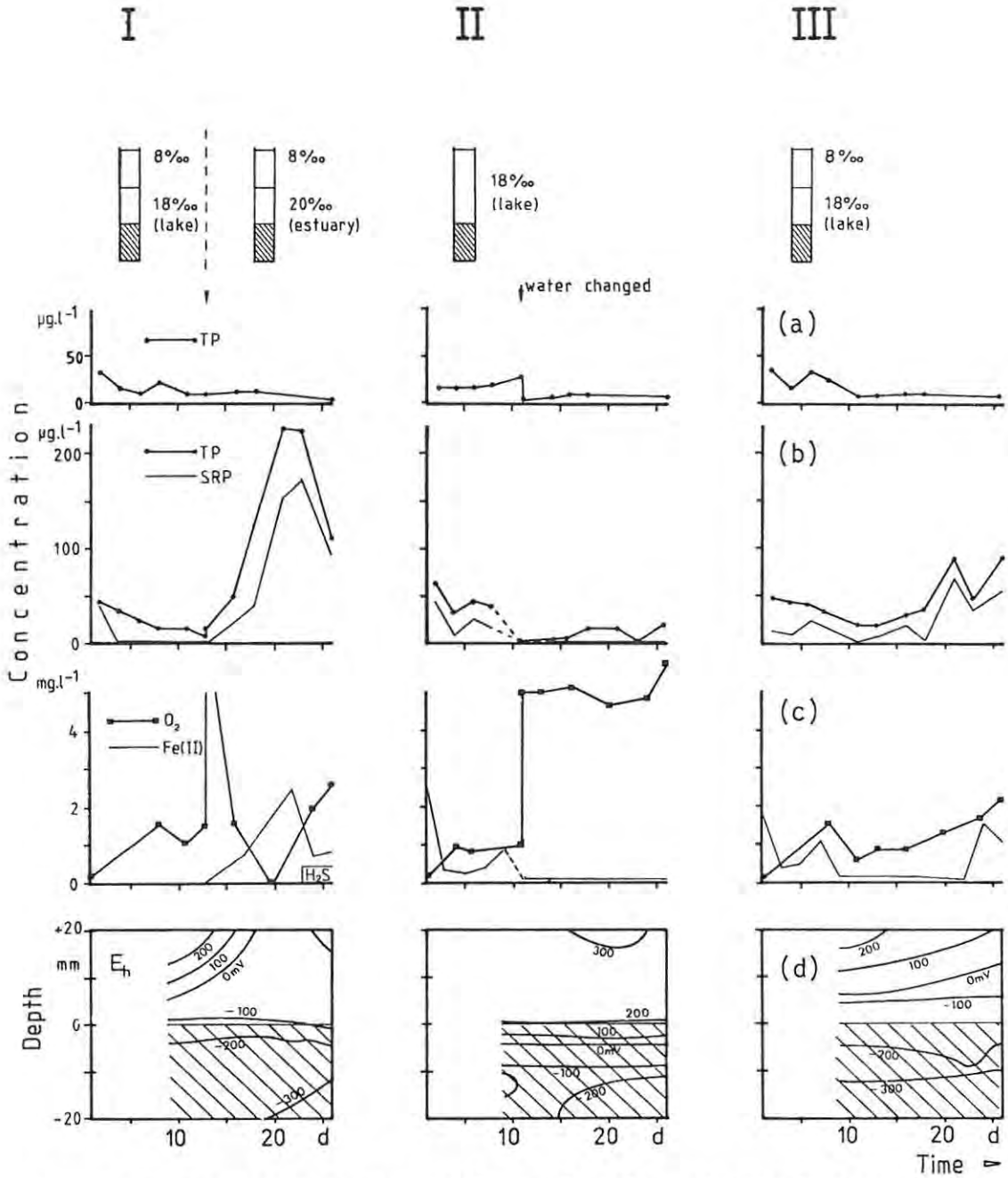

Figure 9. Physical and chemical results for columns I, II and III of the laboratory core sediment. The layout of the experiment is summarized at the top of the diagram.

(a) Total phosphorus in upper water layer.

(b) Total and soluble reactive phosphorus in lower water layer.

(c) Oxygen and iron(II) concentrations in the lower water layer.

(d) Electrode potential isopleths in the sediment and overlying water, to the same scale as Figure 7(b).

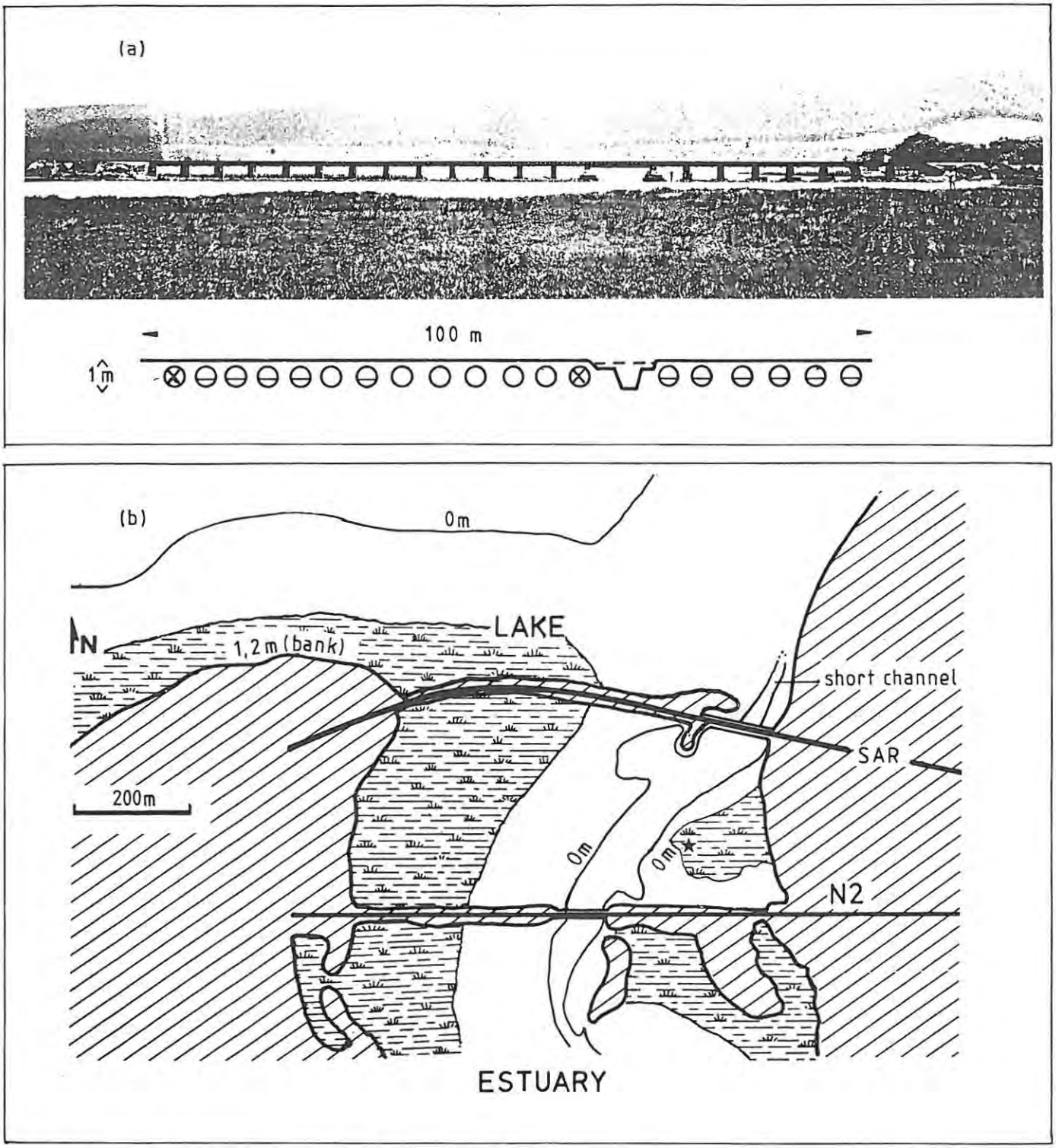

Figure 10. The connection between the lake and the estuary.

(a) The channel cross-section at the railway bridge[from the point marked ★ in (b)]. At high tide, the water just overtops the ballast covering the culverts.

⊗ = blocked culvert;
⊖ = partly obstructed culvert.
(After Kluger, 1975)

(b) The topography and bathymetry of the region surrounding the railway (SAR) bridge and national road (N2) bridge. The 1,2 m bank level applies to the closed (flooded) phase only.

= approximate edge of the lake during the open phase.
(Modified from NRIO, 1975,1976, with the help of aerial photographs reproduced in Robarts, 1973 and Kluger, 1975).

C. BRIDGE INFLOW AND OUTFLOW

The current speeds, water levels, salinities and phosphorus concentrations measured at the railway bridge (Figure 10) over a 12 h period at spring tide have been plotted on a single diagram (Figure 11). The estimated cross-section of the bridge was 10 m^2 (Kluger, 1975; Moes, 1976, with allowance for blocked culverts). The maximum current speed recorded was 1 $m.s^{-1}$. For the purposes of this calculation, the current speed is assumed to be constant across the whole channel, though there is clearly more resistance to flow in the culverts than in the main channel. The maximum flow rate was thus 10 $m^3.s^{-1}$.

IV. DISCUSSION

A. LAKE SAMPLING

The conditions in the lake have considerable bearing on the kinds and rates of phosphorus exchange, and for this reason must be considered in some detail.

1. Oxygen depletion

It is clear from Figure 7 that inflow of large volumes of river water to Swartvlei during the closed - mixed - phase, rapidly induced meromixis. After the mid-October rains, large quantities of organic material entered the lake, and it is probable that the oxygen demand generated by microbial decay of this material is a major factor in the deoxygenation of the monimolimnion.

Strong westerly winds in mid-November caused a downward mixing effect, but the monimolimnion was reinforced toward the end of November, by a combination of river inflow and possible inflow of saline water from the estuary (although no increase of bottom salinity occurred).

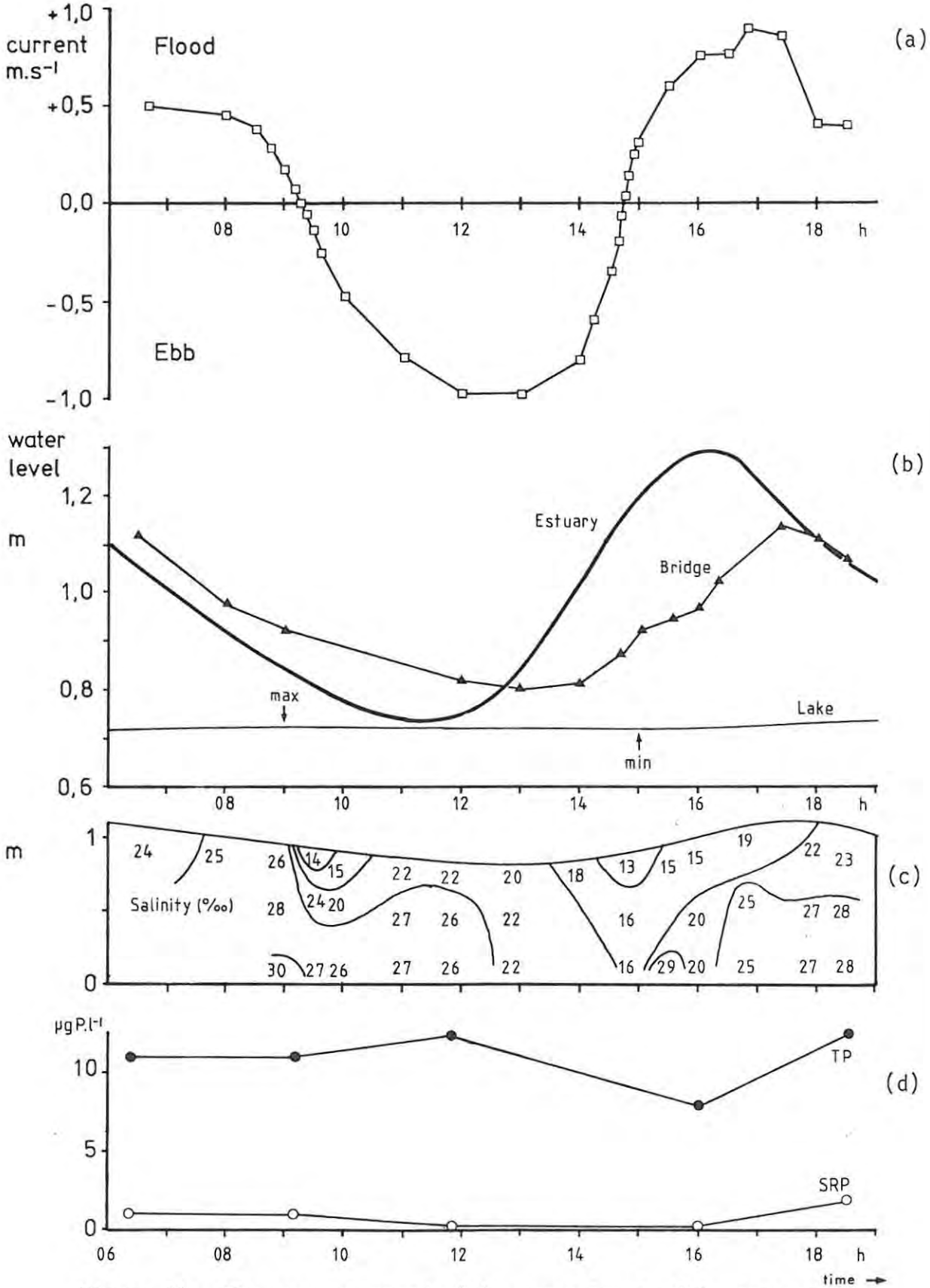

Figure 11. The current speeds (a), water levels (b), salinity changes (c), and phosphorus concentrations (d) at the railway bridge, Swartvlei, during the spring tidal cycle on 21 December 1980.

Further heavy rains in the beginning of December were followed by wind-mixing and broadening of the thermocline, but the 1 mg $O_2.\ell^{-1}$ layer remained about 4 m thick.

2. Salinity and sulphur

The inflow of seawater via the estuary was not studied in detail until the latter half of December. Slight increases in the oxygen concentration of the bottom water could be seen after the spring tides of 22 November and 22 December, but only during the 22 December spring tide was actual confirmation obtained that there had been an inflow of dense oxygenated water. Figure 11 shows that saline water (up to 25%) entered the seaward end of the lake, and until 25 December the bottom-water oxygen levels in the lake were slightly elevated relative to the 8→11 m band of water.

The slight increase in oxygen concentration was reflected in a very marked rise in sediment E_h (Figure 7). By 31 December, the sediment-water interface had become deoxygenated again, and there was a distinct smell of H_2S in the bottom water. On 1 January the H_2S concentration at a depth of 11,5 m had reached 0,1 mg.ℓ^{-1}.

A study of sulphur dynamics was not the aim of this project, and the cation content of Swartvlei water was too high for simple adaptation of freshwater sulphate analysis methods. Inasmuch as the appearance of H_2S might be related to seawater inflow to the lake, it is necessary to comment briefly. Seawater, with a sulphate concentration > 2500 mg.ℓ^{-1} (Tait, 1972), is well-known as a sulphur source for coastal lakes and estuaries (Hutchinson, 1957; Head, 1976), and the sulphate concentration in the rivers feeding Swartvlei is generally < 10 mg.ℓ^{-1} (Dept. Water Affairs/Forestry/Environment Data Bank,

Pretoria). When oxygen resources have been depleted, $SO_4^=$ is one of the alternative oxidizing agents used by bacteria. Sulphate becomes reduced to the -SH group in amino acids, and to H_2S.

In the laboratory simulation of meromixis, it was found that H_2S was only produced in measurable quantities after addition of diluted estuarine water to the lower compartment of column I, while H_2S was never detected in column III, which contained the original lake water (Figure 9). This was very likely the result of $SO_4^=$ input, but complete elimination of oxygen never occurred in column III, so the experiment was not rigorously controlled.

3. Iron

The effects of changes in oxygen concentration on iron are believed to be as follows: when the water above lake, estuarine or marine sediments becomes anoxic, sparingly-soluble hydrous iron(III) oxides at the sediment-water interface, or in suspended particles, are reduced to soluble iron(II) ions, causing break-up of the oxides and release of iron(II) into solution. Iron(II) is subject to precipitation as FeS when H_2S is present, or as iron(II) carbonate and iron(II) hydroxide in alkaline water of low E_h (Einsele, 1936 in Hutchinson, 1957; Mortimer, 1941, 1942, 1971; Doyle, 1968b; Stumm and Morgan, 1970: ch. 7; Cotton and Wilkinson, 1972).

These changes provide one explanation for the uptake and release of phosphate by sediments. Iron forms colloidal, hydrous iron(III) oxides in the presence of oxygen, and these oxides can co-ordinate with phosphate ions. The colloids eventually settle out, taking the attached phosphate with them. Depletion of oxygen at the sediment-water interface and development of low E_h cause iron(III)

to be reduced to iron(II), breakdown of the colloidal complexes and release of phosphate to solution (Einsele, 1936 in Hutchinson, 1957; Banoub, 1977; Lijklema, 1977).

It must be emphasised that the above scheme applies only to systems at low oxygen tension, and that important exchanges may occur at sediment-water interfaces which are always aerobic (Golterman, Viner and Lee, 1977; Lee, Sonzogni and Spear, 1977), although no evidence of this is available here.

The presence of humic substances may be of some importance in Swartvlei. Humic compounds form insoluble complexes with metal ions and their hydrous oxides. Some of these complexes bind phosphate ions and precipitate out of solution (Schnitzer and Khan, 1972: 239-241). This may or may not be a reversible process. Liptrot (1978; Liptrot and Allanson, 1978) has shown that the salinities and pH values encountered in Swartvlei estuary, flocculation of humic materials occurs, and this process plays an important part in the carbon cycle of the estuary. Precipitation of humic materials occurs in the lake itself, but the possible loss of phosphorus to the sediments by this route has yet to be quantified.

Two distinct peaks of iron(II) were observed above the sediment-water interface during the lake sampling programme (Figure 8(b)). The initial peak (25 November) was registered while the monimolimnion was increasing in extent, after a period of wind mixing two weeks previously. It is possible that this peak represents a fault in the handling of the Jenkin sampler, and artificial contamination of the sample. This is suspected because of the large differences found in the initial iron concentrations in the laboratory experimental

columns (Figure 9(c)). The peak is, however, associated with an unusually high SRP concentration; disappearance of both iron(II) and SRP is followed by an increase in TP at the beginning of December (Figure 8(a)). This is in agreement with the mechanism outlined above, in which the transformation of iron(II) to iron(III) leads to precipitation of phosphate as part of an insoluble colloid (detectable by the TP but not the SRP method).

In the second half of December there was a drop in electrode potential at the sediment-water interface and a simultaneous increase in the iron(II) concentration of the bottom water (23 to 31 December). The sampling programme did not continue long enough to detect FeS precipitation, if it occurred, but Watling (1977) detected a fall-off in total iron near the bottom of Swartvlei, when H_2S was present.

B. LABORATORY CORE EXPERIMENT

The experimental intact core system was intended to simulate meromixis in the laboratory, with the replacement of water after routine sampling representing the destabilizing effect of wind action. The results obtained (Figure 9(b) and (c)) in column I clearly show the expected relationship between oxygen concentration and phosphorus release. When the lower compartment of the column became completely anaerobic, the increase in SRP - expressed as an areal release rate and assuming linear changes - was 2,5 $mg.m^{-2}.d^{-1}$. When the oxygen concentration rose above 1 mg. ℓ^{-1} again, the sediment began taking up phosphorus, at an approximate rate of 1,6 $mg.m^{-2}.d^{-1}$. (The range of release rates reported for other lakes encompasses 0,8 $mg.m^{-2}.d^{-1}$ for a Danish oligotrophic lake with sandy gyttja sediment, Grane Langsø, and 36 $mg.m^{-2}.d^{-1}$ for a highly eutrophic lake in Sweden, Södra Bergundasjön (Kamp-Nielsen, 1974; Bengtsson, 1975)).

In column III, there was a simultaneous increase in iron(II) and phosphate concentration near the end of the experiment, when the oxygen level was actually greater than 1 $mg.\ell^{-1}$. The mud in column III was in a more reduced state than that of column I, according to E_h measurements, and the anomalous increase may reflect the importance of interstitial oxygen levels in mediating iron and phosphorus exchange. In the aerobic core, column II, the sediment-water interface was always oxidized, as indicated by the E_h diagram (Figure 9(d)) and the brown colour of the surface 5 mm of mud.

For comparison, actual release rates were calculated from phosphorus data recorded for the lake (Howard-Williams and Allanson, 1978) and the volumes and areas at given depths supplied by the CSIR (1978; Dr Schwartz, NRIO, personal communication; Howard-Williams and Allanson, 1978). The highest release rate, 4,4 mg $P.m^{-2}.d^{-1}$, was over the period June to July 1976. The estuary had been open to the sea for most of the previous nine months, and there had been inflows of seawater. The oxygen concentration was zero, the chemocline was at a depth of about 7 m, and the maximum phosphorus concentration within 2 m of the bottom exceeded 100 $\mu g\ P.\ell^{-1}$ for a period of 3 months, but dropped rapidly again to the former level ($\sim$ 30 $\mu g.\ell^{-1}$).

Erosion of the monimolimnion and oxygenation of the bottom waters in April 1977 and again in June 1978 resulted in the virtual disappearance of phosphorus from the water (concentration < 5 $\mu g.\ell^{-1}$). This underlines an important distinction between a lake which undergoes seasonal overturn after development of an anoxic hypolimnion, and one in which breakdown is gradual. Phosphorus released from the sediments into the bottom waters is brought to the surface at overturn, but in the case of gradual deepening of the oxygenated layer, there is

reprecipitration of phosphorus which never becomes available to primary producers. However, photosynthetic bacteria are possibly able to make use of this P resource by living at the bottom of the mixolimnion (Hutchinson, 1957). Some evidence for photosynthetic activity at the chemocline of Swartvlei has been reported (Howard-Williams and Allanson, 1978; Taylor, 1981). Perhaps a shortfall in the experimental columns was that the effect of gentle mechanical mixing on the upper and lower compartments was not tried. This would have given some indication of what rate of mixing is necessary to bring monimolimnion phosphate up to the surface before it is lost from solution, and whether this mixing rate could be generated by wind action on the lake.

C. THE RAILWAY BRIDGE INFLOW

The maximum vertical salinity gradient under the bridge at slack water was $14°/_{oo}.m^{-1}$, which produced visible refraction effects in the water, and is indicative of a wedge of highly saline water being forced upstream while less dense water flows seaward over the top. The bridge is a very definite dividing line between lake and estuary, and limits the inflow of dissolved salts to the lake (Moes, 1976; Howard-Williams and Allanson, 1978; 1979). Although surface salinity at the bridge rose to $25°/_{oo}$, no subsequent rise in lake bottom water salinity was detected.

The maximum flow rate calculated for the bridge ($10\ m^3.s^{-1}$) is similar to those derived by Moes (1976), namely: mean flow = $10\ m^3.s^{-1}$ and maximum flow = $15\ m^3\ .s^{-1}$. Integration of the current velocity curve in Figure 11 (by weighing) gives a total flood-tide inflow of $126\ 000\ m^3$ and a total ebb-tide outflow of $150\ 000\ m^3$.

The TP inflow to the lake was 1,3±0,2 kg P, and the outflow was ∿ 1,8 kg P. Unfortunately the sampling periods were spaced so that only one TP result was recorded on an ebb tide. During the afternoon flood peak, clumps of drifting *Zostera marina* and filamentous algae amounting to several kg of wet material entered the lake. The phosphate in this material was naturally not taken into account in the analysis of the water samples, but Liptrot (1978) found a net loss of 1,0 kg phosphorus from the estuary in the form of *Zostera* during the 7 March 1977 spring tide. It is reasonable to assume that the inflow of *Zostera* P to the lake was of similar magnitude. If a net mass of 0,5 kg P entered the lake during a 12 h period, this represents a loading to the lake (area = $8{,}9.10^{6}.m^{2}$) of 0,12 $mg.m^{-2}.d^{-1}$ at spring tide. Omitting the *Zostera* P, the load is -0,12 $mg.m^{-2}.d^{-1}$ (net export from lake).

D. MODEL

1. Reasons for considering a model

One of the methods used to predict the effect of a changing environment on a lake is the construction of a computer model. To apply modelling techniques to nutrient dynamics in a natural system, it is necessary to subdivide the system into discrete compartments. These are delimited in such a way that real figures can be obtained for inter-compartmental exchanges. Quantification of nutrient flux in the lake yields the exchange rates necessary for constructing a working model. These can then be used to simulate the behaviour of the lake if the phosphate concentrations or transfer rates are disturbed. Various assumptions are made, such as the physical extent of the compartments, which must be borne in mind when the model results are interpreted.

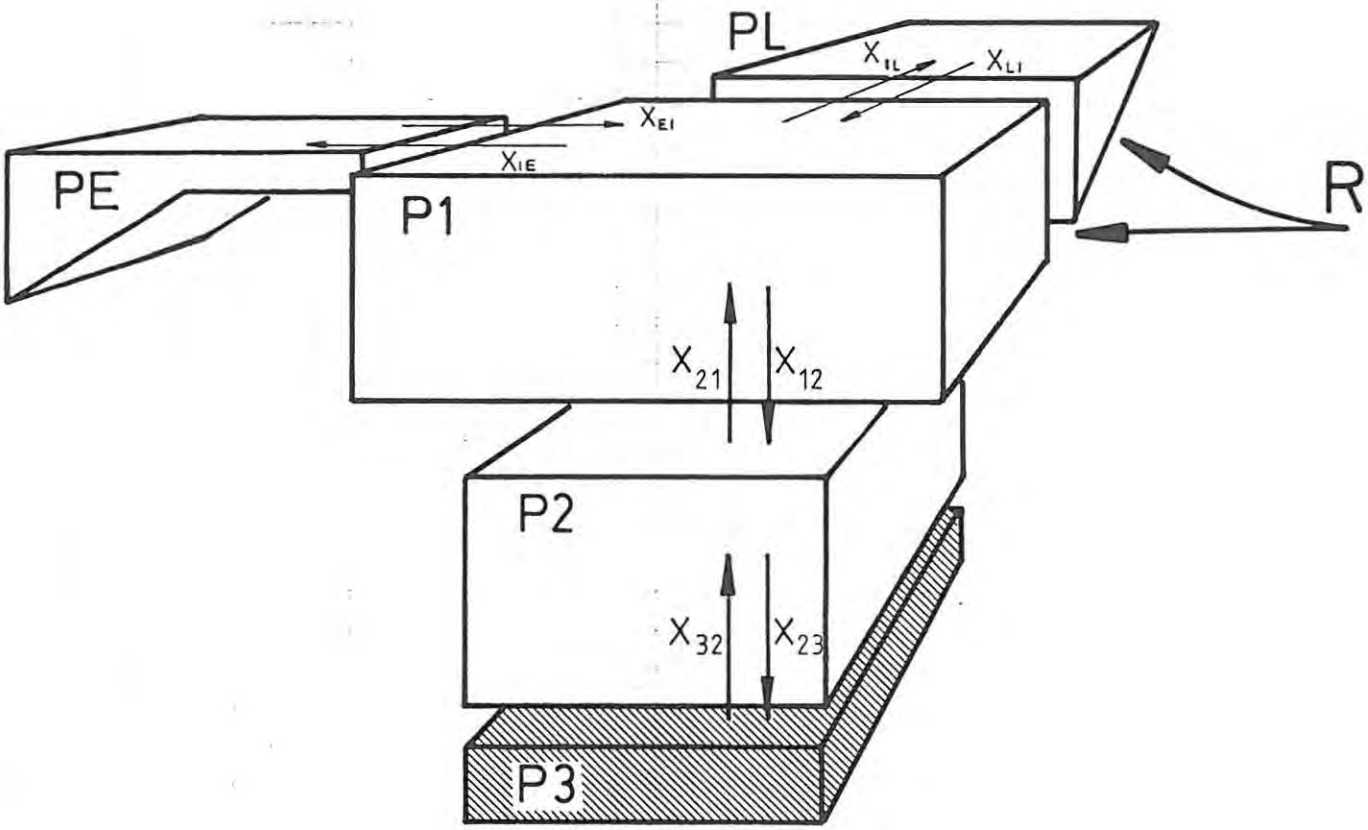

Figure 12. Swartvlei phosphorus model.

A conceptual or dynamic model of Swartvlei, showing the subdivision into compartments, and the exchange rates. This is the outline of the computer model in Appendix C.

PE = estuarine phosphorus compartment
PL = littoral phosphorus compartment
P1 = mixolimnion (6 m deep)
P2 = monimolimnion (6 m deep)
P3 = sediment (very large reservoir)
X_{mn} = exchange rate between m and n
(actual values are given in Appendix C)

R = river input, subdivided into
RL (= 0,43.R) input to PL
R1 (= 0,57.R) input to P1

2. A prototype model

A working model has been constructed for the phosphorus interchanges in the macrophyte beds of the Swartvlei littoral region, by Howard-Williams and Allanson (1978), and has been successfully run as a computer programme by Dr P. Furness, Department of Applied Mathematics, University of the Witwatersrand. A proposed model for the whole Swartvlei system is shown in Figure 12. The model has been written as a computer programme, which is still in the early developmental stages. The phosphate changes performed by the programme are regulated by the physical conditions in the lake, and by the instantaneous phosphorus concentrations in the various compartments. The programme, the assumptions made in developing the model, and a sample output, are given in Appendix C.

V. CONCLUSION

A.1. Ectogenic meromixis, resulting from seawater and river inflow, is the dominating factor controlling phosphate dynamics in the main basin of Swartvlei. When the lake is in the completely mixed state, permitting exchange of water between the deeper and shallower levels, oxygenation of the sediment surface acts as a block to phosphorus release, and the net phosphorus transfer is downwards.

2. During meromixis, the monimolimnion receives phosphorus from the sediments, but the chemocline, because of its sharp density gradient, is an effective barrier to turbulent exchange of phosphorus into the mixolimnion.

B.1. Some form of hydrated iron(III) oxide/humic acid/$PO_4^{\equiv}$ interaction results in the precipitation of dissolved

phosphorus as soon as the monimolimnion becomes aerated by wind mixing. It is possible - although no direct evidence has been sought - that flocculation, as a result of the mixing of humic and saline water, is an important route by which phosphorus reaches the sediments. This aspect warrants further study.

2. The total phosphorus input at the bridge during high tide is a very small contribution to the phosphorus content of the lake. This supports statements by Moes (1976), and Howard-Williams and Allanson (1978), that the railway bridge across the southern end of the lake has moderated the influence of the estuary and the sea on Swartvlei itself.
3. The phosphorus dynamics of the main basin of Swartvlei contribute much less to the nutrient concentration (and hence primary production) of the lake than do the littoral phosphorus interchanges. The exchange of phosphorus and other material between the main basin and the littoral is still an unknown factor: it is likely that littoral phosphorus, if it is transferred to the main body of the lake, is either locked up in the sediments or lost to the sea.
4. The computer model, as it stands, is not satisfactory. Some of the assumptions made, such as the arbitrary rate of sedimentation and the littoral→pelagic exchange rate, need to be quantified. The simulation of rainfall and tides also leaves much to be desired. On the other hand, assembling such a model has indicated where there are missing pieces of information which need to be defined.

As such, the exercise has been of extreme value.

VI. ACKNOWLEDGEMENTS

I would like to thank Professor B.R. Allanson for supervising this project, and Alan and Elspeth Whitfield for their help and tolerance while I occupied the IFWS laboratory at Swartvlei. I also acknowledge the assistance I received with fieldwork from my fellow-student, David Taylor and the co-operation of the staff of the Lakes Nature Conservation Station. Dr Mike Perrin was kind enough to read through the rought draft and provide constructive criticism.

Mr Lee Christmas and Mr Dudley Forsyth were extremely helpful in making and tracking down equipment, and Koos Wagner performed a great deal of fetching and carrying in the field. Mr H. Murray kindly built two sets of platinum electrodes.

I thank Nola Bruton and Sally Guye for locating, copying and despatching references, and Mrs Pat Eva for doing the typing of this report, to a very tight schedule.

I am very grateful to the people of P.J. van Reenen (Pty) Ltd (Sawmillers) for their generosity in providing food and accommodation and for their gift of part of a flawed frame saw, which formed the mooring anchor at station d.

Finally, I take this opportunity to thank the Public Services Commission for providing me with a bursary, and the Department of Water Affairs, Forestry and Environmental Conservation, for allowing study leave, for the duration of the 1980 Limnology course.

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VIII. APPENDICES

APPENDIX A

The equations used for calculation of the density of water, s_t (in $kg.dm^{-3}$), from temperature and salinity (Knudsen, 1901).

$$s_t = 1 + \sigma_t/1000$$

$$\sigma_t = \Sigma_t + (\sigma_0 + 0{,}1324)\,(1 - A_t + B_t.(\sigma_0 - 0{,}1324))$$

$$\Sigma_t = \frac{(t - 3{,}98)^2}{503{,}570}.\frac{t + 283}{t + 67{,}26}$$

$$A_t = t.(4{,}7867 - 0{,}098185.t + 0{,}0010843.t^2).10^{-3}$$

$$B_t = t.(18{,}030 - 0{,}8164.t + 0{,}01667.t^2).10^{-6}$$

$$\sigma_0 = -0{,}069 + 1{,}4708.Cl - 0{,}001570.Cl^2 + 0{,}0000398.Cl^3$$

$$Cl = (S - 0{,}030)/1{,}8050$$

Cl = amount of chlorine in water, expressed as $g.kg^{-1}$ (= $^{\circ}/_{oo}$)

S = amount of salt in water, expressed as $g.kg^{-1}$

t = temperature in °C

APPENDIX B. Phosphorus determination method.

The reagents were made up as follows:

(a) Reagent A: acidic molybdenum + antimony

Sodium molybdate	8,52 g
Potassium antimonyl tartrate	0,572 g
Concentrated sulphuric acid (96%, 1,84 kg.ℓ^{-1})	45,0 ml

The sodium molybdate and potassium antimonyl tartrate were each dissolved in about 200→300 mℓ of water. The sulphuric acid was added to the tartrate solution, and the two solutions were mixed, cooled and made up to 1ℓ. Reagent A was kept up to 1 week in a fridge, before being discarded.

(b) Reagent A′: acidic antimony

This reagent was made up in the same way as reagent A, with the omission of sodium molybdate. It was used for making up a colour-blank reagent, when phosphorus was determined in highly-stained water.

(c) Reagent B: 0,514 M H_2SO_4

Concentrated sulphuric acid	28,6 mℓ

The acid was made up to 1ℓ.

(d) Mixed reagent

Reagent A	100 mℓ
Reagent B	100 mℓ
Ascorbic acid	0,62 g

Reagents A and B were mixed and the ascorbic acid was added. The mixed reagent was kept in a dark bottle at room temperature, and used

within 8 hours.

(e) Standards

Potassium dihydrogen phosphate 4,394 g

The KH_2PO_4 was dissolved in 1ℓ of distilled water and stored in a fridge. The standard was further diluted to 10 mg.ℓ^{-1} and 0,1 mg.ℓ^{-1} before use.

Forty mℓ of sample was transferred by pipette to a 50 mℓ volumetric flask. A piston-type dispenser was used to add 8 mℓ of mixed reagent, and the volume was made up to 50 mℓ. The mixture was shaken and allowed to stand at least 10' for colour development. The absorbance at 882 nm was read in 4 cm cells, using a Shimadzu 4-decimal digital spectrophotometer (UV-150-02, Kyoto, Japan).

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C##################################################################
C#                                                                #
C#     ITERATIVE SIMULATION MODEL FOR SWARTVLEI PHOSPHORUS DYNAMICS   #
C#     ------------------------------------------------------------   #
C#                                                                #
C# THIS MODEL SIMULATES THE PHOSPHORUS FLUX THROUGH SWARTVLEI,        #
C# A SOUTHERN CAPE COASTAL LAKE WHICH UNDERGOES PERIODIC SALINITY-   #
C# INDUCED STRATIFICATION, AND SUBSEQUENT DEOXYGENATION OF THE      #
C# BOTTOM WATERS (MONIMOLIMNION).                                   #
C# THE INTER-COMPARTMENTAL CHANGES HAVE BEEN THE SUBJECT OF THE     #
C# PRESENT STUDY, AND INFORMATION HAS ALSO BEEN OBTAINED FROM       #
C# ROBARTS AND ALLANSON (1977), HOWARD-WILLIAMS (1977) AND HOWARD-  #
C# WILLIAMS AND ALLANSON (1978, 1979).                             #
C# THE DISCUSSION BY GOLTERMAN (1980) HAS BEEN OF GREAT ASSISTANCE. #
C# (GOLTERMAN, H.L. (1980) PHOSPHATE MODELS: A GAP TO BRIDGE.       #
C#  HYDROBIOLOGIA, VOL 72: 61-71.)                                 #
C#-----------------------------------------------------------------#
C# THE ASSUMPTIONS WHICH WERE MADE IN ORDER TO SIMPLIFY THE MODEL    #
C# ARE LISTED BELOW:                                                #
C#                                                                 #
C# A.                                                              #
C# THE PHOSPHORUS EXCHANGE RATES MEASURED IN THE LABORATORY OR IN   #
C# ISOLATED FIELD EXPERIMENTS ARE REPRESENTATIVE OF THE LAKE AS A   #
C# WHOLE, AND REMAIN SO OVER AN EXTENDED PERIOD. (THIS HAS BEEN     #
C# QUESTIONED BY KAMP-NIELSEN (1975).                              #
C# (KAMP-NIELSEN, L. (1975) SEASONAL VARIATION IN SEDIMENT-WATER    #
C#  EXCHANGE OF NUTRIENT IONS IN LAKE ESROM, VERHANDLUNGEN, INTER- #
C#  NATIONALE VEREINIGUNG FUER THEORETISCHE UND ANGEWANDTE LIMNO-  #
C#  LOGIE, VOL 19: 1057-1065.)                                     #
C# B.                                                              #
C# THE LAKE CONSISTS OF FIVE COMPARTMENTS, WHICH HAVE REGULAR       #
C# GEOMETRIC SHAPES:                                               #
C#    1. PL - THE LITTORAL                                        #
C#    2. PE - THE ESTUARY                                         #
C#    3. P1 - THE MIXOLIMNION/LAKE SURFACE LAYER                  #
C#    4. P2 - THE MONIMOLIMNION/DEEP LAKE LAYER                   #
C#    5. P3 - THE BOTTOM SEDIMENTS                                #
C#                                                                #
C#    1. PL IS NOT CONSIDERED TO HAVE ANY INNER WORKINGS, FOR THE  #
C#       PURPOSE OF THIS MODEL. IT HAS BEEN DESCRIBED BY HOWARD-   #
C#       WILLIAMS AND ALLANSON (1978). THERE IS AN ARBITRARY EXCHANGE #
C#       BETWEEN PL AND P1 (NOT YET QUANTIFIED).                   #
C#    2. PE IS AN ARBITRARY RESERVOIR CONSISTING OF THE SEA AND THE #
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```
C#       ESTUARY, AND IS OF VERY LARGE SIZE, COMPARED WITH THE LAKE.  #
C#    3. P1 IS A RECTANGULAR LAYER 6 METRES THICK, WHICH VARIES IN    #
C#       VOLUME FROM 36 000 000 CUB METRES (OPEN PHASE) TO            #
C#       46 000 000 CUB METRES (HIGH FLOOD LEVEL) AT WHICH STAGE IT   #
C#       DISCHARGES WATER RAPIDLY TO REVERT TO THE OPEN PHASE.        #
C#                                                                    #
C#     A 'RANDOM' NUMBER GENERATOR CAUSES A MEAN DAILY DISCHARGE OF   #
C#    158 800 CUB METRES (INCLUDING EVAPORATION LOSS). THE            #
C#    PHOSPHATE LOAD BROUGHT IN BY THE RIVERS IS 10 MG/CUB METRE      #
C#    EXCEPT AT DISCHARGES ABOVE 250 000 CUB METRES/DAY, WHEN THE     #
C#    LOAD INCREASES TO 40 MG/CUB METRE.                              #
C#                                                                    #
C#    4. P2 IS A RECTANGULAR LAYER 6 METRES THICK, WITH A CONSTANT    #
C#       VOLUME OF 14 000 000 CUB METRES. IT RECEIVES INFLOW FROM THE #
C#       SEA DURING THE OPEN PHASE AT SPRING TIDE (THE TIDES FOLLOW   #
C#       A STRICT 7 DAYS NEAP/7 DAYS SPRING CYCLE).                   #
C#    5. P3 IS AN ARBITRARY RESERVOIR OF PHOSPHORUS, WHICH TENDS TO   #
C#       RELEASE PHOSPHORUS AT LOW OXYGEN CONCENTRATIONS ("<1MG/L")   #
C#       AND TAKE UP PHOSPHORUS AT HIGH OXYGEN CONCENTRATIONS. THERE  #
C#       IS CONTINUOUS PRECIPITATION OF DEBRIS.                       #
C#                                                                    #
C#    THE MONIMOLIMNION SWITCHES FROM AEROBIC TO ANAEROBIC ACCORDING  #
C#    TO THE DIFFERENCE IN SALINITY BETWEEN THE UPPER AND LOWER       #
C#    COMPARTMENTS.                                                   #
C# C.                                                                 #
C# THE CHEMOCLINE IS A HORIZONTAL PLANE.                              #
C####################################################################
C
C--------------------------------------------------------------------
C-    THE PROGRAM BEGINS HERE:                                      -
C-                                                                  -
C-    ITERATIVE SIMULATION MODEL FOR SWARTVLEI PHOSPHORUS DYNAMICS  -
C--------------------------------------------------------------------
      MASTER PHOSPH
      REAL LEVEL,RAIN(600)
      DATA TN,TS,BAR /'N','S','-'/
5     WRITE(6,605)
605   FORMAT(' FOR HOW LONG (D)?, SALINE FLUX?, O2 CUTOFF?,PRINT INT.?')
      READ(5,501)SMDAY,FLUX,CUTOF,DAYNR
501   FORMAT(4F0.0)
      RNDM=0
      TIDE=0
      KOUNT=0
C*********************************************************************
C* DEFINITION OF LAKE CONSTANTS AND INITIAL VALUES FOR VARIABLES:  *
C*********************************************************************
C
      LEVEL=5.0E+07
      A=8.9E+06
      UPSAL=10
      DNSAL=20
      P1=60
      P2=60
      P3=10000
      PL=30
      PE=60
      X12=0,05
      X21=0,01
      XIL=0,01
      XL1=0,01
C--------------------------------------------------------------------
```

```
C- THE DO LOOP WHICH PERFORMS ITERATIVE CALCULATIONS OF THE          -
C- PHOSPHORUS CONCENTRATIONS IN EACH COMPARTMENT, BASED ON THE       -
C- "ENVIRONMENTAL" CONDITIONS:                                       -
C---------------------------------------------------------------------
      MDAY=SMDAY
      DO 10 IDAY=1,MDAY
      DAY=IDAY
      WEEK=DAY/7.0
      REST=WEEK-AINT(WEEK)
      KOUNT=KOUNT+1
      RNDM=RNDM+3.14159
      Y=RNDM**5.0
      Y=Y-AINT(Y)
      RNDM=Y
      RAIN(IDAY)=361046.0*RNDM
      IF(TIDE.EQ.0) LEVEL=LEVEL+RAIN(IDAY)
      IF(RAIN(IDAY).GE.2.5E+05) GOTO 21
      RAINP=RAIN(IDAY)*10.0/A
      GOTO 22
21    RAINP=RAIN(IDAY)*40.0/A
22    IF(LEVEL.LE.6.0E+07) GOTO 20
      LEVEL=5.0E+07
      TIDE=1.0
      KOUNT=0
      IOPEN=183
20    CONTINUE
      IF(TIDE.EQ.0) GOTO 33
30    IF(TIDE.EQ.0.5.AND.REST.EQ.0) GOTO31
      IF(TIDE.EQ.1.0.AND.REST.EQ.0) GOTO32
      GOTO 33
31    TIDE=1.0
      GOTO 33
32    TIDE=0.5
33    CONTINUE
      IF(KOUNT.EQ.IOPEN.AND.TIDE.GT.0) TIDE=0
      CUMTID=DAY/14.0
      REM=CUMTID-AINT(CUMTID)
      IF(TIDE.EQ.1.0) DNSAL=DNSAL+FLUX*DNSAL
      DELSAL=DNSAL-UPSAL
      IF(DELSAL.LT.CUTOF) OXY=7.0
      IF(DELSAL.GE.CUTOF) OXY=0.1
      IYST=IDAY-1
      IF(IYST.LT.1) IYST=1
      UPSAL=UPSAL*3.6E+07/(3.6E+07+RAIN(IDAY))
      IF(UPSAL.GT.DNSAL) WRITE(6,601)
601   FORMAT(' ********* CAUTION! YOUR LAKE HAS TURNED OVER *********')
      CUMRAN=DAY/5.0
      REM=CUMRAN-AINT(CUMRAN)
      IF(UPSAL.LT.DNSAL.AND.REM.EQ.0)GOTO 40
      GOTO 50
      DIFPO4=P2-P1
      IF(DIFPO4.LT.0) DIFPO4=-DIFPO4
40    UPSAL=UPSAL+0.2*DELSAL*1.4E07/(LEVEL-1.4E07)
      P1=P1+0.1*DIFPO4*1.4E+07/(LEVEL-1.4E+07)
      DNSAL=DNSAL-0.2*DELSAL
      P2=P2+0.1*DIFPO4*(LEVEL-1.4E+07)/1.4E+07
50    CONTINUE
C---------------------------------------------------------------------
C-                                                                   -
C- THE DETERMINATION OF RELEASE RATES IS DEPENDENT ON THE OXYGEN     -
C- CONCENTRATION OF THE MONIMOLIMNION:                               -
```

```
C-                                                                    -
C---------------------------------------------------------------------
      IF(OXY.GT.1) X23=1.80
      IF(P2.LE.12.0) X23=0.0 .
      X32=0.01
      IF(OXY.LT.1.AND.P2.LE.300)X32=2.50
      IF(OXY.GT.300)X32=0
      X1E=0
      XE1=0
      STTUS=BAR
      IF(TIDE.EQ.0.5) X1E=0.64
      IF(TIDE.EQ.0.5) XE1=0.01
      IF(TIDE.EQ.0.5) STTUS=TN
      IF(TIDE.EQ.1.0) X1E=0.43
      IF(TIDE.EQ.1.0) XE1=0.55
      IF(TIDE.EQ.1.0) STTUS=TS
      RL=RAINP*0.43
      R1=RAINP*0.57
      P1=P1+R1+X21-X12+XL1-X1L-X1E
      PL=PL+RL+X1L-XL1
      P2=P2+X12-X21+X32-X23+XE1
      P3=P3+X23-X32
      REM5=DAY/DAYNR
      RM5=REM5-AINT(REM5)
      IF(RM5.NE.0.AND.IDAY.NE.1) GOTO 10
60    WP1=P1*LEVEL/5.0E+07/6.0
      WP2=P2/6.0
      WPL=PL/3.0
      IF(IDAY.EQ.1)WRITE(6,603)
603   FORMAT(' DAY STATUS SALINITY  OXYGEN   RAIN  LAKE LEVEL',
     &'    P1     P2     P3       PL')
      WRITE(6,602)IDAY,STTUS,UPSAL,DNSAL,OXY,RAIN(IDAY),LEVEL,
     &            WP1,WP2,P3,UPL
602   FORMAT(1X,I4,2X,A2,3F6.1,2F10.0,2F6.1,F8.1,1F6.1)
10    CONTINUE
C---------------------------------------------------------------------
C-     END OF DO LOOP                                                 -
C---------------------------------------------------------------------
      WRITE(6,606)
606   FORMAT(' START THE LAKE AGAIN ? (1=YES, 0=NO)')
      READ(5,502)IYES
502   FORMAT(I0)
      IF(IYES.EQ.1)GOTO 5
      STOP
      END
      FINISH
```

```
SUBFILE:LAKE LC=B200 LENGTH:  32     ZOMS

   SAMPLE OUTPUT FROM THE SWARTVLEI SIMULATION MODEL
   -------------------------------------------------

   "RESULTS" ARE GENERATED ON A DAILY BASIS - EVERY SEVENTH DAY
   IS DISPLAYED.

   STATUS = '-' WHEN ESTUARINE BAR IS CLOSED
          = 'N' AT NEAP TIDE
          = 'S' AT SPRING TIDE
   SALINITY: MIXOLIMNION AND MONIMOLIMNION (GRAM SALT/KILOGRAM WATER)
   OXYGEN:    0.1 = ANAEROBIC
              7.0 = AEROBIC
   'RAIN':    DISCHARGE FROM RIVERS IN CUB METRES / DAY
   LAKE LEVEL: VOLUME OF LAKE IN CUB METRES
   P1 = PHOSPHORUS CONCENTRATION IN MIXOLIMNION (MG / CUB METRE)
   P2 = PHOSPHORUS CONCENTRATION IN MONIMOLIMNION
   PL = PHOSPHORUS CONCENTRATION IN LITTORAL
   P3 = PHOSPHORUS LOAD IN SEDIMENT (MG / SQ METRE)

   NOTE THAT, IN THIS MODEL, THE THE LOSSES FROM THE MIXOLIMNION ARE
   SUCH THAT P1 BECOMES NEGATIVE AFTER LITTLE OVER A YEAR. THIS
   INDICATES THAT ANY OF THE RATES OF EXCHANGE WITH P1 COULD BE
   INCORRECT.

FOR HOW LONG (D)?, SALINE FLUX?, O2 CUTOFF?,PRINT INT.?
600 ,03 2 7
```

DAY	STATUS	SALINITY		OXYGEN	RAIN	LAKE LEVEL	P1	P2	P3	PL
1	-	16.9	20.0	0.1	6640.	50006640.	10.0	10.4	9997.5	10.0
7	-	16.5	18.0	0.1	244005.	50876201.	10.4	13.0	9982.5	10.3
14	-	16.6	16.5	0.1	191528.	52445890.	11.0	15.9	9965.0	10.8
21	-	16.9	17.4	0.1	241654.	53907773.	11.8	18.9	9947.5	11.5
28	-	16.8	13.7	0.1	356312.	55278664.	12.4	21.9	9930.0	12.0
35	-	16.8	12.6	0.1	13427.	56534965.	13.1	24.8	9912.5	12.5
42	-	16.6	12.2	7.0	127119.	57630724.	13.6	22.8	9925.0	12.9
49	-	16.4	11.8	7.0	222932.	58743107.	14.1	20.7	9937.6	13.2
56	N	16.1	11.3	7.0	340965.	50000000.	12.3	18.7	9950.1	13.9
63	S	9.9	11.3	7.0	200892.	50000000.	11.9	16.8	9962.6	14.3
70	N	16.0	12.4	0.1	237396.	50000000.	11.5	17.8	9960.2	14.6
77	S	9.7	12.2	0.1	337922.	50000000.	11.4	18.3	9957.8	15.5
84	N	9.8	13.8	0.1	98421.	50000000.	11.0	19.7	9952.9	15.8
91	S	16.0	12.7	0.1	291743.	50000000.	10.8	20.7	9948.0	16.6
98	N	16.1	14.5	0.1	61530.	50000000.	10.3	22.1	9943.1	16.7
105	S	16.4	13.1	0.1	92202.	50000000.	9.8	23.1	9938.2	17.0
112	N	16.4	14.6	0.1	157473.	50000000.	9.6	24.5	9933.3	17.6
119	S	16.4	14.2	0.1	103257.	50000000.	9.2	25.4	9928.4	18.1
126	N	16.9	14.9	0.1	77667.	50000000.	8.7	26.9	9923.5	18.1
133	S	17.0	14.5	0.1	251360.	50000000.	8.2	27.8	9918.6	18.5
140	N	17.3	15.2	0.1	50672.	50000000.	8.0	29.2	9913.7	19.0
147	S	17.3	14.8	0.1	230229.	50000000.	7.7	30.2	9908.8	19.6
154	N	17.2	16.6	0.1	22119.	50000000.	7.7	31.6	9903.9	20.6
161	S	17.6	15.1	0.1	162434.	50000000.	7.1	32.6	9899.0	20.7
168	N	17.6	16.8	0.1	192249.	50000000.	6.8	34.0	9894.1	21.1
175	S	16.1	15.4	0.1	30194.	50000000.	6.2	35.0	9889.2	21.3
182	N	16.0	17.1	0.1	310665.	50000000.	6.2	36.4	9884.3	22.2
189	S	17.9	16.5	0.1	197590.	50000000.	5.9	37.3	9879.4	22.8
196	N	16.3	17.2	0.1	203417.	50000000.	5.8	38.8	9874.5	23.4
203	S	16.3	16.7	0.1	183254.	50000000.	5.2	39.7	9869.6	23.7
210	N	16.9	17.5	0.1	300499.	50000000.	4.9	41.1	9864.7	24.1
217	S	16.9	17.0	0.1	174759.	50000000.	4.4	42.1	9859.8	24.4
224	N	15.8	19.1	0.1	113286.	50000000.	4.0	43.5	9854.9	24.7
231	S	15.4	17.5	0.1	302803.	50000000.	3.5	44.5	9850.0	25.1
238	N	15.4	19.5	0.1	304565.	50000000.	3.4	45.9	9845.1	25.7
245	-	15.8	17.5	0.1	75442.	51085523.	3.8	46.8	9840.2	26.2
252	-	15.6	16.6	0.1	353622.	52346369.	4.2	47.6	9835.3	26.7
259	-	15.3	15.9	0.1	161737.	53761346.	4.7	48.5	9830.4	27.3
266	-	15.2	15.0	7.0	170747.	54902437.	5.2	48.9	9828.0	27.8
273	-	12.8	14.6	7.0	31126.	56401762.	5.7	47.3	9838.0	28.3
280	-	12.6	13.9	7.0	239320.	57684034.	6.1	45.3	9850.6	28.7
287	-	12.3	13.6	7.0	270489.	58946608.	6.6	43.2	9863.1	29.2
294	N	11.9	13.3	7.0	318247.	50000000.	5.8	41.2	9875.6	29.7
301	S	11.6	13.1	7.0	263639.	50000000.	5.5	39.2	9888.1	30.3
308	N	11.3	15.0	0.1	66638.	50000000.	5.1	40.2	9885.7	30.6
315	S	11.8	14.1	0.1	92178.	50000000.	4.6	41.2	9880.8	30.9
322	N	11.3	15.8	0.1	317967.	50000000.	4.2	42.6	9875.9	31.2
329	S	11.7	15.4	0.1	35798.	50000000.	3.9	43.6	9871.0	31.9
336	N	12.0	16.3	0.1	357534.	50000000.	3.8	45.0	9866.1	32.5
343	S	12.1	15.9	0.1	11594.	50000000.	3.3	46.0	9861.2	32.9

350	N	12.4	16.7	0.1	72156.	500000000.	3.2	47.4	9856.3	33.6	
357	S	12.4	16.2	0.1	112630.	500000000.	2.6	48.4	9851.4	33.8	
364	N	12.4	18.2	0.1	62927.	500000000.	2.3	49.8	9846.5	34.1	
371	S	12.6	16.6	0.1	332551.	500000000.	2.0	49.9	9846.6	34.8	
378	N	12.8	18.5	0.1	330397.	500000000.	1.7	50.1	9849.2	35.2	
385	S	13.2	16.9	0.1	238991.	500000000.	1.2	50.2	9849.3	35.5	
392	N	13.2	18.8	0.1	317035.	500000000.	1.0	50.0	9854.3	36.3	
399	S	13.3	18.1	0.1	131386.	500000000.	1.6	50.1	9854.4	36.5	
406	N	13.9	19.0	0.1	178291.	500000000.	0.3	49.9	9859.5	37.0	
413	S	13.6	18.5	0.1	343336.	500000000.	0.2	50.0	9859.5	37.9	
420	N	14.2	19.3	0.1	320199.	500000000.	-0.1	49.7	9864.6	38.2	
427	S	14.0	18.7	0.1	38100.	500000000.	-0.2	49.9	9864.7	39.3	
434	N	14.0	20.9	0.1	170453.	500000000.	-0.4	50.0	9867.3	39.8	
441	S	14.5	19.0	0.1	61961.	500000000.	-0.8	50.2	9867.3	40.2	
448	S	14.4	21.2	0.1	309127.	500000000.	-0.8	49.9	9872.4	41.1	
455	S	14.9	19.2	0.1	47586.	500000000.	-1.2	50.1	9872.5	41.5	
462	N	15.0	21.4	0.1	185166.	500000000.	-1.5	49.8	9877.5	42.0	
469	S	15.0	20.7	0.1	137858.	500000000.	-2.0	50.0	9877.6	42.3	
476	N	15.5	21.6	0.1	311351.	500000000.	-2.3	49.7	9882.7	42.8	
483	-	15.4	20.3	0.1	195102.	513192222.	-1.9	49.7	9882.8	43.5	
490	-	15.4	18.5	0.1	330133.	529750333.	-1.3	49.8	9882.8	44.5	
497	-	15.1	17.8	0.1	127051.	542751717.	-1.1	49.8	9882.9	44.8	
504	-	14.8	17.3	0.1	85679.	553999247.	-0.8	49.8	9883.0	45.2	
511	-	14.6	16.3	7.0	346352.	567678017.	-0.5	49.5	9885.6	45.7	
518	-	14.1	15.9	7.0	164509.	582130377.	-0.0	47.8	9895.6	46.4	
525	-	13.8	15.2	7.0	153187.	597228907.	0.4	45.8	9908.1	46.9	
532	N	13.6	16.5	0.1	18234.	500000000.	0.2	45.8	9910.7	47.4	
539	S	13.3	16.3	0.1	297067.	500000000.	-0.2	46.8	9905.8	47.9	
546	S	13.7	17.6	0.1	44149.	500000000.	-0.7	48.2	9900.9	48.0	
553	S	13.7	17.3	0.1	42371.	500000000.	-1.1	49.1	9896.0	48.4	
560	N	14.1	18.4	0.1	46052.	500000000.	-1.4	49.7	9896.1	48.8	
567	S	14.0	18.0	0.1	350936.	500000000.	-1.9	49.9	9896.2	49.2	
574	N	13.8	20.3	0.1	266116.	500000000.	-1.8	50.0	9898.7	50.2	
581	S	14.2	18.5	0.1	35584.	500000000.	-2.2	50.2	9898.8	50.6	
588	N	14.2	20.6	0.1	44829.	500000000.	-2.4	49.9	9903.9	51.1	
595	S	14.7	18.8	0.1	251147.	500000000.	-2.9	50.0	9904.0	51.6	

START THE LAKE AGAIN ? (1=YES, 0=NO)

FOR HOW LONG (D)?, SALINE FLUX?, O2 CUTOFF?,PRINT INT.?
600 .04 2 7

DAY	STATUS	SALINITY	OXYGEN	RAIN	LAKE LEVEL	P1	P2	P3	PL
1	-	10.0	20.0	0.1	6640.	500006640.	10.0	10.1	9999.3	10.0	
7	-	10.5	18.0	0.1	244005.	500876261.	10.4	10.9	9995.1	10.3	
14	-	10.6	16.5	0.1	191528.	502445890.	11.0	11.7	9990.2	10.8	
21	-	10.9	14.4	0.1	241654.	503907773.	11.8	12.6	9985.3	11.5	
28	-	10.8	13.7	0.1	356312.	505278664.	12.4	13.5	9980.4	12.0	
35	-	10.8	12.6	0.1	13427.	506534965.	13.1	14.3	9975.5	12.5	
42	-	10.6	12.2	7.0	127119.	507630764.	13.6	12.3	9988.0	12.9	
49	-	10.4	11.8	7.0	222932.	508743107.	14.1	10.2	10000.6	13.2	
56	N	10.1	11.3	7.0	340965.	500000000.	12.3	8.2	10013.1	13.9	
63	S	9.9	11.5	7.0	200892.	500000000.	11.9	6.3	10025.6	14.3	
70	N	10.1	13.1	0.1	237396.	500000000.	11.5	7.7	10020.7	14.6	
77	S	9.8	12.9	0.1	337922.	500000000.	11.4	8.6	10015.8	15.5	
84	N	10.0	15.3	0.1	98421.	500000000.	11.0	10.0	10010.9	15.8	
91	S	10.3	14.0	0.1	291743.	500000000.	10.8	11.0	10006.0	16.6	
98	N	10.6	16.3	0.1	61530.	500000000.	10.3	12.4	10001.1	16.7	
105	S	11.1	14.8	0.1	92202.	500000000.	9.8	13.4	9996.2	17.0	
112	N	11.3	17.2	0.1	157473.	500000000.	9.6	14.8	9991.3	17.6	
119	S	11.4	16.7	0.1	103257.	500000000.	9.2	15.8	9986.4	18.1	
126	N	12.2	18.0	0.1	77667.	500000000.	8.7	17.2	9981.5	18.1	
133	S	12.3	17.5	0.1	251360.	500000000.	8.2	18.2	9976.6	18.5	
140	N	13.1	19.0	0.1	50672.	500000000.	8.0	19.6	9971.7	19.0	
147	S	13.1	18.4	0.1	230229.	500000000.	7.7	20.5	9966.8	19.6	
154	N	13.1	21.5	0.1	22119.	500000000.	7.7	21.9	9961.9	20.6	
161	S	13.9	19.3	0.1	162434.	500000000.	7.1	22.9	9957.0	20.7	
168	N	14.1	22.5	0.1	192249.	500000000.	6.8	24.3	9952.1	21.1	
175	S	14.9	20.2	0.1	30194.	500000000.	6.2	25.3	9947.2	21.3	
182	N	15.0	23.5	0.1	310665.	500000000.	6.2	26.7	9942.3	22.2	
189	S	15.1	22.7	0.1	197590.	500000000.	5.9	27.7	9937.4	22.8	
196	N	16.0	24.3	0.1	203417.	500000000.	5.8	29.1	9932.5	23.4	
203	S	16.2	23.5	0.1	183254.	500000000.	5.2	30.1	9927.6	23.7	
210	N	17.3	25.4	0.1	300499.	500000000.	4.9	31.5	9922.7	24.1	
217	S	17.5	24.7	0.1	174759.	500000000.	4.4	32.4	9917.8	24.4	
224	N	17.8	28.9	0.1	113288.	500000000.	4.0	33.8	9912.9	24.7	
231	S	18.7	26.0	0.1	302603.	500000000.	3.5	34.8	9908.0	25.1	
238	N	18.9	30.3	0.1	304565.	500000000.	3.4	36.2	9903.1	25.7	
245	-	19.9	26.3	0.1	75442.	511855523.	3.8	37.1	9898.2	26.2	
252	-	19.7	24.9	0.1	353622.	523466369.	4.2	38.0	9893.3	26.7	
259	-	19.3	23.8	0.1	161737.	537613466.	4.7	38.8	9888.4	27.3	
266	-	19.3	22.2	0.1	170747.	549024377.	5.2	39.7	9883.5	27.8	

273	-	18.7	21.5	0.1	31126.	56401762.	5.7	40.5	9878.6	28.3
280	-	18.4	20.4	0.1	239320.	57684034.	6.1	41.4	9873.7	28.7
287	-	17.9	19.9	7.0	270489.	58946608.	6.6	41.4	9873.8	29.2
294	N	17.4	19.5	7.0	318247.	50000000.	5.8	40.6	9878.9	29.7
301	S	17.0	19.4	0.1	263639.	50000000.	5.5	40.0	9883.9	30.3
308	S	16.9	23.3	0.1	66638.	50000000.	5.1	41.4	9879.0	30.6
315	S	17.5	21.7	0.1	92178.	50000000.	4.6	42.3	9874.1	30.9
322	S	17.7	25.6	0.1	317967.	50000000.	4.2	43.7	9869.2	31.2
329	S	17.5	24.2	0.1	35798.	50000000.	3.9	44.7	9864.3	31.9
336	S	18.5	27.2	0.1	357534.	50000000.	3.8	46.1	9859.4	32.5
343	S	18.8	26.4	0.1	11594.	50000000.	3.3	47.1	9854.5	32.9
350	S	19.7	28.6	0.1	72156.	50000000.	3.2	48.5	9849.6	33.6
357	S	19.8	27.8	0.1	112630.	50000000.	2.6	49.5	9844.7	33.8
364	S	20.1	32.3	0.1	62927.	50000000.	2.3	50.1	9844.8	34.1
371	S	20.9	29.3	0.1	332351.	50000000.	2.0	50.2	9844.9	34.8
378	S	21.4	34.1	0.1	330397.	50000000.	1.7	49.9	9849.9	35.2
385	S	22.5	30.6	0.1	238991.	50000000.	1.2	50.1	9850.0	35.5
392	S	22.8	35.6	0.1	317035.	50000000.	1.1	49.8	9855.1	36.3
399	S	23.3	34.3	0.1	131386.	50000000.	0.6	50.0	9855.2	36.5
406	S	24.8	37.1	0.1	178291.	50000000.	0.3	49.7	9860.3	37.0
413	S	24.6	35.9	0.1	343356.	50000000.	0.2	49.9	9860.3	37.9
420	S	26.3	38.7	0.1	320199.	50000000.	-0.1	50.0	9862.9	38.2
427	S	26.1	37.4	0.1	38100.	50000000.	-0.2	50.2	9862.9	39.3
434	S	26.4	43.7	0.1	170453.	50000000.	-0.4	49.9	9868.0	39.8
441	S	27.9	39.1	0.1	61961.	50000000.	-0.8	50.1	9868.1	40.2
448	S	28.1	45.5	0.1	309127.	50000000.	-0.8	49.8	9873.1	41.1
455	S	29.6	40.7	0.1	47586.	50000000.	-1.2	49.9	9873.2	41.5
462	S	30.3	47.2	0.1	185166.	50000000.	-1.5	50.1	9875.8	42.0
469	S	30.6	45.5	0.1	137858.	50000000.	-2.0	49.8	9878.4	42.3
476	S	32.4	49.0	0.1	311351.	50000000.	-2.3	50.0	9880.9	42.8
483	S	32.5	45.5	0.1	195102.	51519222.	-1.9	50.0	9881.0	43.5
490	S	32.7	40.8	0.1	330133.	52975033.	-1.3	50.1	9881.1	44.5
497	S	32.2	39.0	0.1	127051.	54275171.	-1.1	50.1	9881.2	44.8
504	S	31.7	37.6	0.1	85679.	55399924.	-0.8	49.7	9883.7	45.2
511	S	31.2	35.4	0.1	346352.	56767801.	-0.5	49.8	9883.8	45.7
518	S	30.3	34.5	0.1	164509.	58213037.	-0.0	49.8	9883.9	46.4
525	S	29.6	32.8	0.1	153187.	59722890.	0.4	49.8	9884.0	46.9
532	N	29.3	36.7	0.1	18234.	50000000.	0.2	49.8	9886.6	47.4
539	S	28.7	36.6	0.1	297067.	50000000.	-0.2	49.9	9886.6	47.9
546	S	30.1	41.0	0.1	44149.	50000000.	-0.7	50.1	9889.2	48.0
553	S	30.2	40.3	0.1	42371.	50000000.	-1.1	49.8	9891.8	48.4
560	S	31.5	44.3	0.1	46052.	50000000.	-1.4	50.0	9894.3	48.8
567	S	31.6	43.3	0.1	350936.	50000000.	-1.9	50.1	9894.4	49.2
574	S	31.5	50.9	0.1	266116.	50000000.	-1.8	49.9	9899.5	50.2
581	S	33.0	45.2	0.1	35584.	50000000.	-2.2	50.0	9899.6	50.6
588	S	33.5	53.4	0.1	44829.	50000000.	-2.4	49.8	9904.6	51.1
595	S	35.4	48.0	0.1	251147.	50000000.	-2.9	49.9	9904.7	51.6

[NOTE THE RUNAWAY SALINITIES WHEN THE INFLUX OF SALT IS
CHANGED FROM 0.03 (FIRST RUN) TO 0.04 (SECOND RUN).]
START THE LAKE AGAIN ? (1=YES, 0=NO)