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Crow Island, Mattakkuliya, Colombo-15, Sri Lanka

Salt and Water Balance in the Mundel Lake: A Strongly Choked Coastal Lagoon.

H.B. JAYASIRI[1] & J.K. RAJAPAKSHA[2]

1,2 Oceanography Division, National Aquatic Resources, Research and Development Agency, Crow Island, Colombo 15.

Abstract

KEY WORDS: HYPER SALINITY; RESIDENCE TIME; SALT BUDGET; WATER EXCHANGE

The Mundel Lake is an extremely shallow lagoon on the west coast of Sri Lanka. It is connected to the Puttalam Lagoon through 15 km long Dutch Canal. Salinity measurements and daily sea level data were obtained fortnightly from January 1993 to March 1994 and they were used to quantify the salt and water budget along with precipitation, evaporation and freshwater runoff.

Extreme fluctuations of salinity and sea level are striking features of the system. Salinity of the Mundel Lake and Dutch Canal varied from 5 - 46.5 and 6 - 61 ppt respectively while the sea level ranged from -0.25 to +1.2 m . Tidal variations were not seen in the lagoon due to it's long narrow canal system. Salt budget showed that the deposition of salt on the lagoon bottom during periods of decreasing water level. During increasing water level, salt is dissolved again. Flow of water through the Dutch Canal between the Puttalam Lagoon and Mundel Lake is driven by the changes in sea level. These changes are mainly due to seasonal changes of net freshwater supply and, to a lesser degree, to seasonal changes in sea surface height. As the flow rates are small due to the long and narrow canal, the residence times ranges between two months and several months in the Mundel Lake, except during season of high freshwater supply.

As the water exchange is weak, the Mundel lake becomes hypersaline with strong fluctuations in salinity. This implies a stress to all lagoon dwelling aquatic organisms and also to aquaculture practices in the area.

Introduction

The areas around Puttalum Lagoon and Mundel Lake have been found to be suitable for prawn culture. A great number of prawn farms have already been established connecting the two water bodies (Corea *et al.,* 1995). Prawn farms require salinities between 10 and 35 ppt and all the farms depend on the Dutch Canal and the lake as a discharge point for water and associated effluents. Because of intermittently low fresh-water supply and high evaporation very high salinities might appear in the area (Arulananthan *et al.*, 1995 and Jayasiri *et al.*, 1995). The prawn farms therefore require freshwater to avoid hypersalinity. During low waters, vast areas are suffering from evaporite salt deposits.

The salinity of the Mundel Lake depends on the flushing through the Dutch canal and on local evaporation, precipitation and runoff. During periods of limited exchange of water, the Mundel Lake is likely to become strongly hypersaline. This intern may cause intrusion of salt water into farm lands thereby affecting the flora and fauna. Increasing population in the area experience strong difficulties in obtaining drinking water of high quality, among other difficulties as a result of salt-water intrusion in to the wells. Rainy seasons on the other hand will cause flooding in the area as there is no proper drainage outlet. The Dutch Canal is long and narrow and presently there is a sand bar at Udappuwa (Fig 1). Aim of this study is to estimate the exchange of water and salt between Mundel Lagoon and Indian Ocean. The observed salinities and sea levels within the lagoon are related to the net freshwater balance.

Moore and Slinn (1984) studied the annual hydrological cycle (long term) of the Caimanero-Huizache lagoon system on the Pacific coast of Mexico. They studied seasonal changes of meteorological parameters such as precipitation and evaporation and fresh-water runoff. When the water level was decreasing during dry season, salt water entered, some of which was stored on the lagoon bed as evaporite deposits like Mundel Lake/Dutch Canal system.

Robinson *et al.*, 1983 studied the mechanisms which control sea level fluctuations of the Fleet, a long system of channels and lakes (12.5 km) in Southern England where the tidal wave almost completely disappears by the time it reaches the end of the system. There is no tide in the Mundel Lake too due to long, narrow canal system (Jayasiri et, al 1998).

The Study Area

Mundel Lake (Fig 1) is an extremely shallow coastal lagoon on the west coast of Sri Lanka. The surface area of the lake is approx. 30 km^2 at local mean sea level, which is above the oceanic. The mean depth is about 0.75 m. The lagoon is nearly 12 km long and the width varies from 1-3 km. The Lake is connected to the Puttalum Lagoon through Dutch Canal in the Northern end (Fig. 1) and to Chilaw Lagoon in the south. The length of the Dutch Canal from Puttalum Lagoon to Mundel Lake is 16 km and its width is about 10 m but at high water large areas may be flooded.

The salinity of the Mundel Lake is low during rainy season, but high during the dry season (Guruge *et al.*, 1987). They found the salinities lower than 3 ppt during the rainy season but 40-50 ppt during the dry period.

The lagoon is separated from the ocean through an about 100 m wide permanent sand bar at Udappuwa which obstruct the direct exchange of water with the ocean. During periods of heavy rain, however the sand bar has been actively broken to prevent flooding of the low land. The Battulu Oya river enters freshwater from south, particularly during the rainy season (Fig 1).

The area is located in the arid zone of Sri Lanka. It experiences two monsoon periods, the south-west (May-Sep) and the north-east monsoon (Oct-Jan). The rainfall is markedly seasonal and 70% of the rains occur during the north-east monsoon. According to measurements at Vanathavillu, near the Puttalam weather station, the average rainfall is 1200 $mmyear^{-1}$. The average maximum daily air temperatures are high varying between of 30.4 - 33.6 °C and the average minimum temperature during night varies from 19 - 25 °C. In general, the temperatures are lower during the north-east monsoon. The average pan evaporation is 1800 $mmyear^{-1}$ (Fig 4), indicating that evaporation dominates over precipitation.

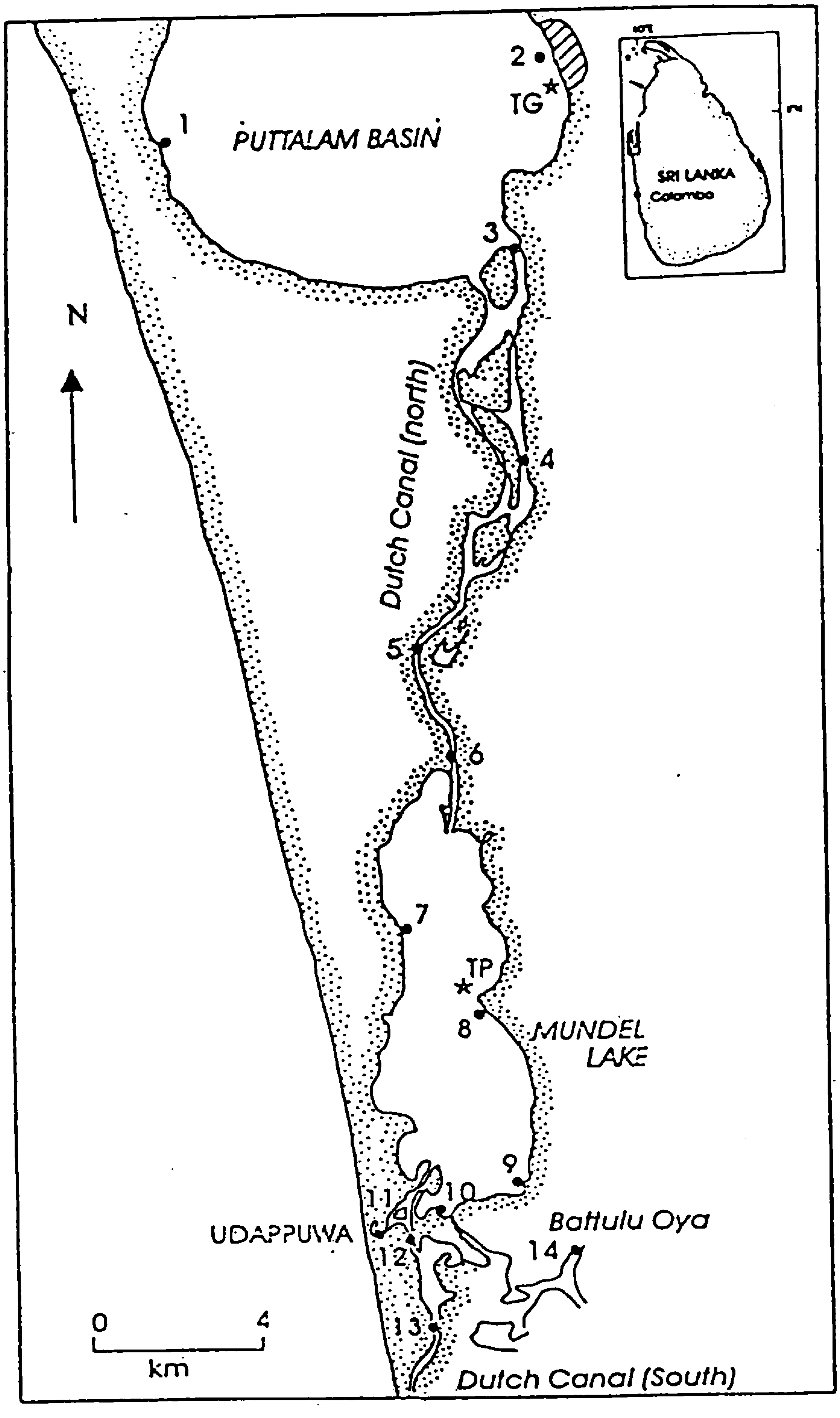

Fig.1: The study area including stations for salinity sampling and tide gauges

Materials & Methods

Salinity measurements were carried out fortnightly at 14 stations from February 1993 to July 1994 (Fig 1). The salinities were determined with an Autosal laboratory salinometer. The accuracy of this instrument is 0.001 ppt. Some water samples were diluted with water before being analyzed since the salinities are out of the range of these samples for this salinometer (>42 ppt).

The freshwater supply was measured from June to October 1993 in Battulu Oya. Two current meter moorings, each with three pendulums (Cederlöf *et al.*, 1996) hanging in a rope were deployed at surface, middle and bottom of the Battulu Oya river. This devise gives a direct estimate of velocity and the direction. Daily sea levels in the Mundel Lake were carried out manually using a tide pole from 20 Feb 1993 to 31 March 1994. The accuracy of the tide pole measurements is about ±2 cm.

Daily rainfall and evaporation were obtained from the Vanathavillu from Jan 1993 to March 1994, which is close to the study area. These parameters are shown as monthly averages in Fig 6. Half hourly sea level data from Colombo harbour were obtained for the year 1993.

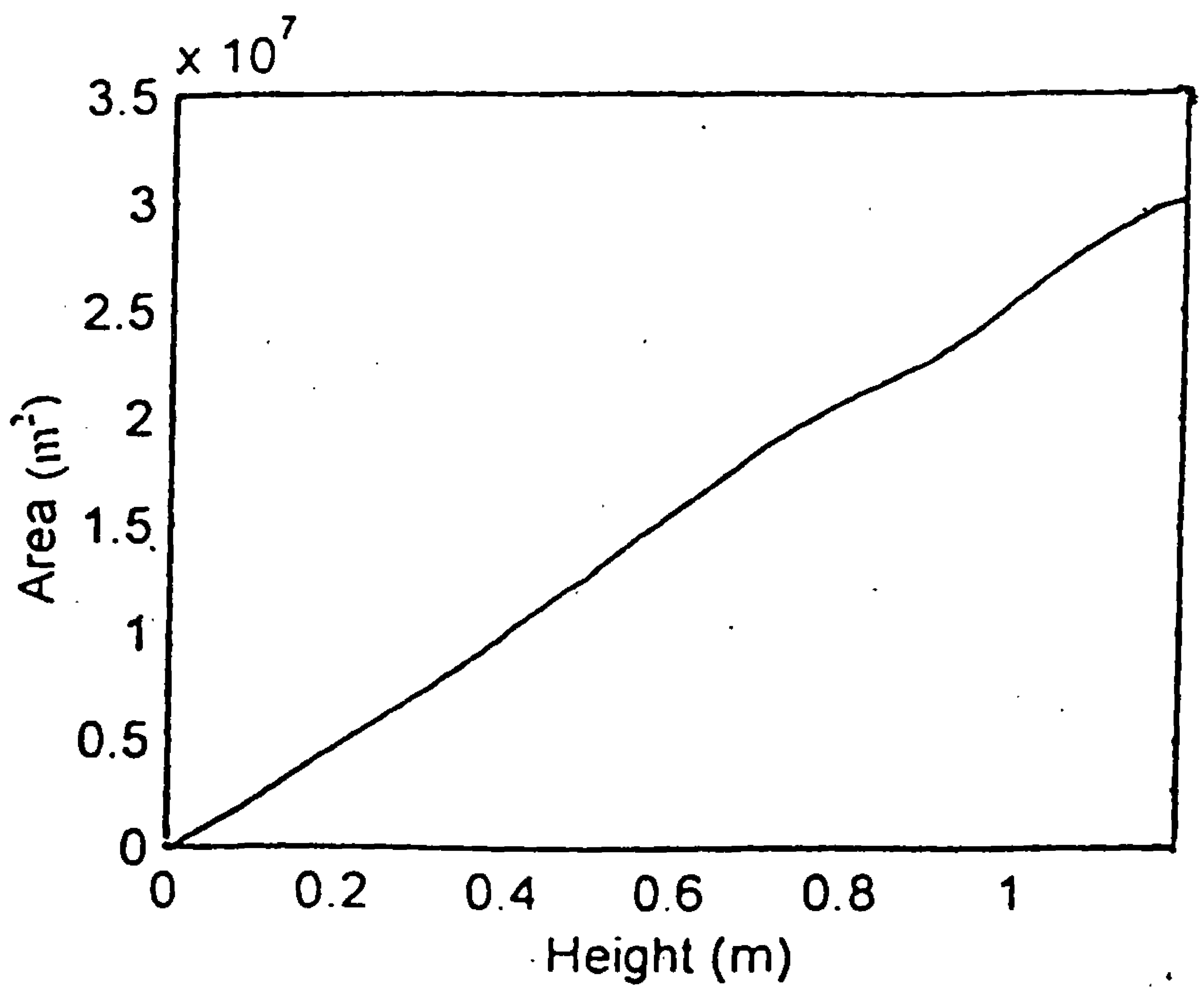

Fig.2: A hypsographic curve of the Mundel Lake

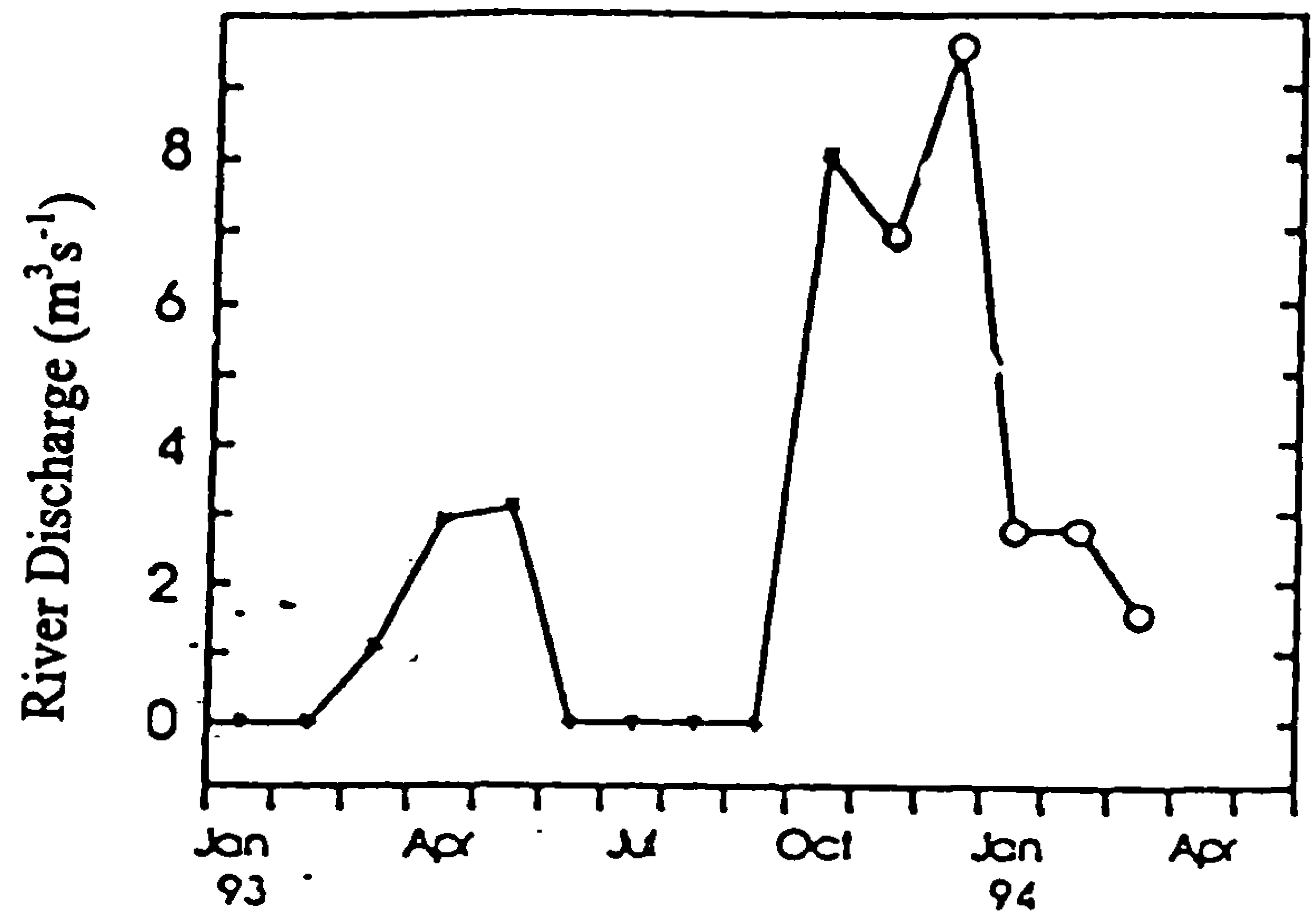

Fig.3: Measured (*) and Estimated (0) fresh water supply in Battulu Oya, January 1994 to March 1994

Theory

Long-term canal flow, salt and water balance

To estimate salt and water budget including the flow through the Dutch canal, the conservation of salt and mass (volume) were used.

The net freshwater supply Q_f is given by

$$Q_f = Q_r + Q_p - Q_e$$

Where Q_r . Rate of river discharge, Q_p – Rate of precipitation, Q_e – Rate of evaporation

Volume conservation gives

$$\frac{dV}{dt} = Q_D + Q_f$$

Where V is volume of the lake, Q_D is flow through the Dutch Canal

Conservation of salt is written

$$\frac{d(VS_m)}{dt} = Q_D S_{m,p} + R$$

$S_{m,p}$ – Mean salinity of the Mundel Lake or Puttalam Basin

S_m – Mean salinity of the Mundel Lake

S_p – Mean salinity of the Puttalam Basin

Where $S_{m,p}=S_m$ if Q_D is towards the ocean and $S_{m,p}=Sp$ if the flow is towards the lake. R is the salt deposition (or re-solution), negative for deposition will be assumed. For small changes in the sea level Where S is the salinity at the beginning of a period of decreasing water level. For a period of increasing water level, S is the salinity at the end. This assumption however may need some explanation, and does not hold but areas which are not typically tidal flats. The residence time (Tf) for fresh-water may be written as $Tf=V/Q_f$ while residence time (T_r) for lake water may be written as $T_r=V/Q_f+Q_D$.

Mundel Lake exchanges water with the ocean or rather, the Puttalum Lagoon according to a rather odd scheme. There are periods when the level of water in the lake is lower the oceanic water level. Thus, to estimate the water exchange, studies were carried out different periods that the flow was unidirectional, moving out from or into the Mundel Lake.

It was also found that there is a sill (or obstruction) in Dutch Canal situated at approx. -10 cm, which excludes any flow when the sea levels are below that value. It should be made clear that particularly the Mundel Lake water level may be a few cm above the mean level due to extremely high water levels at the end of the period.

Table 1: Selected sampling periods for calculation of flow through the canal and salt deposition or re-solution

Serial Number	Period	Flow/R	
I	19 Feb - 5 Apr (50- 95)	$+Q_D$	in
II	10 Apr - 20 May (100 - 140)	$-Q_D$	out
III	29 July - 7 Sep (210 - 250)	-R	deposition
IV	8 Sep - 17 Oct (251 - 290)	+R	re-solution
V	1 Nov - 21 Nov (305 - 325)	$-Q_D+R$	out, re-solution

Results were obtained on Q_D, and R for the five (sampling) periods selected. They are given in Table 1 and the deposition and re-solution of salt were also compared according to the formula suggested for calculation of salt deposition.

Results

Salinity

The salinity shows strong fluctuations on the time scale of months (Fig 4). In Puttalum Basin, the salinity varied from 7 - 63 ppt, in Mundel Lake from 5 - 45.5 ppt, in Dutch Canal (North) 6 - 60 ppt, and in Dutch Canal (South) from 0 - 33 ppt. There is a gradient from south to north, basically during the whole 1.3 year period and there is good correlation between the four different areas, when the variations at 2 week intervals were taken into account. The salinity in Puttalum Basin and Dutch Canal (N) exhibits maxima in August and September 1993 respectively and minima in February 1994 after a period of very heavy rains (see Fig 4). The variation is similar in Mundel Lake and Dutch Canal (S) but the salinities are generally lower (10 - 20 ppt). The overall mean salinity in Mundel Lake is 25.0 ppt and in the Puttalum Basin 39 ppt. There are two maximum salinity levels and two minimum salinity levels per year which could be related to the rains. Only in the Puttalam Basin, from February - March a maximum value was not clearly indicated. It is also interesting to note that the salinity of the lake from January to February 1994 dropped by 15 ppt when compared with values during 1993 which indicates that a study over a one year period is not sufficient to indicate all the variations.

Sea Level

The sea level in Mundel Lake is influenced by evaporation (about 1 m^3s^{-1}), precipitation (0-3 m^3s^{-1}), river discharge (0-7 m^3s^{-1}) and the external, oceanic sea level (Fig 5). From October to December the water level was very high due to heavy rainfall. The lowest daily sea level (-0.35 m) occurred during July-August due to minimum rainfall and absence of river discharge (Fig 3) including relatively high evaporation (Fig 6b). In December, a rapid increase occurred when the area was flooded. The maximum sea level during this period was 1.10 m. The hypsographic curve shows that the area of the Mundel Lake is changing linearly as a function of the height of water (Fig 2).

River Discharge

Battulu Oya enters the Mundel Lake from its southern end. All the water which discharge from the river can not be expected to enter the lagoon. During dry seasons there is probably no significant freshwater supply. because there is a dam upstream to prevent salt water intrusion into upstream areas. During rainy season

maximum discharge of 9 m^3s^{-1} was indicated (Fig 3). Measurements were carried out form January to October, and during the other months, freshwater discharge was estimated from rainfall data.

From the results it was possible to identify a sill or other obstructions in the Dutch Canal (N). This sill implies a complete cut-off of the canal flow at depths of about 10 cm below the mean sea level. This "sill" implies that no ocean water entered or exchanged from Day 200 up to Day 295 (Fig 5).

Salt and Water Budget

Salt and water budget during different periods are described below.

I. During Day 50-95, the sea level was slightly higher than the lagoon. There is basically no change of volume in the lagoon and the precipitation and evaporation were 0.35 m^3s^{-1} and 0.95 m^3s^{-1} respectively. The river discharge was zero. Conservation of volume claims an inflow of 0.6 m^3s^{-1}. During this period the salinity of the lagoon increased from 19 to 34 ppt due to a net inflow of saline water through the Dutch Canal (N). Conservation of salt indicated an inflow of 0.85 m^3s^{-1}. As the average salinity of the Dutch canal water was 45 ppt, the transport of salt into the lagoon is 38 kgs^{-1}. The residence time for the lagoon waters in this case was 82 days.

II. During the period from Day 100-140, the water level of Mundel lake was higher than the sea level. The lagoon level however did not change during this period, as the precipitation and evaporation were almost equal. The river discharge which is about 1 m^3s^{-1}. This means that the outflow was equal to the river discharge. As the freshwater discharged into the lagoon, the salinity

decreases from 33 to 23 ppt. The conservation of salt also gave similar results (0.65 m^3s^{-1}). During this period the salt transport from Mundel to Puttalam was 28 kg s^{-1} while the mean salinity of the lagoon was 28 ppt.

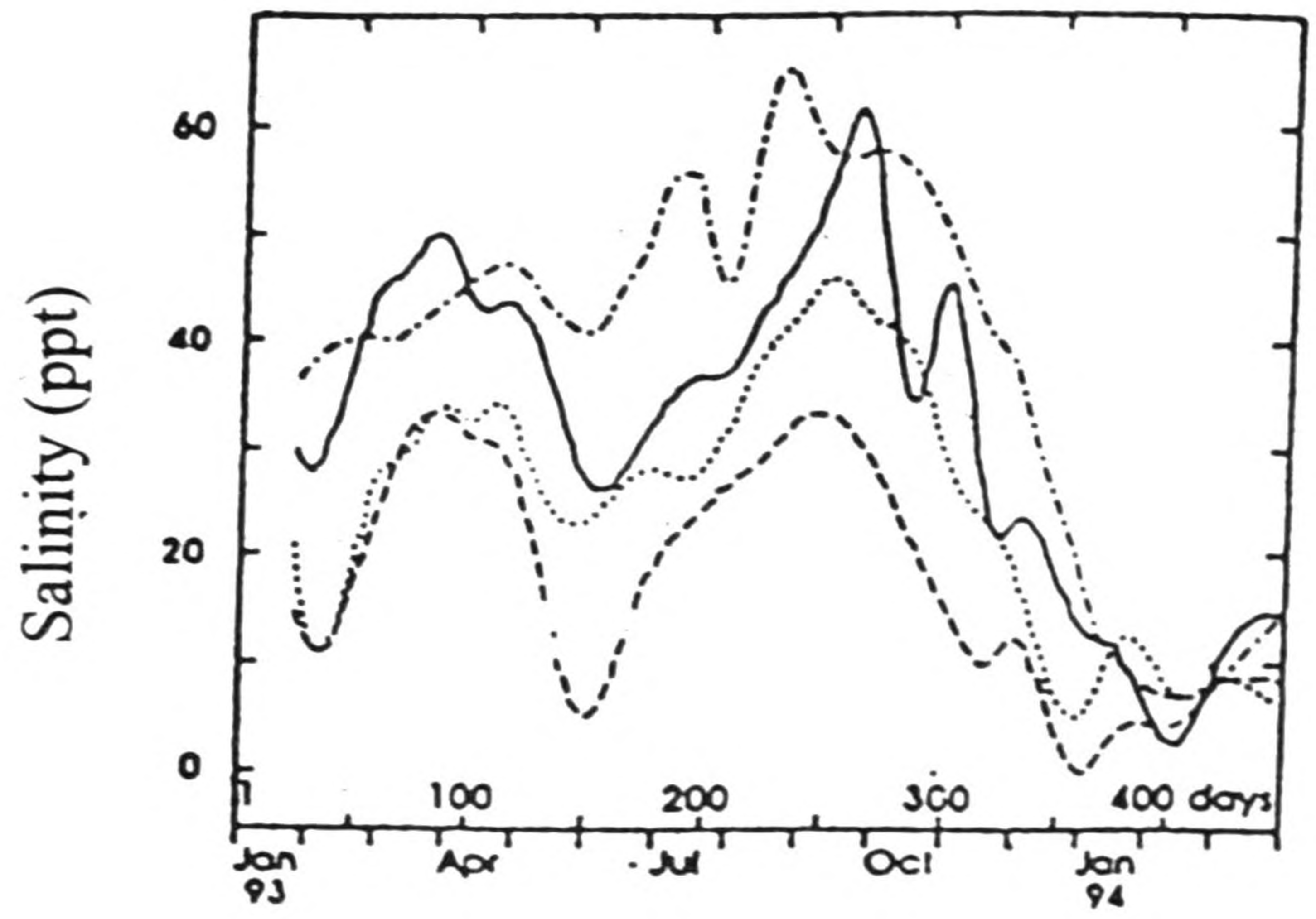

Fig.4: Salinity variations from January 1993 to March 1994 in 4 sub areas: Puttalam Basin, Dutch Canal(N), Mundal Lake, Dutch Canal(S)

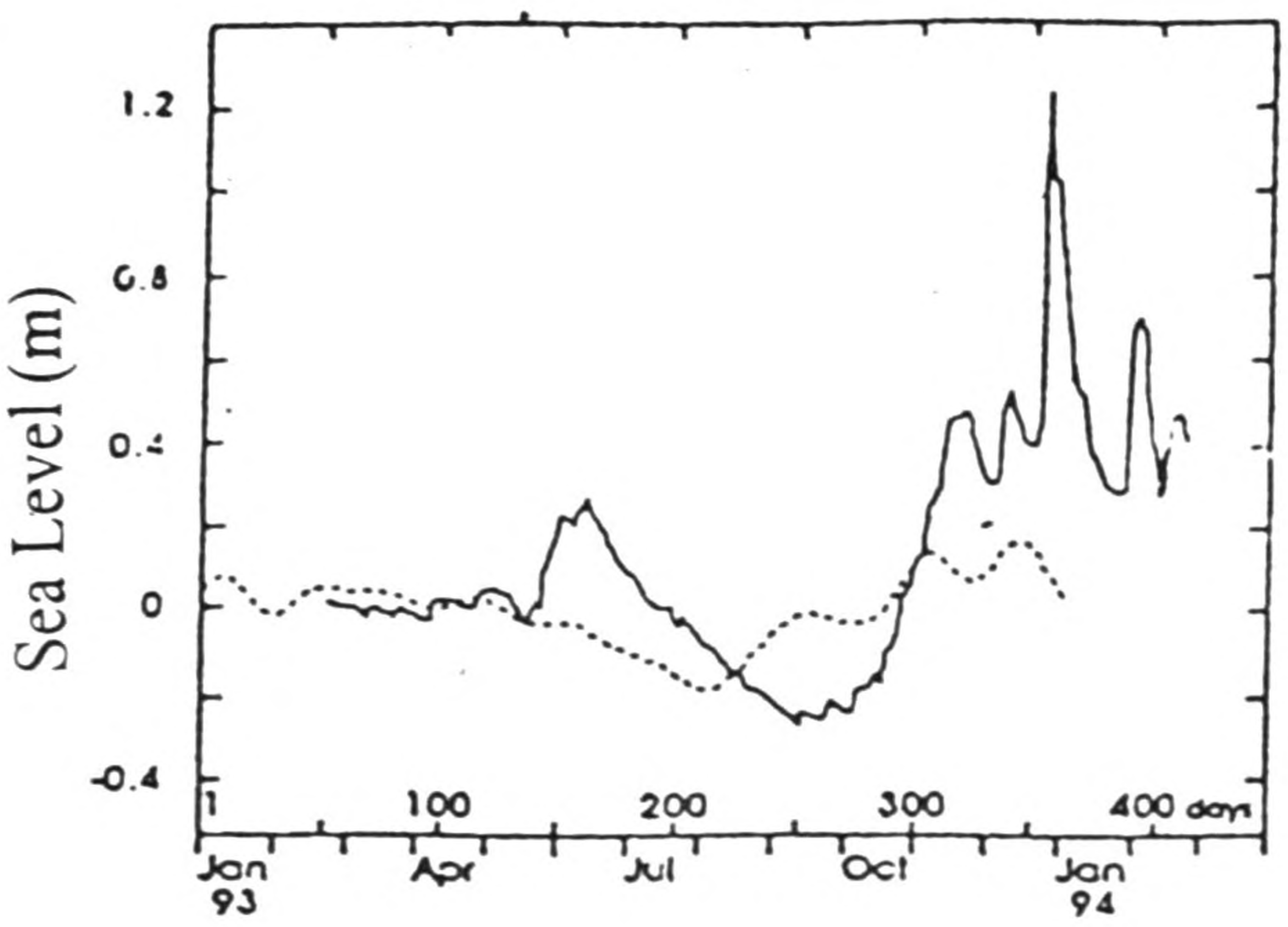

Fig.5: Daily sea levels in the Mundal & in Colombo from January 1993 to March 1994.

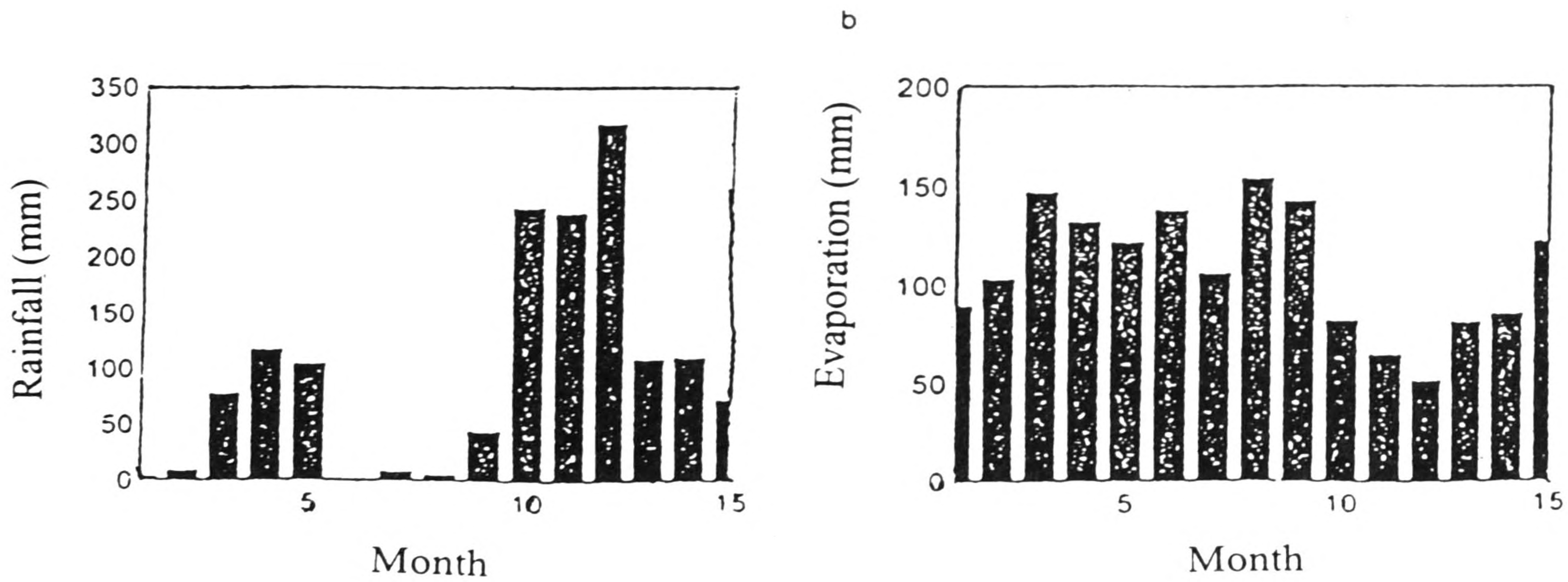

Fig.6: (a) Monthly rainfall, (b) monthly evaporation, at Vanathavillu meterological station from January 1993 to March 1994

III. From the Day 210- 250, there was no exchange of water with the Puttalam Lagoon as the canal flow was blocked by a sill located about 10 cm below the mean water level. During that period the volume of the lagoon changed due to evaporation. There was no precipitation or river discharge at this time. The volume change and the evaporation rate were exactly the same (0.7 m3s-1or 4.6 mm/day). The high evaporation increased the salinity of the lagoon from 30 to 46 ppt but the salt content of the lagoon waters decreased due to a detain of salt in the lagoon bed as evaporate deposits at a rate of, R=10.5 kg s-1. Using the equation $\left(\frac{dV}{2}\right)S$ gives 11.0 kgs-1.

IV. During the period from Day 250 - 290, the sealevel and the water level in the lagoon increased but there was no exchange of water through the canal. The rates of precipitation and evaporation are almost equal (4.7 mm day^{-1}). Therefore the rate of volume change (1.7 m^3s^{-1}) was only due to river runoff and the salt deposits dissolved at a rate of 13.7 kgs^{-1}. Therefore the salt content of the lagoon waters increased, but salinity decreased from 46 to 32 ppt. The re-solution of salt according to the equation $\left(\frac{dV}{2}\right)S$ was 11.1 kg s^{-1}, which was quite close to the observed value.

V. From Day 305 - 325, the difference of oceanic and lagoon water levels (0.2 m) created an outflow from Mundel to Puttalam. The precipitation and river runoff were 2.5 m^3s^{-1} and was observed respectively. The rate of volume change was 3 m^3s^{-1}. The outflow through the canal was 2.8 m^3s^{-1} and salt flushed out at a rate of 61 kg s^{-1}. Re-solution added salt to the lagoon water but the salinity decreased from 32 to 20 ppt. The residence time was about 56 days during this period.

In general, the results show that the exchange rates are very small except during heavy rainy season. The net flow through the canal was unidirectional seasonally but mainly directed outwards. Residence times in the Mundel Lake was estimated to be between two to several months except during the season where there was a very high freshwater supply, during which residence time becomes shorter.

Discussion & Conclusions

The seasonal variations in water and salt exchange result from interactions among precipitation, freshwater runoff, evaporation and sea level variations. Sea level variations determine the direction of the flow through the Dutch canal. Often the dominance of one or the other of these processes determines the quality of the water at a particular season. Due to dominance of different phenomena strong fluctuations of salinity and water level in the lagoon occur. It indicated that the periods of inflow are short compared to the periods of out flow, but the salinity was relatively high. The net freshwater input dominates during the rainy season but ceases in between.

Mean salinity of the Mundel Lake was 25 ppt during 1993 - 1994 with variations between 5 - 46.5 ppt. Mean salinity of Puttalam Lagoon was normally higher than the oceanic mean (Arulananthan *et al.*, 1995), but in the southern end it was even above 40 ppt. During the period of observation, the mean salinity of the Puttalam Basin was above 40 ppt, but it varied from 7-63 ppt indicating very large fluctuations. Meshal (1987) showed that the Habita Lagoon of the Red sea is hypersaline through out the year and salinity varied from 51-113 ppt and he related the salinity in the lagoon to the mean water level of the Red sea, and to the precipitation/evaporation cycle.

From 20 July - 8 Sept 1993, the sea level was higher than the water level of Mundel Lake. As there was no flow in to Mundel Lake, it was assumed that there is a sill or a barrier somewhere within the canal. During this period sea level decreased by 4.60 mm day^{-1} (Fig 5). The observed evaporation was 4.58 mm day^{-1}. Seepage of seawater through the sand bar at Udappuwa may be a reason for salinity increase in the lagoon during drought periods. The entry of sea water occur probably only through the canal. In October due to heavy rains, water level in Mundel Lake increased but still lower than the oceanic sea level. During this period the flow in the canal was towards to Mundel Lake as indicated by increasing salinities by day 300 (Fig 4). During November and thereafter a very large out flow which also resulted flooding in the area between Mundel Lake and Puttalam Lagoon was observed. Minimum salinity was observed during this period and in certain areas it became nearly freshwater. This situation however is probably not very common; the precipitation during 1994 strongly exceeded normal values.

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Comparison with the coarse assumption that $\left(\frac{dv}{2}S\right)$ gave surprisingly good results, although the formula is valid only for small changes in water level where there is a "flat" bottom. Increases in salt content due to re-solution of salt could be easily seen during all periods when the water level in Mundel Lake was rising, which was quite clearly seen at the beginning of 1994 when freshwater flooded large areas.

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