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THE IMPACT OF PINE PLANTATIONS ON THE GROUND-WATER RESOURCES OF THE EASTERN SHORES OF LAKE ST LUCIA

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CONTENTS

SUMMARY

Pine plantations on the Eastern Shores area of Lake St Lucia have been blamed for contributing to high lake salinity and, more recently, for affecting the adjacent indigenous habitats detrimentally. However, no detailed study of the hydrology of this region, nor quantification of the impact of plantations, has been undertaken to date. This report is confined to the hydrological effects of the pines of Eastern Shores as they relate to lake salinity and habitats in the vicinity of the plantations.

Water level records for 12 years from a 19-borehole network on the lower-lying parts of Eastern Shores were studied. The data were deficient because of absence of lithological records, poor hydraulic contact, some anomalous readings, and occasional gaps in the record. Nonetheless, tentative conclusions were drawn from the information. There is a shallow water table which shows a flattened response to rainfall. A low hydraulic conductivity and discontinuous aquitards are indicated. Under the full range of conditions monitored, there appears to be an adequate hydraulic gradient to maintain ground-water flow, which is probably dominated by lateral components.

Additional evapotranspiration loss from the area due to the 4 684 ha of Pinus elliottii plantation is estimated to be 10 million m^3 per year. This water loss will translate to reduced ground-water discharge, which must be partitioned, in probable order of magnitude, amongst (i) the occasio-

nally tidal upper estuary, (ii) the eastern lake shore in the vicinity of the plantation, (iii) Nkazana Stream, (iv) the sea, and (v) consumptive use by the pans and swamps. The impact of this reduced discharge will be proportionately larger in dry seasons and periods, and is expected to be localized to certain habitats on Eastern Shores. Our results lead us to suggest that (i) enough is known about the hydrological effects of pine plantations to decide the future of the Eastern Shores plantations, (ii) further studies should concentrate on the ecological impacts of reduced discharge, and (iii) the St Lucia area is not particularly suitable for research into ground-water interactions with plantations. Recommendations are also made with regard to the upgrading of the existing borehole network and hydrological data base for monitoring purposes, and the best means for detailed investigation of the ground-water system on Eastern Shores, should this be considered desirable.

1. INTRODUCTION

Lake St Lucia is a large estuary situated on the coastal plain of northern Zululand. The lake and a half-mile strip along its shore are a provincial game reserve. The lake and adjacent ecosystems are regarded as a unique and important natural heritage of both national and international significance (MacDevette and Bainbridge 1982).

Under natural conditions, Lake St Lucia experiences fluctuating salinity. Although St Lucia is essentially a saline lake, the maintenance of the ecosystem depends on its water being less than half the salinity of sea water, which averages about 35 000 mg/l. Natural fluctuations in salinity are considered beneficial to the ecosystem, but extreme salinity conditions endanger plant and animal life.

Concern over perceived threats to the animal and plant life of Lake St Lucia led to the appointment in 1964 of a Commission of Enquiry (Kriel 1966) to investigate allegations of continued deterioration of the system. A primary concern was lake salinity. For example, during the dry year of 1948 salinity values at different locations in the lake ranged from 35 000 mg/l to 52 000 mg/l destroying much of the lake flora and fauna (Hutchison and Pitman 1973). Peak salinities of over 100 000 mg/l have been measured in the north of the lake and in False Bay (Hutchison and Pitman 1973).

The salinity of the lake is controlled mainly by the volume of fresh water inputs. However, upstream abstraction from the major rivers entering the lake have reduced inflows to the lake. Tinley (1969) believes that the extensive sand catchment east of the lake is the last major source of perennial fresh water, and that ground-water seepage from Eastern Shores into the lake is crucial in regulating salinity levels, particularly during drought periods. Ground-water seepage is important to the maintenance of fresh water lakes in the sand flats of the Mocambique and Zululand coast (Tinley 1971). These bodies may be dependent on subsurface sources of water, such as at Mzingazi Lake where, though less than 3% of inputs were estimated to be direct ground-water seepage to the lake, seepage to feeder streams and the lake was estimated to be potentially close to 30% of total inputs (Worthington, 1978).

It has been stated (Kriel 1966; Tinley 1971; Hutchison 1973) that afforestation of large tracts of the peripheral sands with pines (Pinus spp) could have played an important role in increasing salinity levels by reducing fresh water discharge to the lake. At the same time, terrestrial ecosystems may be modified by lower ground-water levels as a result of increased transpiration losses caused by afforestation (R. Taylor 1982; D.R. MacDevette, personal communication; and D.N.S. Tomlinson, personal communication). The Commission of Enquiry recommended that areas afforested with exotic trees within the proposed conservation area should not be extended and that existing plantations should be cropped as soon as economically possible, and the area allowed to revert to indigenous vegetation (Kriel 1966, Chapter 13). This was endorsed by Tinley (1971) in a study of methods of increasing fresh water supplies to the lake.

The Commission's recommendations for a conservation area around Lake St Lucia were not implemented fully. A Natal Town and Regional Planning Commission report (A'Bear et al 1977) recommended dual use of the Eastern Shores area for conservation and timber production, and allocated 22 000 ha of the Eastern Shores and Cape Vidal State Forests for plantations. The present approved policy for the area (MacDevette and Bainbridge 1982) has as joint management objectives, amongst others, to "maintain essential ecological processes on which lakes, estuary and coastal wetlands and adjacent terrestrial systems depend" and to "provide for timber production". The policy further calls for investigations into the effects of land use on the hydrology and ecology of the area, to clarify possible conflicts in the objectives. Meanwhile it is the intent of the plantation management to maintain the present afforested area of 4 684 ha, without expansion, to produce timber on a 25 year rotation (I. Stam, personal communication).

No detailed study of the hydrology of the Eastern Shores area has been undertaken to date, despite controversy over the impact of the pine plantations. The purpose of this report is to provide an assessment of relevant data with particular reference to accumulated water level measurements. The report is an initial response to the requests for investigations into the hydrology of Eastern Shores. Its scope is limited to the plantations of Eastern Shores, their role in lake salinity and possible hydrological effects on adjacent indigenous communities.

2. DESCRIPTION OF THE ST LUCIA SYSTEM AND EASTERN SHORES

The Lake St Lucia system is located (Fig. 1) on a low-lying plain 16 - 24 km wide with steep vegetated dunes, up to 152 m high, along the sea shore (the cross-sectional profile is similar to that in Fig. 4). The vegetation is sub-tropical coastal forest and grassland, with prominent sedge swamps, hygrophilous grassland, swamp and dune forest. Much of the land west of the lake has been cleared for farming and forestry.

The Eastern Shores State Forest is 17 838 ha in extent of which 26% is afforested (Fig. 2) with _Pinus elliottii_, a species from the coastal plains of the south-eastern USA . In March 1964 the afforested area on Eastern Shores was 3 853 ha (Kriel 1966) which has since been increased by 21% to 4 684 ha.

2.1 **Hydrology**

The lake is a large shallow body of water, varying in area between 420 and 255 km^2 depending on lake level, and less than 1,5 m deep on average (Hobday 1976), with a long-term mean level of 0,17 m above mean sea level. When the lake level falls below sea level (as a result of high evaporation and insufficient fresh water inflow) saline water is brought into the system from the sea, via the estuary. In the past the estuary mouth was closed by sandbars during dry periods, but is now kept open by dredging. This allows continued import of saline water to the estuary

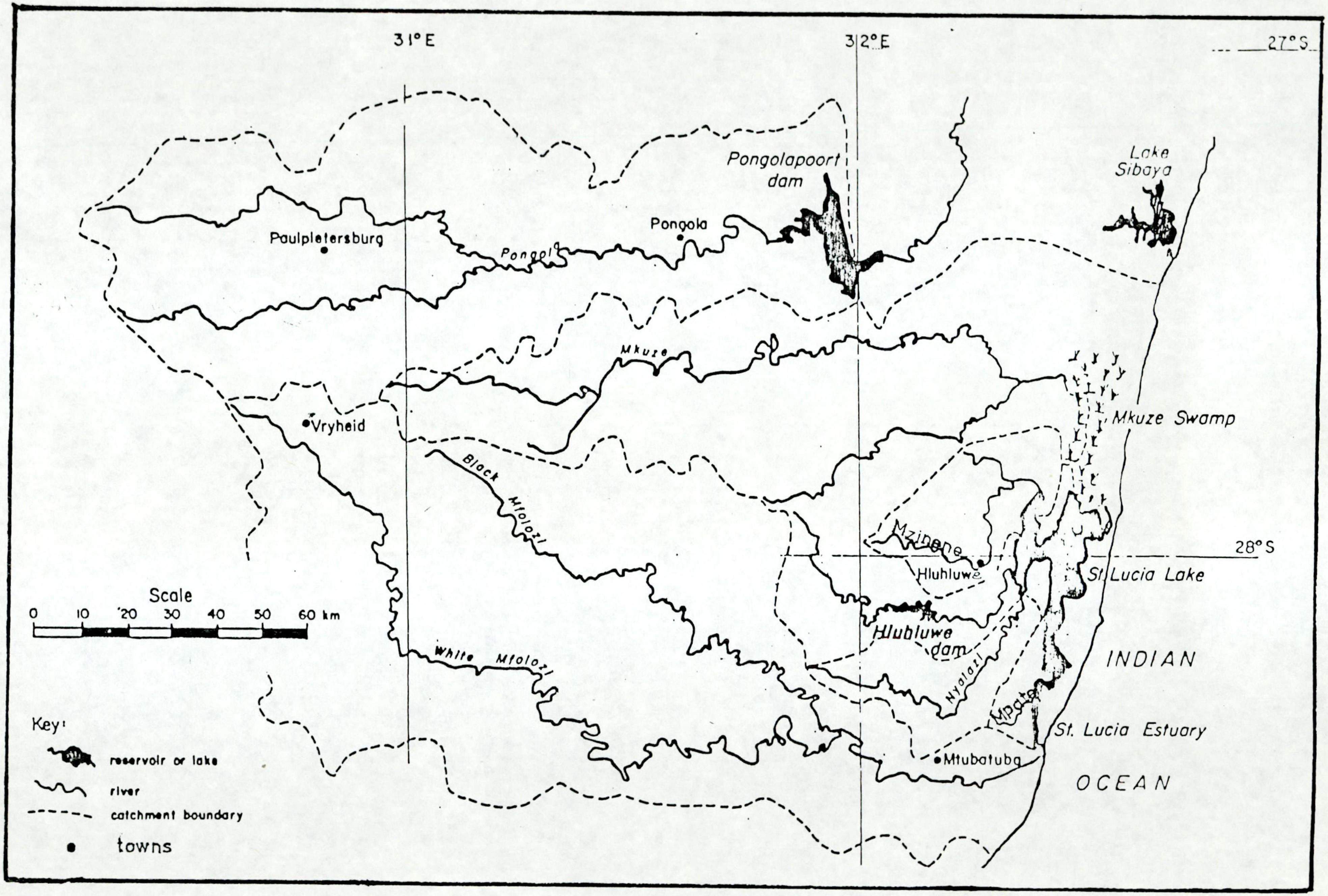
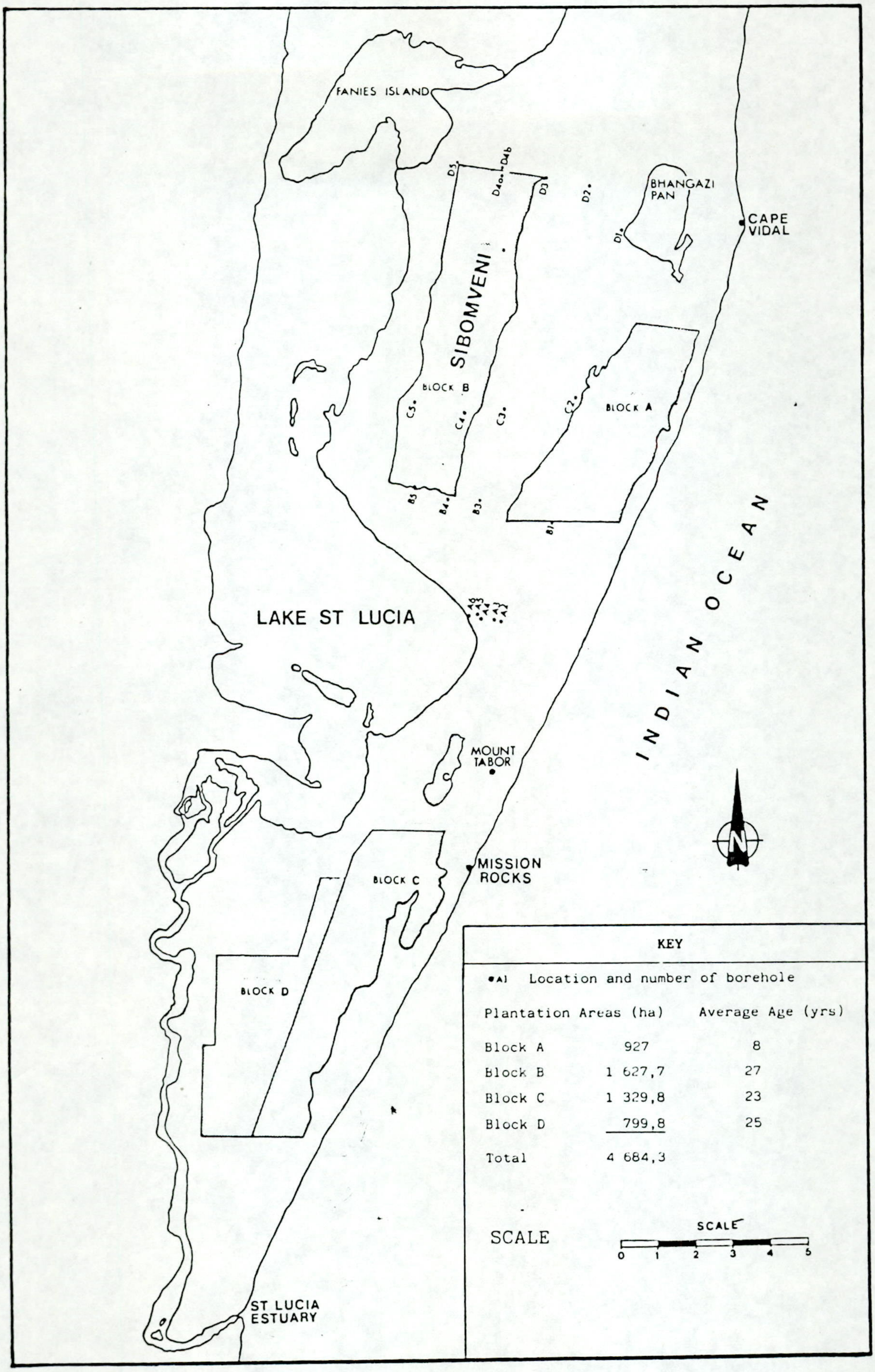


FIGURE 1: Location of the Lake St Lucia system on the Northern Zululand coast, showing the rivers of the region and their catchments



Plantation Areas (ha)		Average Age (yrs)
Block A	927	8
Block B	1 627,7	27
Block C	1 329,8	23
Block D	799,8	25
Total	4 684,3	

FIGURE 2: Location and extent of the timber plantations and the location and numbers of the monitored boreholes on Eastern Shores State Forest

during low lake levels. Hutchison (1976) estimated that this factor had a relatively minor influence on overall lake salinity because of the narrowness and length of the estuary. Following floods the lake level is around 1,5 m above mean sea level (Hobday 1976) and some of the salt is flushed out to the sea.

Hutchison (1976) estimated the water balance for the lake (Table 1). Fresh water enters the lake in three ways; by direct rainfall, by inflow from five river systems, and by groundwater seepage. Fresh water leaves the system by way of evaporation, and at times by outflow through the estuary to the sea. The balance between inflows and outflows controls the salinity of the lake.

2.1.1 Rainfall

Rainfall decreases rapidly in a north-westerly direction from the Estuary. Mean annual precipitation ranges from over 1300 mm at Cape St Lucia to less than 700 mm north-west of the lake (Hutchison 1976). Rainfall to the east of the lake zone is less markedly seasonal than that to the west of the lake, occuring throughout the year with a summer maximum (Fig. 3).

2.1.2 River inflow

Lake St Lucia is fed by five rivers, namely the Mkuze, Mzinene, Hluhluwe, Nyalazi and Mpate (Fig. 1). Only the Hluhluwe is perennial. The Umfolozi River was diverted in 1952 and no longer enters the estuary. All the rivers except for the Mkuze have been dammed, and the Mkuze is

Table 1: Mean annual water budget for Lake St Lucia as estimated by Hutchison (1976)

Source	Mean Annual $10^6 m^3$	Volume %	Catchment Area km^2
<u>**INPUTS**</u>			
Fresh water			
Precipitation	268	42,4	
*River flow			
Mkuze	164	25,9	4 815
Mzinene	22	3,5	710
Hluhluwe	28	4,4	1 030
Nyalazi	24	3,8	710
Mpate	11	1,7	250
Groundwater seepage			
Lake eastern catchment	37	5,8	170
Estuary eastern catchment	9	1,4	55
Total Fresh water Input	**563**	**88,9**	
Saltwater			
Inflow from ocean	70	11,1	
Total Hydrological Input	**633**	**100**	
<u>**OUTPUTS**</u>			
Evaporation (gross)	397	62,7	
Outflow through estuary	236	37,3	
Total loss from the system	**633**	**100**	

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*These figures are slightly lower (less than 10%) than estimates derived from the tables and methods of Pitman <u>et al</u>, 1981.

extensively tapped for agriculture in its upper reaches. Peak irrigation and agricultural demands are during the dry months when the lake's fresh water requirements are highest.

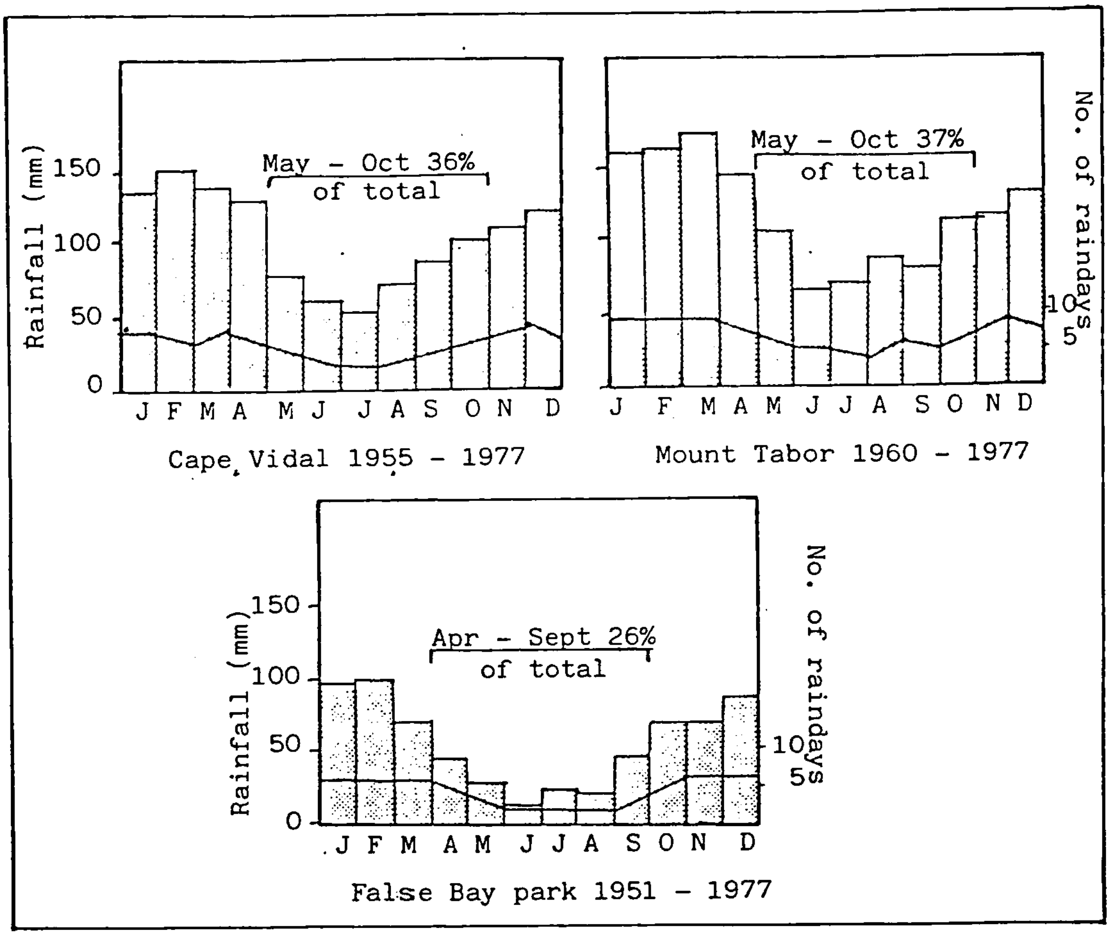


FIGURE 3: Mean monthly rainfall (histogram) and raindays (line plot) for two stations on the coastal dunes (Cape Vidal and Mount Tabor) and one on the west of Lake St Lucia (False Bay park), showing that rainfall and raindays are greater on the coastal dunes and seasonality of rain is less (W. Taylor 1982).

2.1.3 Seepage of groundwater

The sand plains catchment of the eastern shore of Lake St Lucia is believed to contain substantial ground-water reserves feeding the lake. Hutchison's (1976) model of the St Lucia water balance (Table 1) estimates that about 8% of fresh water inputs arise from this source: Kriel (1966, appendix 5) estimates this input to be 10%.

2.2 **Geology**

The geology of the St Lucia area has not been mapped in detail, but there is a considerable amount of scattered information. Extrapolations are also made here from detailed work in the Richards Bay area roughly 70 km south of St Lucia (Du Preez 1975; Worthington 1978).

The St Lucia flats are bounded below by low permeability Cretaceous siltstones which appear to dip slightly eastwards (Du Preez 1975) and which at Eastern Shores are shallowly below sea level (van Zijl 1971a). The overlying material consists of units of unconsolidated Pleistocene fine sand, with silt, clay and organic material, of alluvial, estuarine and aeolian origin. These are topped with shallow Holocene cover sands, while over the coastal dunes these recent sands are much deeper.

The origin of the geology provides useful insight into its structure. A succession of sea-level changes during the Pleistocene caused alternating periods of deposition and erosion of the coastal deposits (Hobday 1976; van Heerden 1976). During regressions (low sea-levels) exposed material was re-distributed by wind. Early in the current inter-glacial Lake St Lucia was considerably larger and covered much of the present Eastern Shores area (Hobday 1976). The lake capacity and size has been greatly reduced by deposition in estuarine conditions, including the deflocculation of clay minerals due to the saline water (Hobday 1976; van Heerden 1976).

Geological sections from Richards Bay (Fig. 4, Worthington 1978) provide insight into the possible structure of the geology and particularly the irregularity of succeeding formations. A series of boreholes drilled south of Bhangazi Pan (Reid 1969) show an irregular sequence of fine sands, sandy loams, and fine silty sands, with discontinuous bands of peat and clay which could form impermeable layers and cause perched water tables. A resistivity survey at Eastern Shores showed a water-bearing sand overlying a clayey bedrock and underlying a surface layer of dry sand (van Zijl 1971a).

2.3 **Geo-hydrology**

2.3.1 Geo-hydrological properties

No specific measurements of geo-hydrological properties are available but inferences can be made from the available information on the geology.

2.3.1.1 Hydraulic conductivity

Based on the above geological description it is assumed that the hydraulic conductivity (K) of the waterbearing material is not constant in all

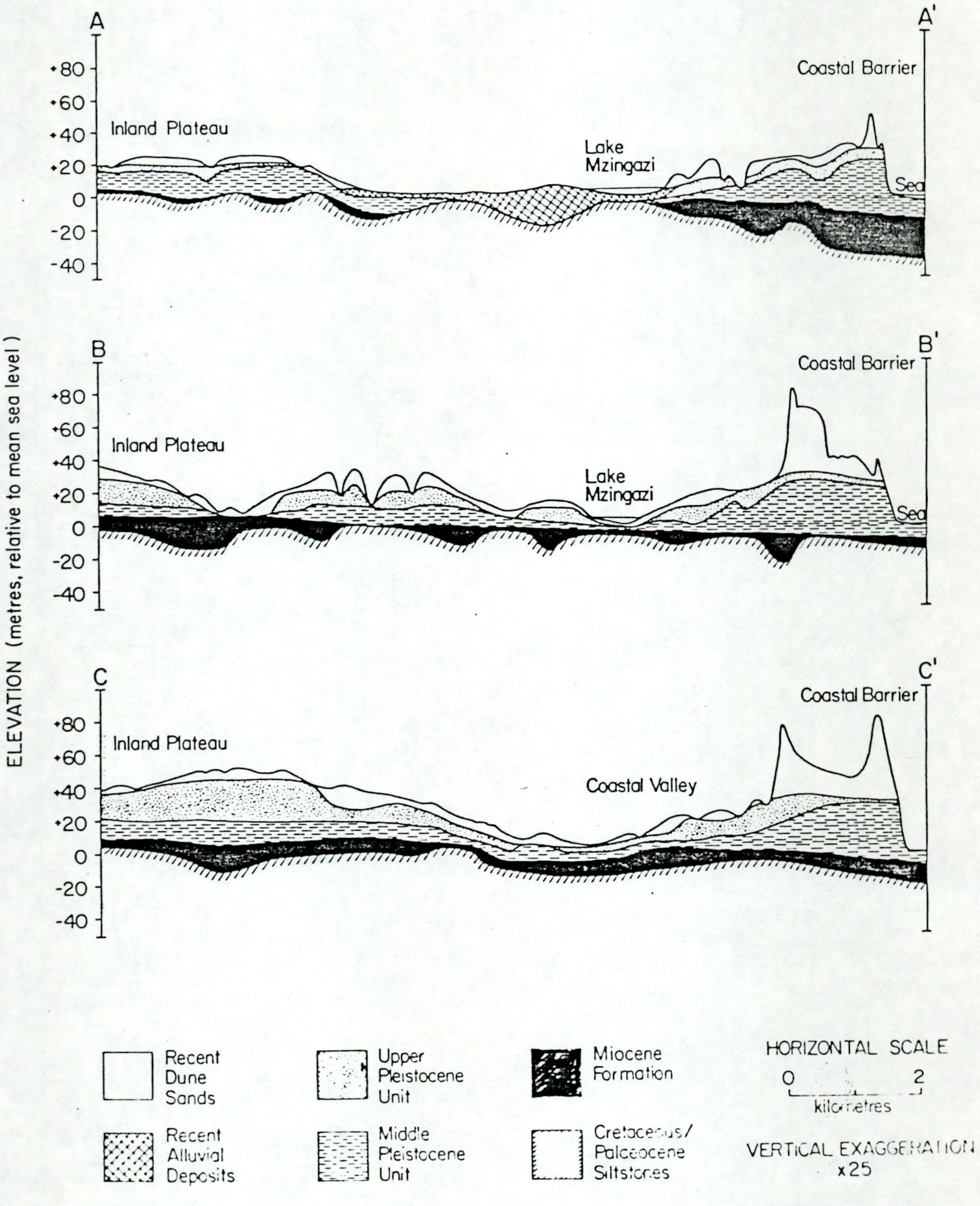


FIGURE 4: West - East sections showing post-Paleocene geology and topography north of Richards Bay (c. 70 km south of Eastern Shores) (from Worthington 1978)

places (homogeneous) nor is it equal in all directions (isotropic), i.e. it is heterogeneous and anisotropic. It is likely though that the heterogeneity is layered horizontally (following the sequence of deposits). This means that the overall K will be much greater horizontally (parallel to the layering) than it is vertically (Freeze and Cherry 1979), a difference which is probably in the vicinity of an order of magnitude. With increasing probability of the occurrence of fine material at depth in the Pleistocene deposits (Reid 1969; van Heerden 1976), K is expected to decrease with depth.

The water table appears to follow the topography closely, except under the deep dune sands, as shown by Reid (1969), van Zijl´s (1971a) resistivity survey, and our borehole data. This indicates a low hydraulic conductivity (Worthington 1978). Numerous pans at various elevations are evidence of localized confining layers causing perched water tables. Other evidence of low K on the coastal flats is cited by Nänni (1968) and van Zijl (1971a). Worthington gives a figure of 1.2 x 10^{-6} m/sec for the vertical K in the Pleistocene deposits north of Richards Bay.

2.3.1.2 Porosity and specific yield

The pore volume (porosity) of unconsolidated material is relatively high and will be highest for well-sorted fine textured deposits. A likely range of porosities for the type of material found in the Bhangazi drillings by Reid (1969) is 30-50%. This represents the volume of water in saturated deposits.

The difference between field capacity (specific retention) and porosity in an unconfined aquifer is the specific yield. Likely specific yield figures for the Eastern Shores material would be 30% for the coarser deposits, down to 15% for finer textured deposits. This represents the volume of water yielded under a unit head drop in an unconfined aquifer.

2.3.2 Main aquifers at Eastern Shores

The fine Pleistocene deposits of the coastal flats north of Richards Bay are not capable of transmitting large quantities of water (Worthington 1978). Here an underlying coarse sandy Miocene limestone ($K = 3 \times 10^{-5}$ m/sec) is the principal aquifer or, where this formation is absent, a buried alluvial channel deposit is the main aquifer.

Miocene limestone has not been recorded at Eastern Shores. If it does remain in adequate thickness it is likely to play a significant role in the movement of ground-water. Without specific knowledge of such potential aquifers, predictions of ground-water flow on Eastern Shores will remain tentative.

2.3.3 The sea wedge

The fresh/sea water contact along the coast has the form of a steeply angled wedge beneath the land, the slope of which is explained by the Ghyben-Hersberg principle (Fetter 1980).

There are two factors which protect the fresh waters of Eastern Shores from the risk of intrusion of the saline sea wedge. First is the high fresh water ridge beneath the coastal dune which has the effect, according to the Ghyben-Herzberg principle, of making the angle of the fresh/salt interface very steep. Second is the probability that the ground-water from beneath the dunes is discharging into the sea, which has the effect of shifting the fresh to saline interface off-shore (Fetter 1980).

2.3.4 Water chemistry

Water chemistry can provide useful information on ground-water behaviour. The total dissolved solids (TDS) and pH of ground-water usually increases with increasing time underground. The TDS measurements from boreholes near Bhangazi (Reid 1969) range from 100-300 mg/l which is normal for fresh water close to the coast. There is no simple trend in the available TDS values with depth or location which would indicate increasing residence time with depth or locality. This possibly confirms a complex recharge and movement pattern in the ground-water.

3. DATA COLLECTION, ANALYSIS, AND RESULTS

3.1 **The Eastern Shores boreholes and water levels**

A network of shallow boreholes was drilled on Eastern Shores by the Natal Provincial Administration in 1973. The locations of the boreholes (Fig. 2) were based on some of the recommendations in van Zijl's (1971b) report, although the drillings did not conform with van Zijl's requirements. All boreholes were drilled only until water was struck. No records of the methods used, or the borehole logs, were kept. A few of the original holes were lost or damaged soon after drilling. Water levels in the remaining 19 have been monitored on a roughly fortnightly basis since 1973 (with the exception of an 18 month period between 1976 and 1978). Borehole depths and elevations are tabled in Appendix 1. The water levels over the period of measurement are plotted for each borehole in Fig. 5.

3.2 Slug Tests

In October 1985 the efficiency of the monitored boreholes was checked with regard to their hydraulic connection with the aquifer, by means of a slug test. The underlying principle of a slug test is that there must be a free interchange of water between the aquifer and the borehole. After injecting a slug of water into the borehole, the efficiency of the hydraulic contact is determined by the rapidity with which the water level in the borehole returns to the original measured rest water level (RWL).

After RWL had been determined, water was poured down each borehole until the water level was a few centimetres from the top of the collar. The water level in each borehole was measured after 4,5 hours, and again after 24 hrs to determine the length of time it took for the water level to return to RWL (Table 2). The boreholes were to have been measured daily for seven days following the 24 hour test. Heavy rainfall, though, cut off access to the boreholes for three weeks, preventing further testing.

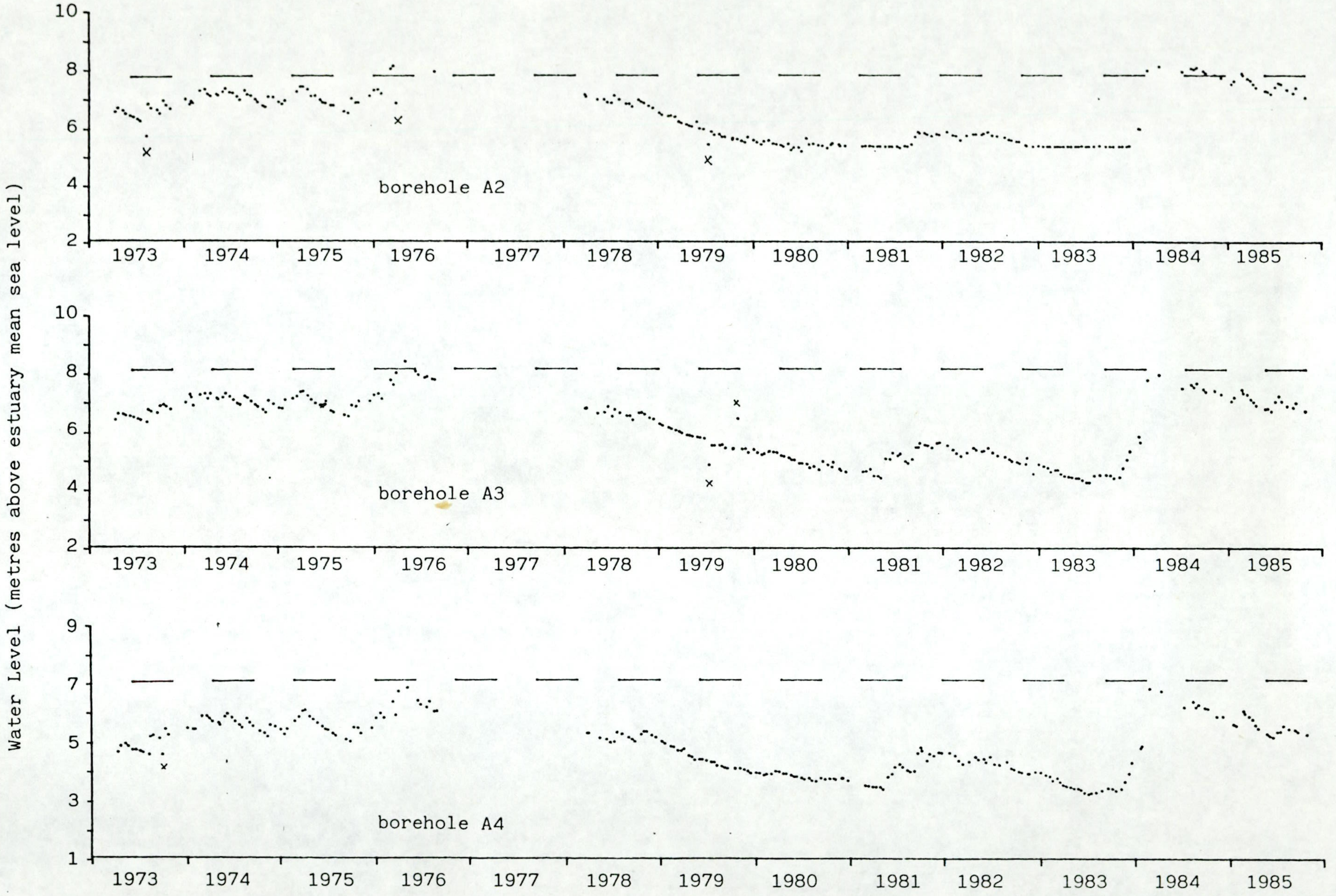


FIGURE 5: Water level hydrographs for the boreholes on lines A, B, C and D at Eastern Shores for the period 1973-1985. Gaps indicate periods when no reading was taken; x marks apparently anomalous readings; the straight dashed line represents ground level at the particular borehole.

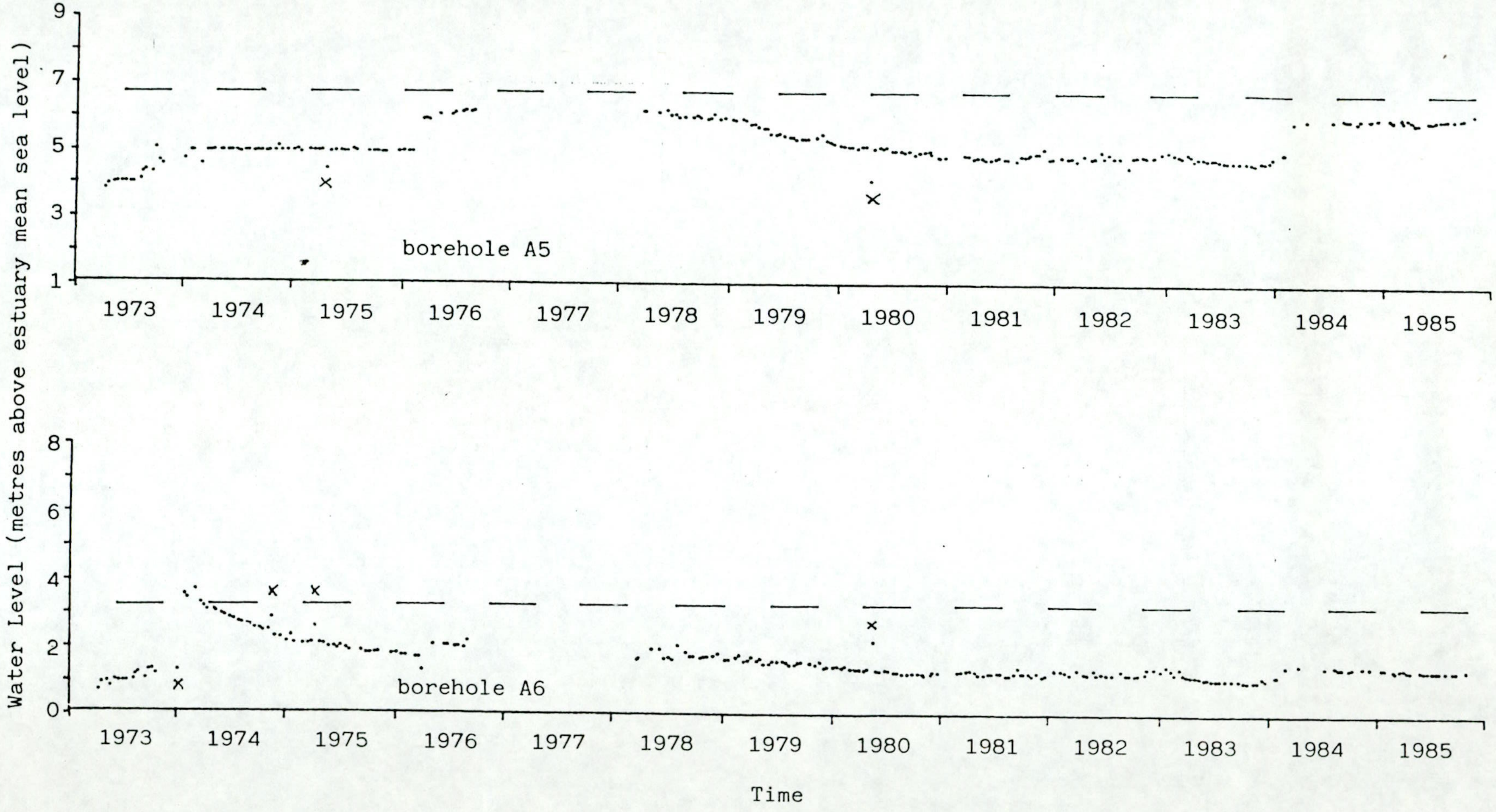
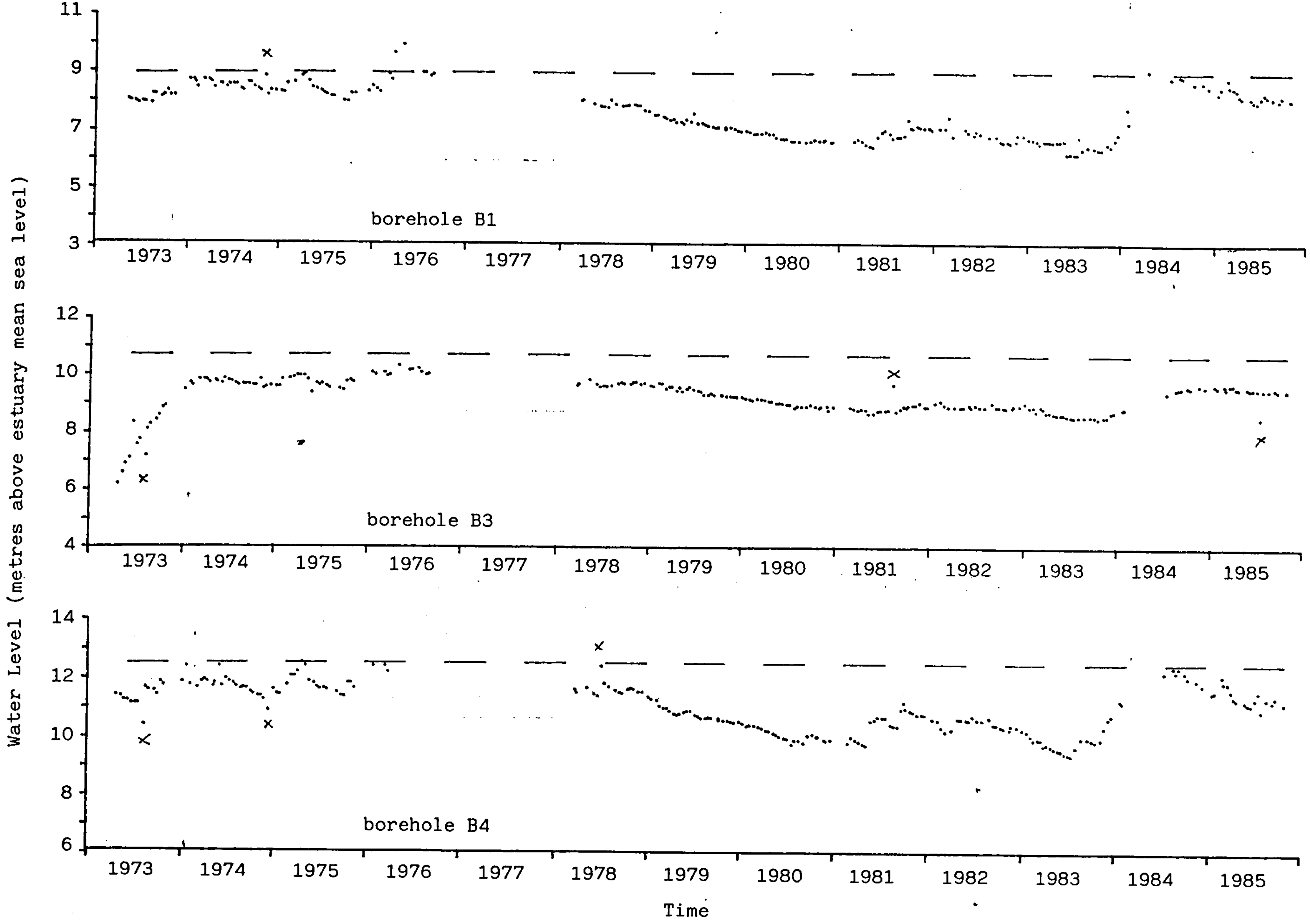


FIGURE 5: Continued



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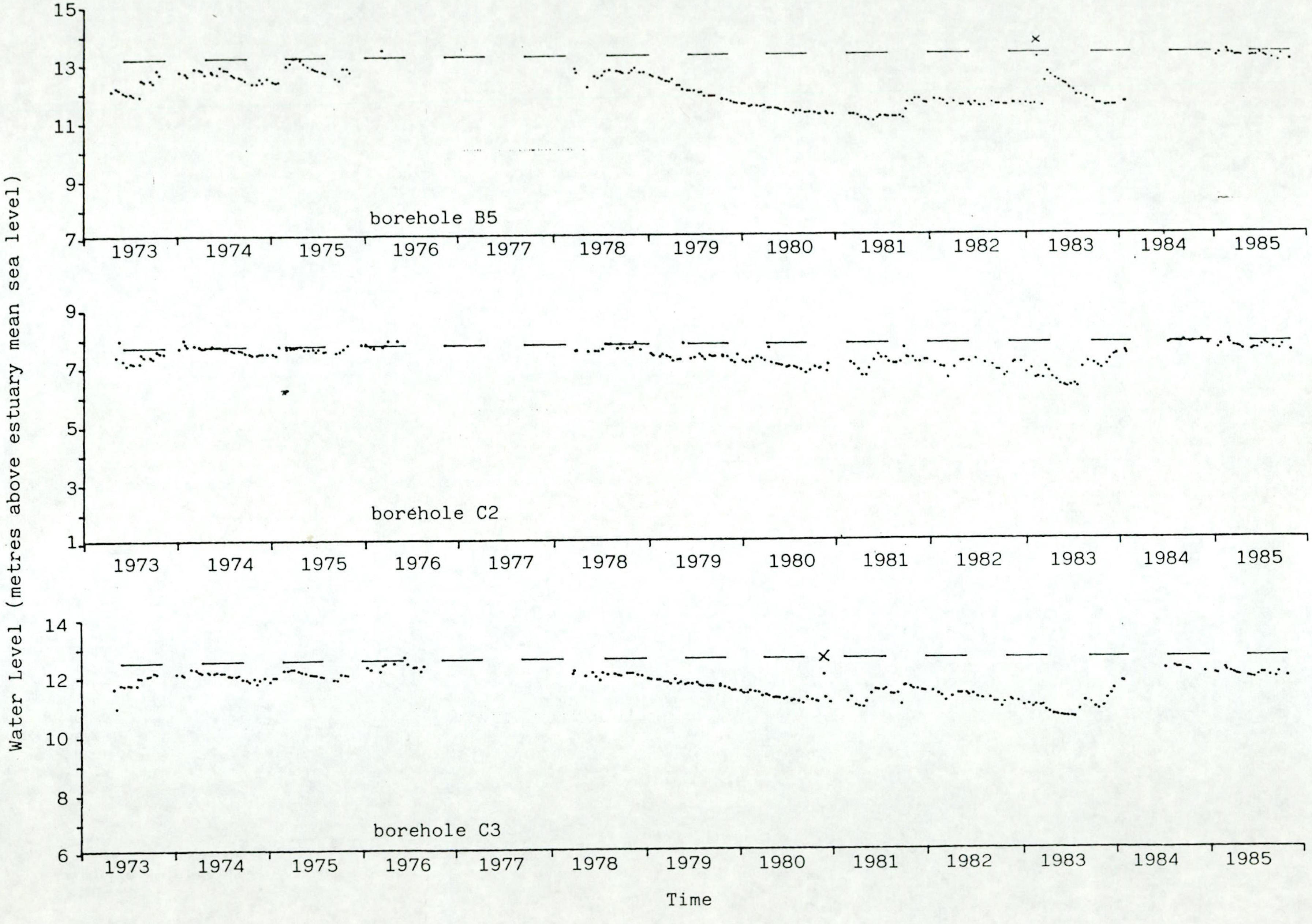

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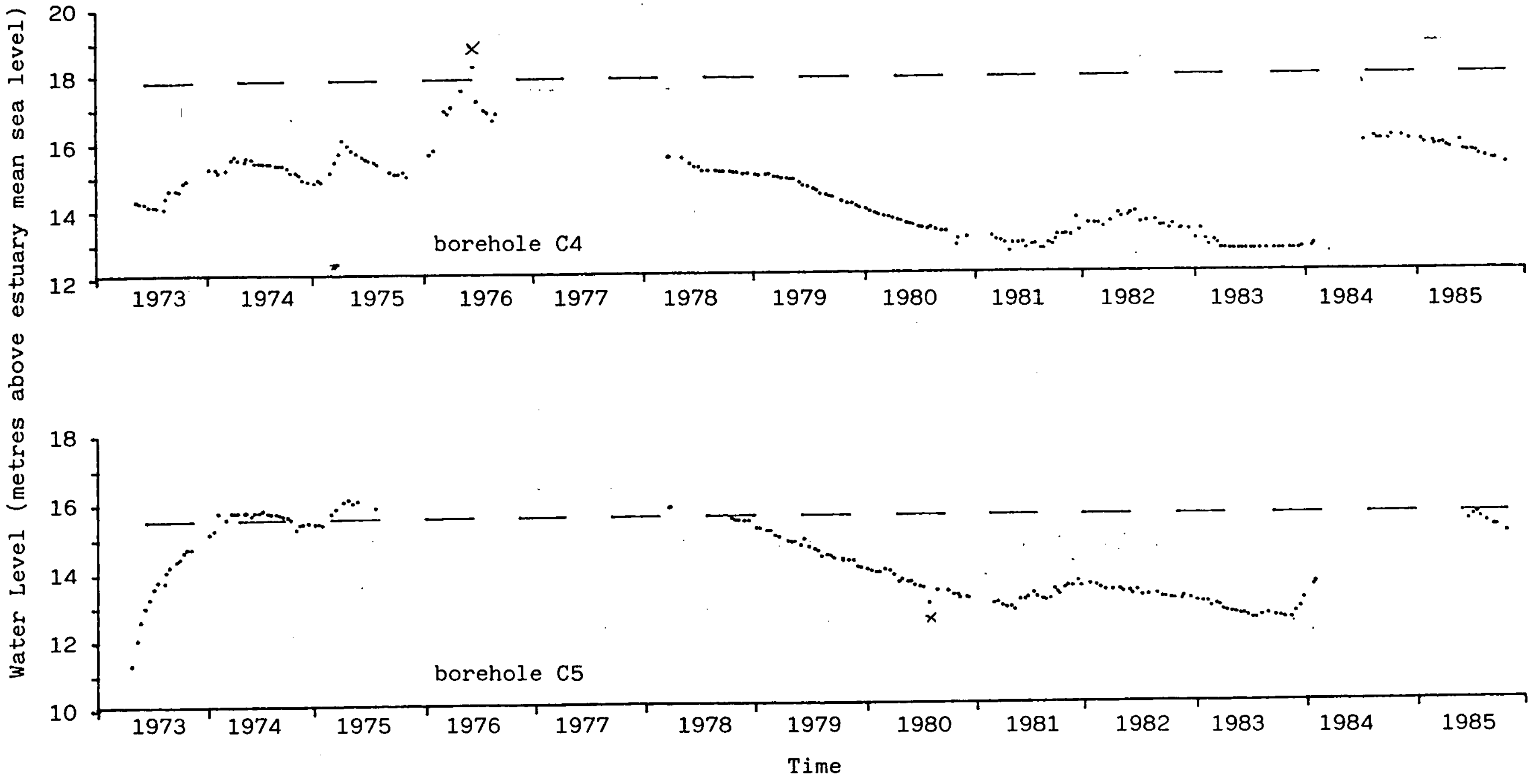

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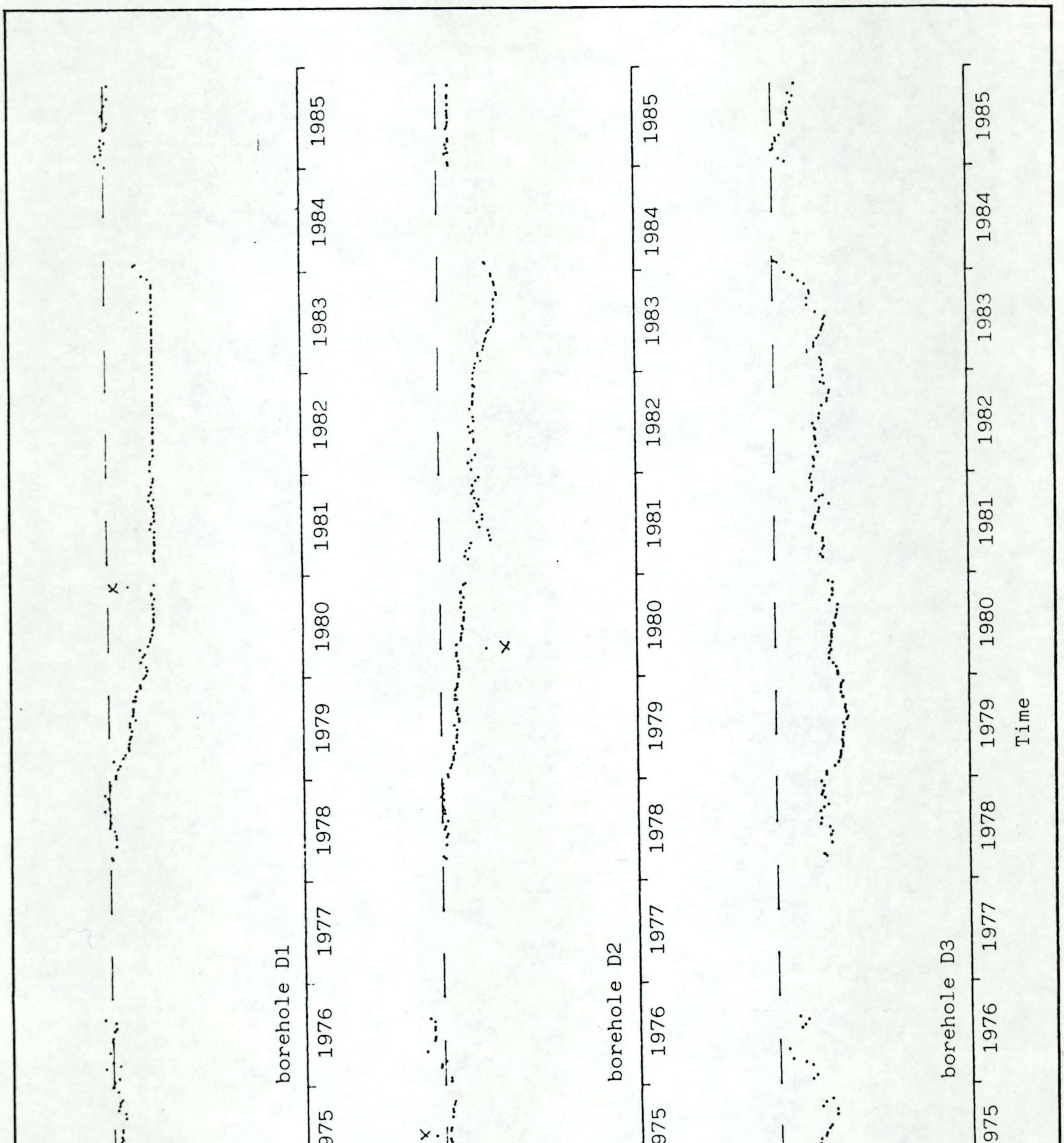

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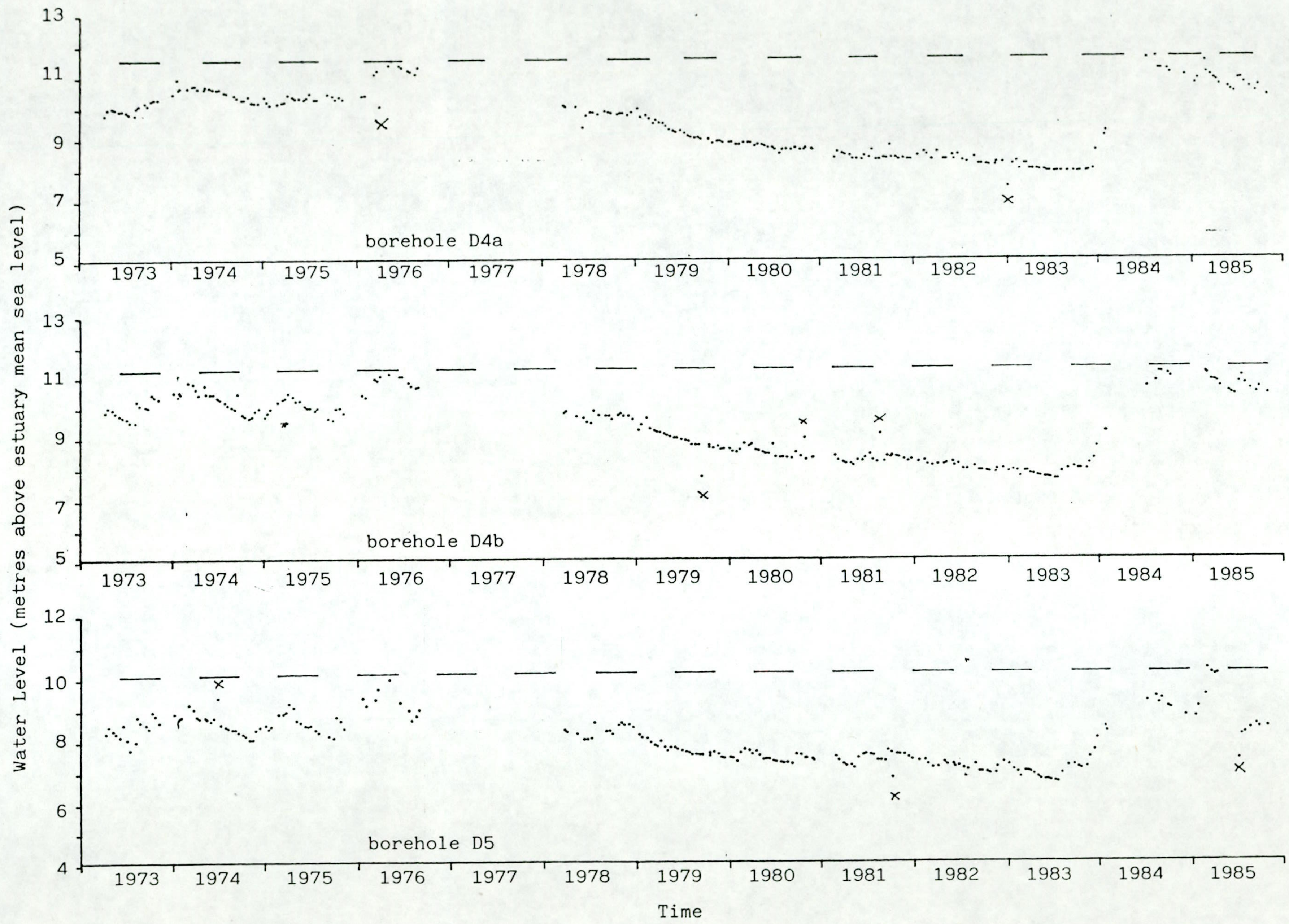

FIGURE 5: Continued

The results of the tests are presented in Table 2. These show extremely poor hydraulic contact in borehole numbers B3, B5, D2, D3 and D5 indicating that the boreholes are probably clogged with fine sediments. Inadequate, though better, hydraulic connection was evident in boreholes A6, B1, C4 and D4a.

Table 2: Percentage drop to original rest water level following a 24-hour slug test

Borehole (Fig. 2)	% drop after 4,5 hours	% drop after 24 hours
A2	14	70
A3	30	63
A4	77	100
A5	73	100
A6	8	30
B1	10	36
B3	0	0
B4	76	100
B5	0	0
C2	100	100
C3	93	100
C4	4	19
C5	100	100
D1	100	100
D2	0	0
D3	0	0
D4a	11	46
D4b	92	100
D5	0	0

Clogging leads to a slower hydraulic interchange, resulting in an exaggerated time lag between fluctuations of water levels in the borehole and aquifer. Where a borehole is badly clogged, the measured water levels do not necessarily reflect the conditions in the aquifer. The clogging sediments can create the illusion of a perched water table, the accumulated sediment acting as the confining layer.

3.3 **Analysis of water level data**

3.3.1 Shortcomings of the data set

(a) No boreholes were sited within the older plantations, e.g. Sibomveni, although some were located on the periphery. Two boreholes (C4 and C5) are located within the five-year-old plantations (Fig. 2). In order to derive an adequate basis for comparison of the geo-hydrological conditions in both planted and unplanted areas, it is essential to locate boreholes both inside and outside the timber plantations (see recommendations, p. 46).

(b) The water level record from 1973 to 1985 is not continuous. Gaps in the record arose during times of limited access to the borehole sites, for example after high rainfall, while at the other times measurements were simply not taken.

(c) Errors in the data set are indicated by a number of apparently spurious readings. A drop in water level of 1 metre or more over a 2 week period is unlikely in this terrain (refer to records marked **X** in Fig. 5). Inaccuracies in the data set may be the result of recording instrument malfunction, unreliable measurements, or errors in recording.

(d) The boreholes are too shallow to permit accurate water level measurements[1] during dry periods. The boreholes were drilled during a wet year (1973) when the water table was higher than average. The records for subsequent drier periods show boreholes remaining dry for more than a year as a result of water levels dropping below the bottom of the borehole (Fig. 5.A2 and 5.D1). The "dry" records constitute missing data.

(e) Hydraulic interchange between the aquifer and borehole is restricted by the small diameter of the holes (18 mm). Water levels may not accurately reflect conditions in the aquifer, particularly as it appears that the casing is not perforated at the base. Water entry is restricted to the small diameter nest of filtering sieves.

(f) Without lithological records the depth and location of the main waterbearing zones cannot be determined and it cannot be assumed that the base of the borehole is in an aquifer.

(g) Slug tests (section 3.2) have indicated poor hydraulic contact with the aquifer. Clogging may be caused by sediments in the borehole, or by corrosion of the filtering sieves. Where boreholes are badly clogged, spurious measurements may result and response patterns will be masked.

(h) The rainfall records are not entirely suitable for the analysis of data from Eastern Shores. The nearest rainfall recording stations in the Eastern Shores area are on the coastline at Cape Vidal and Mount Tabor. The rainfall recorded at these coastal stations is probably higher than that which falls immediately inland of the dunes (see para. 2.1.1). For this reason the rainfall plotted in Fig. 7 is the mean of measurements from the above stations, and those at Charter´s Creek and Fanies Island on the western shores of the lake.

3.3.2 Observations

The available data set is sufficient for qualitative inference, but not for quantitative inference. The following observations are possible:

(a) It appears that the boreholes were not properly developed at the time of drilling.

(b) There are dynamic water surfaces, with definite fluctuations in water levels for wet and dry seasons and years. For example, rainfall during the period 1979-1984 was below average, and this is illustrated by a drop in water levels during this period (Fig. 5).

(c) Water levels follow the topography within the area covered by the boreholes (Fig. 6). Van Zijl´s (1971a) resistivity survey also showed this pattern. This has not been shown to apply under the deep sand dunes : Reid´s (1969) boreholes indicate a deep water table under these well-sorted sands. It cannot be assumed that the measurements are of a single continuous water table because of the evidence of perched water tables and discontinuous confining layers.

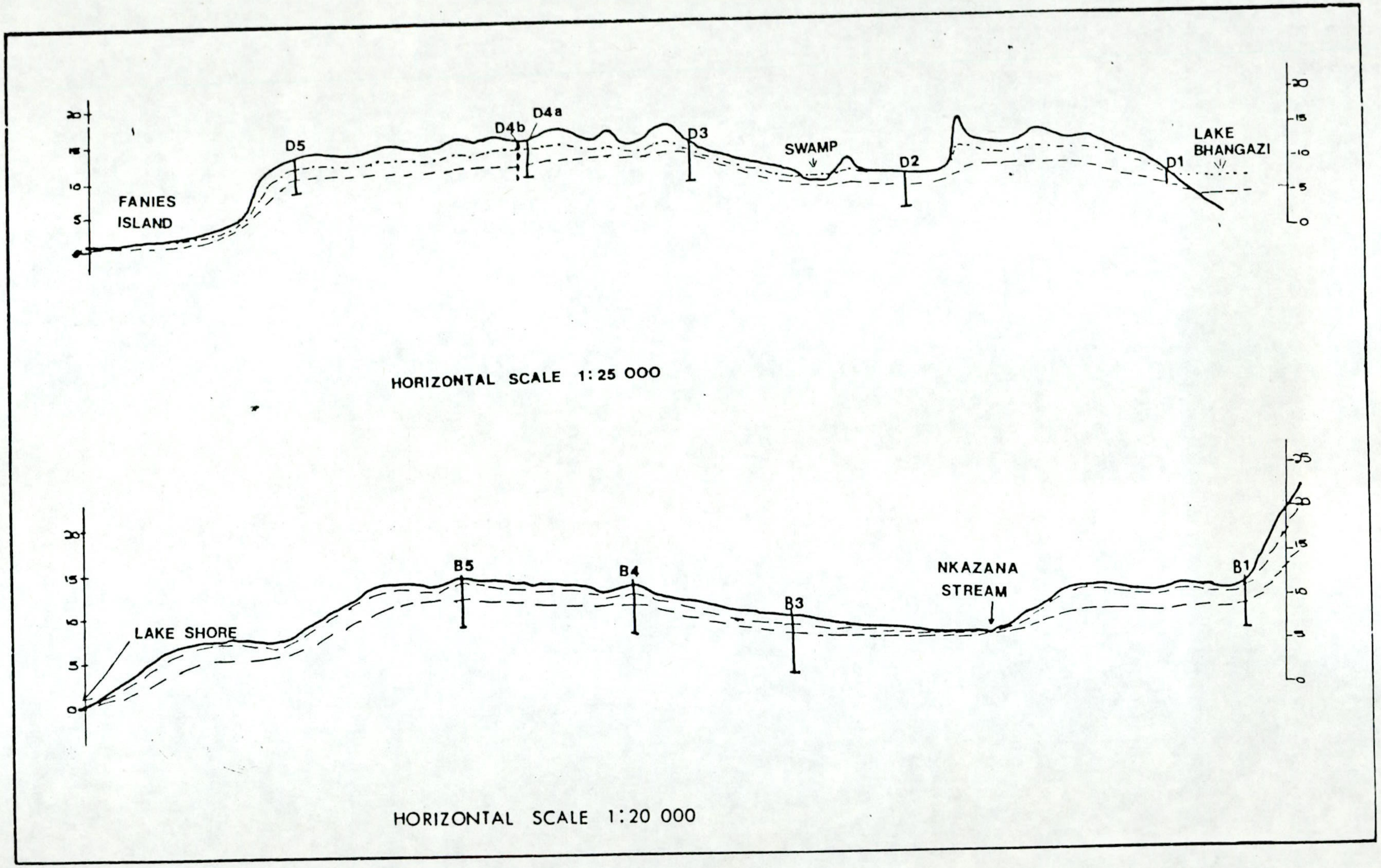

FIGURE 6: West-East topographic sections along borehole lines 'B' and 'C' on Eastern Shores showing position and depth of boreholes, and interpolated ground-water elevation for Autumn 1974 (upper level) and Autumn 1981 (lower)

(d) Figure 7 shows water levels in selected boreholes and weekly rainfall plotted against time for two 1 300 day periods. Statistical correlations between rainfall and water levels have not been attempted, as this would require a series of daily water level measurements following major storm events (refer to para 6.4.9).

The response in water levels to rainfall is greatly flattened and lagged (Fig. 7), with a seasonal pattern emerging. The recharge response to large storms is fairly quick (less than 30 days) even after prolonged dry periods. This response is faster than appears likely from theoretical calculations of percolation through the unsaturated zone. It may be explained either by a high vertical hydraulic conductivity in the cover sands of most of the area, or by localized zones of rapid recharge to the water table.

(e) The discharge response of the water table is, as can be expected, relatively slower than the recharge response. During the prolonged dry period from October 1978 to July 1981 the water levels dropped gradually with mean reductions in storage of less than 1 mm per day.

(f) The existing borehole network is insufficient to establish lines of equal ground-water head (equipotential) with much certainty. A map of inferred equipotential lines is given as Fig. 8. Flow would be at right angles to these lines. Worthington (1978) concluded that the shallow observation wells at Richards Bay would give a general reflection of the hydraulic potential surface despite the presence of heterogeneous

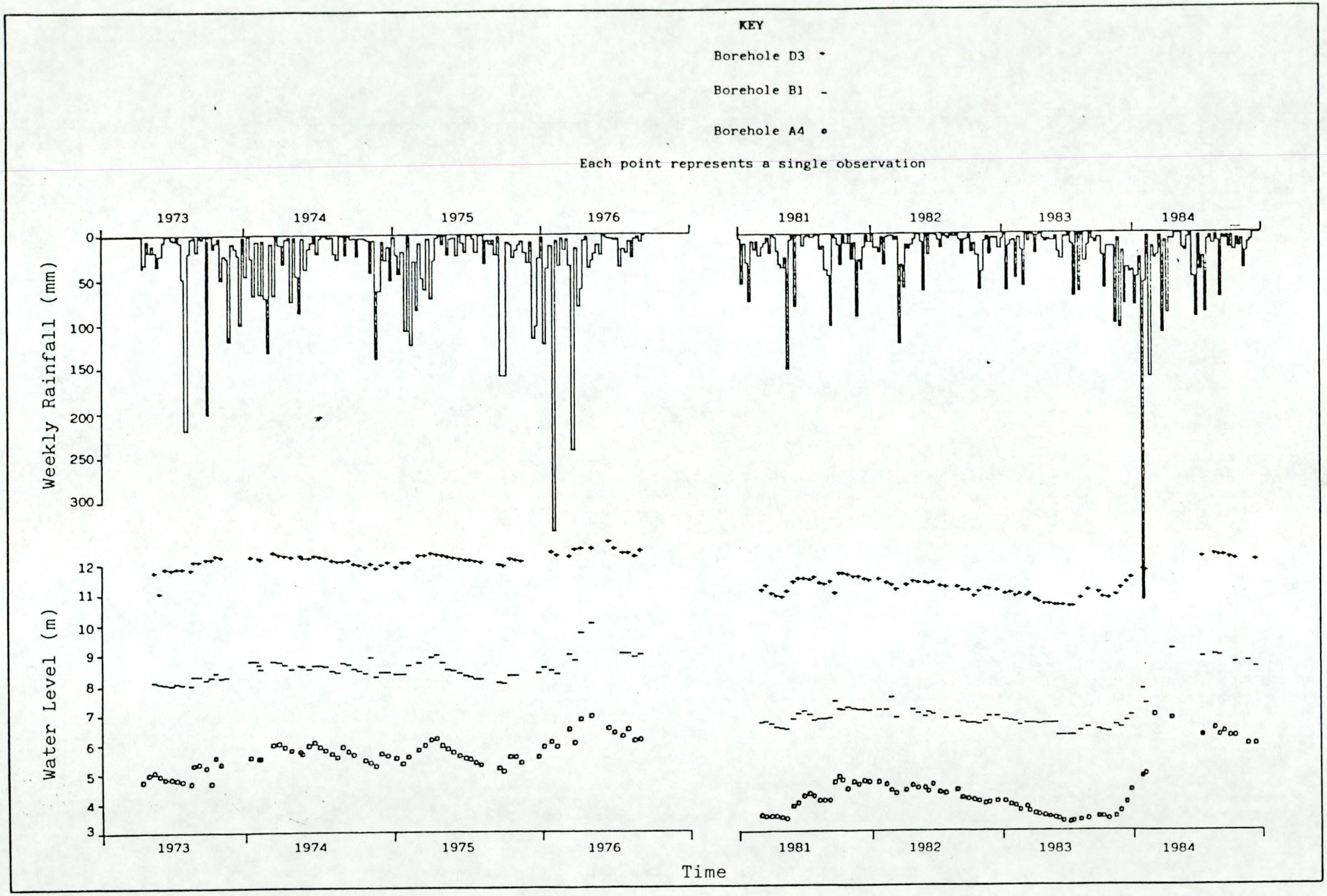

FIGURE 7: Water level hydrographs for selected boreholes, and weekly rainfall for the "wet" period April 1973 to September 1976 and the "dry" period July 1981 to October 1984 showing the response of water levels to rainfall, the variability in levels in a single borehole, and some unlikely and missing data.

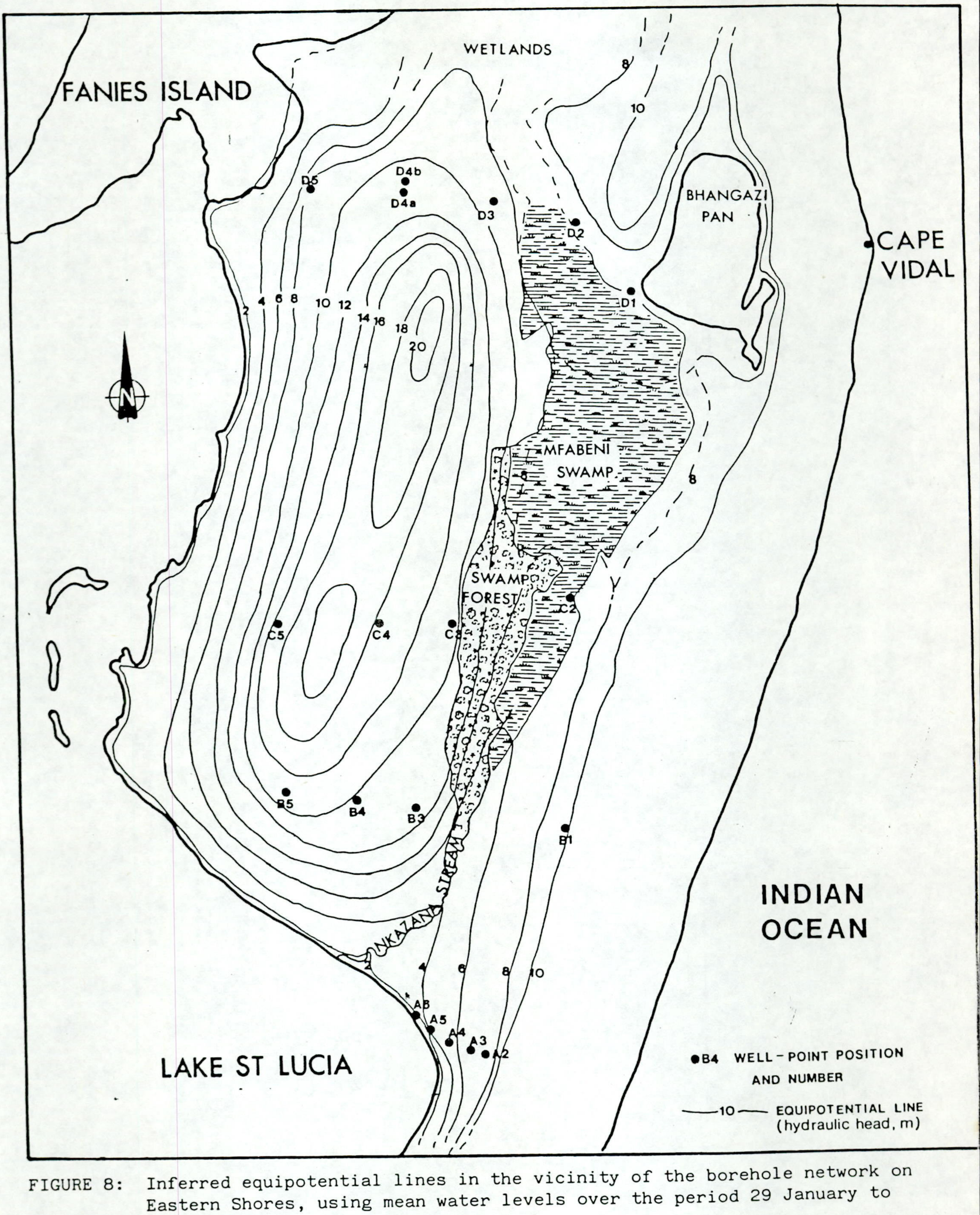

FIGURE 8: Inferred equipotential lines in the vicinity of the borehole network on Eastern Shores, using mean water levels over the period 29 January to 15 May 1974

substrates and perched water tables. In other words, flow appears likely to follow the general topography. A little more than half of Eastern Shores, therefore, would drain inwards to the Bhangazi Pan, Mfabeni Swamp, the wetlands to the north and Nkazana Stream's catchment. The westward facing slopes of Sibomveni (Fig. 2) alone would appear to discharge directly to the lake. The ground-water below the high (coastal) dunes will divide its discharge between the sea (to which there is a greater gradient) and the swamps and lake to the west.

3.4 Streamflow in Nkazana Stream

On the recommendation of Nänni (1977) an effort was made to monitor streamflow in Nkazana Stream which he felt would be most significantly affected by afforestation on Eastern Shores. A crude Parshall flume was installed just below the road crossing and periodic discharge readings were taken from March 1979 till September 1984, by which time the stream had bypassed the flume. Of the sample of 124 readings the discharge was below the minimum flume capacity of 1.5 l/sec (130 m^3/day) on nine occasions and exceeded the maximum capacity of 110 l/sec (9 556 m^3/day) on ten occasions.

On the basis of the Parshall flume readings a mean annual discharge of 1 million m^3 has been estimated for Nkazana Stream. During 1980 discharge is estimated to have been a mere eighth of this amount, while during 1984 it is estimated to have been at least 3,5 times as much. It is clear that Nkazana Stream can make little contribution to fresh water inflow to the lake during dry periods. Its significance may lie in its ability to provide micro-habitats of fresh water on a perennial basis. The main fresh water inputs to the lake from Eastern Shores therefore appear to be as ground-water flow.

The present flume on the Nkazana cannot give accurate discharge measurements, nor can the results be used for research. It is adequate for approximate assessment of streamflow for managements monitoring function. A modelling approach based on present data, could be used to estimate Nkazana streamflows more accurately.

4. GROUND-WATER AND VEGETATION INTERACTIONS

4.1 Dynamics of the ground-water store

The plains of Eastern Shores have a shallow water table (usually within 0-3 m of the surface). This allows a two-way interaction between the saturated and unsaturated soil moisture zones whereby ground-water is directly recharged by percolating precipitation and discharged by evaporation and transpiration. Capillary processes may raise water from the groundwater to replenish evapotranspired soil moisture depending on the particle size distribution of the soil (Kovacs et al 1981).

According to Tinley (1971, 1982) extensive, shallow water tables of sand plains with subsurface, indurated "pan" horizons are important in determining vegetation patterns. Lateral flow is low due to a small gravitational gradient in such systems. Tinley contends that abstraction by transpiration by vegetation with roots tapping the ground-water affects the rate of outflow markedly. The ratio of vertical to lateral movement would therefore increase if grassland were replaced by plantations of trees. Exotic timber plantations could be the principal reason for the reduction of perennial fresh water seepage around the lake (Tinley 1971).

Under natural, undisturbed conditions, an equilibrium develops where recharge to ground-water is balanced by drainage to a lake or river and evapotranspiration. Where there is a long-term change in terrestrial, (for example land use) or meteorological conditions, the groundwater system generally adjusts to a new equilibrium. This will however depend on the nature of the disturbance and the prevailing climatic conditions.

Clearly what needs to be established, for the current debate, is whether soil moisture extraction by the timber plantations is sufficient to reduce the amount of fresh water replenishment to Lake St Lucia, and if so, to what extent this reduction in seepage is affecting the lake ecosystem. In short, what is the maximum permissible rate of water use that will not adversely affect the ecology of the lake?

4.2 **Forest water use**

Evapotranspiration by forests accounts for more water than that by vegetation with a lower biomass in the same regional climate (Balek 1977; Lee 1980). In a review of 94 catchment experiments, Bosch and Hewlett (1982) estimated that changing vegetal cover from grassland to mature conifers or eucalypts causes, roughly, a 400 mm reduction in water yield.

Pines and eucalypts on the Zululand coastal plain develop deep tap or pseudo-tap roots which are greatly branched in the capillary zone above the water table (Haigh 1966). The rooting depth appeared to be dependent on the depth of the zone of saturation: in one sampled 15 year old *Pinus elliottii* roots were up to 5 m deep, which was 25% of the tree height. Thus pines can tap the capillary fringe of shallow water tables directly. In a humid area such as Eastern Shores trees need not be in contact with the water table; the dune forests apparently thrive on moisture stored in the unsaturated zone of the soil profile (D.R. MacDevette, personal communication). This is probably the case too with the pines on the dunes and higher dune remnants. Carbon *et al* (1982) found that *Pinus pinaster* plantations on deep sands in Western Australia could reduce recharge to the water table simply by tapping soil moisture to a greater degree than the xerophytic hardwood forests they replaced.

Tables 3 and 4 give estimates of water use due to afforestation at Eastern Shores, based on experimental data (Bosch 1982). Experimental results from Cathedral Peak and Jonkershoek catchments indicate that pine trees start using more water than grassland or shrubland after approximately four to five years. This increase in water use continues for 20 to 25 years after which it stabilises (Bosch 1982).

Table 3: Estimated additional water use by all plantations in the Eastern Shores catchment (i.e. blocks A, B, C and D)

Assuming an average stand age of 12,5 years (based on a 25 yr cutting cycle)	
Increase in evapotranspiration (Bosch 1982, fig. 2)	= 220 mm/yr
Over a planted area of 4 684 ha this represents (Fig. 2)	10 302 600 m^3/yr
Volume of ground water seepage (Table 1)	= 46 000 000 m^3/yr
Increase in water use as proportion of ground water seepage	= 22,4%
Increased water use as a proportion of total fresh water inputs of 563 000 000 m^3/yr (Table 1)	= 1,8%

It cannot be assumed that trees able to tap saturated soil profiles will necessarily transpire more water than trees that do not have access to the water table. Availability of water is only one of the factors controlling evapotranspiration. If water is freely available vapour loss may still be limited by the magnitude of the vapour pressure difference between source and sink, or by the efficiency of the transport mechanism at the exchange surface. At Eastern Shores the vapour pressure deficit may frequently be limiting because of the high perennial rainfall and the proximity to the sea, which moderates air temperatures and increases humidity.

Also, in humid areas such as Cathedral Peak (mean annual precipitation = 1 400 mm), it seems likely that the pines, being deeply rooted, are seldom if ever limited by water availability, dispite high vapour pressure gradients.

Riekerk _et al_ (1978) determined the water balance of three watersheds on the lower coastal plain of Florida, USA. The vegetation was mature _Pinus elliottii_ with a dense shrub understory and _Taxodium distichum_ (swamp cypress) in ponds. Temperatures were more variable that at Eastern Shores; summer monthly means were the same, but winter monthly means were an average of 6 °C cooler. Surface soils were permeable sands with a water table within a metre of the surface for most of the year, and hydraulic gradients almost a tenth of those on Eastern Shores. Water was therefore certainly not limiting, yet evapotranspiration (Et) losses accounted for only 887 mm or 58% of the annual rainfall of 1 530 mm. These are considerably lower total and proportional figures than those (1 100 mm or 78%) measured for mature _Pinus patula_ plantations in steep, well-drained basins at Cathedral Peak by Bosch (1980). Thus it is felt that use of the Cathedral Peak results at Eastern Shores is unlikely to lead to underestimates of Et losses, despite the obvious differences between these localities. From the results summarized by

Bosch and Hewlett (1982) there appears to be broad agreement amongst results of afforestation experiments in South Africa, and amongst those in other humid regions of the world.

Ground-water flow into the estuary can be ignored when considering lake salinity as it will be overwhelmed by sea water moving up the estuary during dry periods. The estimates derived in Table 3 cannot be treated as absolute, but give an indication of the magnitude of the influence of the pine plantations.

The proportional reduction in ground water seepage will be less during wet years and greater during dry years. The impact of the pines on the overall lake salinity is negligible, especially as the contribution from the area under blocks C and D feeds into the tidal estuary. The effect of the plantation on the water balance in their immediate vicinity is apparently considerable, and may warrant further study. These deductions are roughly the same as the conclusions drawn by Nänni (1977) in a report for the St Lucia Scientific Advisory Council.

5. CONCLUSIONS

5.1 The hydrological effects of pine plantations

5.1.1 The borehole data base is insufficient to allow precise conclusions regarding any significant lowering of the water table by exotic timber plantations to be drawn.

5.1.2 The pines at Eastern Shores are expected to increase evapotranspiration rates as compared to a grass cover, by a similar amount to those measured in afforestation experiments elsewhere in South Africa. The shallow water table under most of the plantations is not expected to lead to greater evapotranspiration losses. The 4 584 ha of plantation at Eastern Shores returns, roughly, an additional 10 million m^3 of water to the atmosphere per year (Table 3). = – 10 million m^3/annum.

5.1.3 The additional evapotranspiration by the pines compared with a grass cover is likely to reduce soil moisture beneath the plantations and cause a lowering of the water table in underlying and adjacent saturation zones (as found in Western Australia by Carbon <u>et al</u> 1982) by an amount equivalent to that estimated above (para 5.1.2). = – another 10 million m^3

5.1.4 The resultant reductions in ground-water seepage from the areas affected by the plantations will be partitioned between direct groundwater and surface water discharge to the lake, discharge to the swamps, pans and marshes, and discharge to the sea. The open water surfaces on pans and marshes, and discharge to the sea. The open water surfaces on Eastern Shores are probably net consumers of water (Kriel 1966, chapter 5), hence only a portion of the water lost to these systems would have reached the lake.

5.1.5 The desiccating effects of the pine plantations are likely to be proportionately higher, and hence most noticeable, during the dry season or times of drought.

5.1.6 The reductions in fresh water inputs to Lake St Lucia which can be attributed to the 4 684 ha of plantation constitute a very small part (mean value <2%) of the total fresh water inputs to the lake, and hence are considered to have a negligible influence on general lake salinity. The influence of the plantations on lake salinity would be even less if contrasted against inflows before abstraction and damming of the river water. Their role as a land use should be seen in this perspective.

5.1.7 The dredging of the estuary month will have a similar negative effect as the pine plantations on lake salinity and in the same region of the lake during dry periods.

5.1.8 It is misleading to indicate the pine plantations of Eastern Shores as a major cause of high salinities in Lake St Lucia. The major contributor of fresh water to lake St Lucia is the Mkuze river, hence the protection of this source should be given particular attention by the custodians of the lake.

5.1.9 The impact of the pines will be localized to the lake shore in the vicinity of the plantings and to fresh water habitats. Water salinities along the discharge zone of the shore will be somewhat higher; the size, depth and number of open water habitats will be slightly reduced; and streamflow in the Nkazana stream will be lower, especially during dry times.

If the vegetation is strongly controlled by water table depth, as indicated by Tinley (1982) and Conlong and Breen (1982), some readjustment of the extent and location of indigenous communities is likely to occur. This effect will be superimposed on the changes in communities (G.F. van Wyk, personal communication) that are caused by natural periodic fluctuations in rainfall (drought periods and flood periods).

5.2 <u>The geo-hydrology of Eastern Shores</u>

5.2.1 The geo-hydrology of the Eastern Shores area appears to be relatively complex, and is not well understood at present. Conclusions drawn from an assumption of a single homogeneous aquifer with a continuous water table are simply `best guesses´ at this stage.

5.2.2 The horizontally layered heterogeneity in the geological substrates of Eastern Shores (see para. 2.3.1) will cause lateral flow to dominate ground-water movement. The borehole data indicates an adequate hydraulic gradient to drive ground-water flow during both wet and dry periods. Theoretical estimates of ground-water discharge using the Dupuit equation

(Appendix 2) show that the maximum recorded decline in water levels would not have reduced discharge by more than 30%.

5.2.3 Plots of water levels, such as Fig. 8, indicate the potential for water to flow both north and south out of Mfabeni Swamp, and for flow between Bhangazi Pan and the swamp to be reversed with changes in water levels.

5.3 The Eastern Shores area does not provide a satisfactory site for research on the effects of plantations on ground-water (i) because of the lack of an adequate control basin, (ii) because the ground-water system is poorly understood at present and (iii) because of the apparent heterogeneity of the substrates which complicates ground water behaviour and could confound treatment effects.

6. RECOMMENDATIONS

6.1 Present knowledge of the water use by the existing extent of pine plantations at Eastern Shores is adequate for decision-making purposes. Little additional knowledge on the general hydrological effects of pines will be derived from a detailed study in this area. As a decision on the future of the plantations of Eastern Shores must be taken in consideration of many factors besides their hydrological impact, sufficient information on this specific aspect is thought to be available.

6.2 There is a need, though, for a better understanding of the water use characteristics of timber plantations on high water table plains, where the partitioning of water use may differ from that determined in previous catchment experiments.

6.3 The present information does not allow a complete understanding of the ground-water hydrology at Eastern Shores. Such an understanding can be acquired by an intensive investigation as recommended by van Zijl (1971b) and Worthington (1978), involving a high density of electrical resistivity soundings associated with a network of deep boreholes and observation wells. It will be an expensive study to be undertaken by a qualified geo-hydrologist. The information it should yield is the configuration, transmissivity and storativity of the aquifers, and the directions and quantities of ground-water flow. As pointed out, in 6.1 above, though, this level of detail is not required for the setting of policy on timber plantations on Eastern Shores.

6.4 Eastern Shores is not recommended as a site for research into the effects of timber plantations on ground-water resources, for the reasons outlined in section 5.3. If research is to be done on water use by plantations on the Zululand coastal plain a more suitable location, with a simpler and better understood geology and adequate experimental control should be sought.

6.5 Ecologists of the managing authorities should investigate the potential ecological implications of the estimated reductions in fresh water (up to 20%) to the surface water, high water table and near-shore habitats of Eastern Shores. These investigations may place the hydrological effects of the pine plantations in a more meaningful light.

6.6 A hydrological model could be developed which would estimate likely effects of various management options that might be considered by decision-makers.

6.7 Attention should be given to land use, abstractions and damming in the Mkuze River catchment because of this rivers importance to Lake St Lucia. Co-operation amongst interested parties, at a basin-scale level, should be sought.

6.8 <u>The future of the borehole network</u>

For purposes of studying the effects of the pine plantations on the ground-water the borehole data at present have little use, and in the light of above recommendations it is not necessary to continue these measurements. If the data are desired for some other purpose, such as management monitoring, or as part of a detailed geo-hydrological study, then the boreholes and data can be improved. The recommendations which follow apply should it be decided to continue monitoring of the water levels. Much can be done, at minimal cost, to ensure good quality data from the existing network.

6.8.1 All boreholes need to be cleaned to eliminate accumulated sediment. This can be done by jetting the boreholes with a high-pressure hose to flush out any loose sediment.

6.8.2 After sufficient data have been collected (one year), water level measurements from the cleaned boreholes should be compared to previous measurements to check the accuracy of the data and response times.

6.8.3 The depth of the boreholes below the ground should be measured to provide a check on previous water level measurements.

6.8.4 Deep augering should be done near each borehole to provide information on geology and confirmation of water levels.

6.8.5 The slug tests carried out in 1985 should be repeated, and the network monitored daily for at least seven days after the test to ensure that free hydraulic contact is maintained with the aquifer.

6.8.6 The present water level recorder should be replaced with a more reliable instrument. The existing instrument is not sufficiently sensitive, particularly bearing in mind the narrow diameter of the boreholes. It can be replaced with a more reliable instrument at relatively low cost (approximately R150).

6.8.7 The automatic recorders should be re-installed in boreholes A2 and D1 to provide a check on the present manual recorder.

6.8.8 A routine of regular measurements needs to be introduced, even if this involves a lesser frequency. This routine should be adhered to as far as possible.

6.8.9 The response of the water table to rainfall should be determined after a sample of major rain events, by taking daily water level readings.

6.9 Expansion of the existing borehole network

If it is decided to undertake ground-water studies at Eastern Shores, despite recommendtations 6.1, 6.3 and 6.4, the existing borehole network could usefully be expanded by the addition of a number of shallow observation wells, both adjacent to and between existing boreholes. Some of these boreholes should be located within the plantations to provide a basis for comparison with boreholes not in the plantations. Such observation wells should be drilled to below the present rest water level. An expanded network of observation boreholes will supply sufficient data to confirm the plot of equipotential lines (Fig. 13).

The main specifications for any additional boreholes would be

(a) a diameter of 100 mm,

(b) perforated casing in addition to an adequate filter, e.g. bidum,

(c) adequate well development following drilling to ensure that no sediment is left in the boreholes,

(d) continuous water level recorders should be installed on a selection of the observation wells.

6.10 Water Quality Measurements

Any additional boreholes should have a large enough diameter (minimum 50 mm) to permit water samples to be taken. Water samples should then be taken on a regular basis, to assist in the determination of ground-water movement, residence time and recharge rates.

6.11 Rainfall Measurements

Because of the high spatial variability of rainfall it is recommended that one or possibly two, preferably recording, rain-gauges be installed in the plains area of Eastern Shores to provide accurate rainfall measurements in the vicinity of the borehole network.

6.12 Research Co-ordination

There is potential for co-operative ground-water studies on Eastern Shores. Contact should be maintained with the research co-ordinating sub-committee for the St Lucia system, chaired by Prof C. Breen, University of Natal, Pietermaritzburg.

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APPENDIX 1 : Heights and depths of the boreholes in the monitoring network at Eastern Shores, Lake St Lucia

BOREHOLE NUMBER	COLLAR ELEVATION (metres above e.m.s.l.)*	COLLAR HEIGHT ABOVE GROUND (m)	TOPOGRAPHIC ELEVATION (m above e.m.s.l.)	ESTIMATED DEPTH OF BOREHOLE (m)
A2	8.56	0.76	7.8	2.46
A3	8.9	0.71	8.2	6.22
A4	8.31	1.21	7.1	5.54
A5	8.04	1.35	6.7	5.35
A6	4.57	1.25	3.3	4.45
B1	10.38	1.37	9.01	4.96
B3	12.89	1.27	11.62	5.61
B4	13.63	1.14	12.49	5.73
B5	13.23	0.02	13.21	5.66
C2	7.79	0.02	7.77	5.06
C3	13.68	1.06	12.62	5.68
C4	19.40	1.54	17.86	5.31
C5	15.62	0.02	15.60	5.50
D1	9.01	1.05	7.96	1.61
D2	9.2	1.39	7.81	5.05
D3	9.7	0.02	9.68	5.17
D4a	13.0	1.32	11.68	5.54
D4b	12.55	1.32	11.23	1.02
D5	11.82	1.71	10.11	5.03

*Estuary mean sea level (e.m.s.l.) is 0,71 m above Durban geodetic mean sea level

APPENDIX 2 : Calculation of potential ground-water discharge along the eastern shore of Lake St Lucia using the Dupuit equation

Assumptions: (i) the hydraulic gradient is equal to the slope of the water table, and (ii) the equipotential lines are vertical and flow is horizontal, parallel to the confining layer beneath the aquifer. Then the Dupuit equation for discharge per unit width (Q) from an unconfined aquifer is:

$$Q = ,5\ K\ \left(\frac{h_2^2 - h_1^2}{L}\right)$$ - where

K is horizontal hydraulic conductivity
h is the saturated thickness of the aquifer
L is the distance between two points of measurement of aquifer thickness (Fetter 1980).

For discharge to the lake west of Sibomveni, assuming a confining aquifer floor at -2m above e.m.s.l. and estimates of aquifer thickness based on water level measurements, then, for wet conditions $h_1 = 18$ m, $h_2 = 4$ m, and for dry conditions $h_1 = 15$ m, $h_2 = 3$ m, and L = 2 500 m

then $Q_{wet} = ,5\ K\ \left(\frac{18^2 - 4^2}{2\ 500}\right)$

$= \underline{0,0616\ K\quad m^3/sec}$ (for K in m/sec)

and $Q_{dry} = ,5\ K\ \left(\frac{15^2 - 3^2}{2\ 500}\right)$

$= \underline{0,0432\ K\quad m^3/sec}$ (for K in m/sec)

thus discharge during dry periods would be 70% of discharge during wet periods.

Results vary slightly for different depths to the confining floor of the aquifer, but the general picture stays the same.