Research Report 2

Water Quality Characteristics of Eight Billabongs in the Magela Creek Catchment

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Hart, B.T. and McGregor, R.J. (1982). Water quality characteristics of eight billabongs in the Magela Creek catchment. Supervising Scientist for the Alligator Rivers Region, Res. Rep. 2.

A six-week survey of the physico-chemical limnology of eight billabongs in the Magela Creek catchment of the Northern Territory was conducted between December 1977 and January 1978. This covered the important period corresponding to the end of the dry season and the commencement of the wet season. Each billabong was sampled approximately weekly.

At the end of the dry season, the billabong waters had elevated conductivity and turbidity, and generally higher sodium, potassium, chloride, phosphate, nitrate and chlorophyll *a* concentrations. They were generally slightly acidic and, in some, the bottom water was anaerobic.

With the commencement of the wet season, the billabongs were flushed and a significant improvement in water quality was noted. Temperature, dissolved oxygen and redox potential data were used to classify these billabongs tentatively as polymictic. Under certain circumstances mixing did not occur for several days, during which time the bottom waters became significantly depleted in dissolved oxygen. From the limited nutrient and chlorophyll *a* data available, it would appear that the billabongs at the end of the dry season are mesotrophic.

1 INTRODUCTION

The Ranger Uranium Environmental Inquiry identified the billabongs downstream of the Ranger uranium deposits as being potentially endangered if the mining and milling of uranium takes place in the future. The mining of the Jabiluka deposits by Pancontinental Mining Limited a little further downstream will also add to the possible problems.

Both companies propose to discharge contaminated waters to Magela Creek at times of high flow. Among the possible problems that may result is the accumulation of contaminants such as radium, uranium and toxic heavy metals (Cd, Cu, Pb, Zn, Hg, Mo etc.) in the billabongs. If these materials are remobilised during the subsequent dry season (May-December) they could significantly add to the stresses already faced by the aquatic biota that survive the harsh extremes of climate in this region by virtue of their billabong habitat.

It therefore follows that a detailed understanding of these billabong ecosystems is needed if the Supervising Scientist for the Alligator Rivers Region is to be able to determine monitoring programs that will enable the detection of any deleterious environmental effects due to the mining operations.

The study reported here is one of a series aimed at providing a basic understanding of the limnological changes occurring in typical billabongs in the Magela Creek catchment.

2 THE STUDY

The objectives of this study were:

- to determine the general limnological characteristics of selected billabongs in the Ranger/Pancontinental area of Magela Creek over a six week period in 1977-78 including the end of the dry season and the commencement of the wet;

- to determine the nutrient status of these billabongs with particular emphasis on changes occurring after the first flush of water enters them.

2.1 Sampling Program

Some eight billabongs were sampled approximately weekly over a six week period from 4 December 1977 to 17 January 1978. The billabongs selected for study are shown in Figure 1. They include four backflow billabongs (Georgetown, Coonjimba, Gulungul and Corndorl) in close proximity to the Ranger operation, two billabongs in the Magela channel (Mudginberri and Island) and two billabongs on the flood plain (Jabiluka and Nankeen). Only the last two billabongs are downstream of the Jabiluka deposits.

Weekly depth profiles of conductivity, pH, temperature, dissolved oxygen (DO) and redox potential (Eh) were taken in each billabong; the depths were surface, 0.2 m, 0.5 m, 1.0 m and at either 0.5 m or 1.0 m intervals to the bottom. In addition, surface water samples, water depth and Secchi depth were taken on each sampling occasion. The water samples were analysed either the same day or within 24 hours for alkalinity, NO_3-N, PO_4-P and chlorophyll *a*. A detailed description of all analytical methods used is given in the Appendix. On those occasions when the profiles indicated that the billabong was stratified, additional water samples were taken at depth. A portion of this sample was generally analysed for the above parameters.

2.2. General Features of Billabongs Studied

2.2.1 Backflow billabongs

The four 'backflow' billabongs, Georgetown, Coonjimba, Gulungul and Corndorl are shown in Figure 1. They are all positioned close to where tributaries join the main Magela Creek channel. Each billabong is separated from the Magela channel by a low natural levee. Hydrologically they are rather similar in that, at the commencement of the wet season, they are probably filled initially by runoff from their catchment. Subsequently water may either flow over the levee into Magela Creek or from Magela Creek back into the billabong (backflow situation); the direction of flow will depend upon the relative flows in Magela Creek and the billabong feeder stream. During most wet seasons a backflow condition would be expected to exist in each of these billabongs for at least part of the wet, since the flow in the Magela Creek will exceed that in the feeder streams. Backflow tends to deposit fine sediments and organic material in the billabongs, whereas flow down the tributaries tends to flush them.

The four billabongs are shallow (1-2 m deep), with shelving banks and clay or silt bottoms with accumulations of organic matter. There is little bankside vegetation around these billabongs, this probably having been destroyed by buffalo. The waters are normally very turbid, particularly during the dry season.

2.2.2. Channel billabongs

Mudginberri and Island Billabongs are positioned in the main Magela channel and appear to be well flushed each year by the main creek flow. They are most attractive with well vegetated, steep banks and deep clear water. The sediments are quite sandy. They probably receive seepage input from the surrounding sandy aquifers for some time after Magela Creek stops flowing.

2.2.3. Floodplain billabongs

The two billabongs on the flood plain that were selected for study were Jabiluka and Nankeen. Both are to the north of the Jabiluka deposits.

These billabongs are reasonably deep (Jabiluka 3.3-5.3 m, Nankeen 3.0-4.4 m) with muddy bottoms and shelving banks. During the dry season they become very turbid as a result of use of the waters by buffalo and waterbirds. There is still some bank vegetation around them, mainly pandanas palms and freshwater mangroves.

During the wet season they lose their identity as water from the Magela channel spreads over the plains and covers them. It is unlikely that they are scoured by the flood waters which appear to travel relatively slowly over the flood plains.

3 GENERAL HYDROLOGICAL PATTERN OVER STUDY PERIOD

It is essential in seeking a full understanding of the limnology of the billabongs in the Magela Creek catchment, that the flow regime existing in Magela Creek at the time of study be taken into consideration. This is particularly so for the period we have studied, the commencement of the wet season, when the most marked hydrological changes are expected in the billabongs.

The following discussion of the flow regime in Magela Creek during the time of our study has drawn heavily on the flow records for gauging stations GS821008, GS821009 and GS821017, which are all in Magela Creek (see Fig. 1; GS821008 is further south than the limit of the map), and for gauging station GS821012 which is situated in Gulungul Creek. Rainfall records at Jabiru and Jabiluka have also been used. The rainfall is plotted in Figure 2 and the flows in Figure 3.

In general terms the hydrological regime for Magela Creek is quite predictable. Flow only occurs in the study region during the wet season and, progressively over the dry season, the stream dries up to leave a series of billabongs. The wet season flow comprises a series of flood peaks superimposed on a baseflow which begins in an average year about mid-December and ceases about the end of June.

The low lying areas along the main stream channel are usually flooded between January and April to a depth of up to 1 m. On entering the plains near Jabiluka, water from Magela Creek spreads widely. About 200 km^2 are flooded in most years but this can double in wet years. The sedge areas of the flood plain are generally under water for three to six months and the swamps for six months or more.

It is probable that some billabongs receive groundwater inflow during the dry season but the extent of this is unknown.

Magela Creek commenced to flow past Jabiru (GS821009) on 30 November 1977 just prior to the commencement of our study (Fig. 3). By about 8 December, water had crossed the main road and progressively spilled over the plains area between the road and Jabiluka Billabong, with the first flow being recorded at Jabiluka (GS821017) on 13 December. Perhaps a day or so later water would have filled the flood plain to Nankeen Billabong. At no time during our survey period did Magela Creek flow into the East Alligator River.

At Jabiru the main flow during the study period occurred in the middle part of December (see Fig. 3). This was followed by quite low flows to 17 January when the study was terminated.

A similar flow pattern was noted at Jabiluka (GS821017) where the main flow during the study period occurred between 22 and 27 December, followed by a reduction in flow into the early part of January. By the end of the study the flow had begun to increase again.

It is unfortunate that our study was not able to commence a little earlier than it did, since there is evidence that at least some of the billabongs had received runoff before the first sampling. For example, Ranger personnel suggested that the water level in Georgetown Billabong had begun to rise about 26 November. Such runoff would of course change the water quality in the billabong; change in quality from dry season to wet season was one of the aspects we wished to study. However, we believe this change was observed in our study of the northernmost billabongs, Island, Jabiluka and Nankeen, which received little if any runoff until some time after sampling commenced.

The general hydrological regime during the study period is reflected in the water level changes measured in each billabong. These are plotted in Figure 4.

Gulungul Billabong possibly reflects best the water level changes in the backflow billabongs. It appears that this billabong initially filled between 6 and 9 December and, from this latter date, the level remained essentially constant until just before the end of the survey when the level again rose. The data do not permit us to comment upon whether this billabong was filled by catchment runoff or by backflow from the Magela.

It is unlikely that the water level in this billabong was as constant as the data plotted in Figure 4 would suggest. Figure 3 shows that the flow in Magela Creek (GS821009) was low on each occasion the billabong water level was measured. On those occasions when the Magela Creek flow was higher, the water level in Gulungul would probably also be higher due to backflow of Magela Creek into the billabong.

The first measurement in Georgetown was on 9 December, at which time a backflow condition was thought to exist (visual observation, no current directions were taken). From this time to early January 1978 the water level dropped approximately 0.5 m, but by the end of the survey had risen again to 3.1 m, approximately the water level at 9 December. Coonjimba Billabong remained essentially constant in depth from the first measurement on 18 December until the end of the survey (17 January).

The water level changes observed in Island and Nankeen Billabongs reflect an increase in level as the wet season progresses which can be explained by the billabongs 'filling up' as water moves further north down the Magela. It was noted elsewhere that water crossed the road about 8 December and from this time would have flowed into Island Billabong. This is shown in Figure 4 where data indicate that the water level increased by over 1 m between 4 and 18 December. The level continued to rise to a maximum depth of 6.3 m by 23 December, then dropped slightly, but had again risen to over 6 m by the end of the survey.

It is difficult to comment meaningfully upon the water level fluctuations in Mudginberri Billabong except to note that the levels appear to be extremely dependent upon the flow in Magela Creek. This is not surprising, since the course of the Magela at this point is directly through Mudginberri Billabong.

The water levels in both floodplain billabongs reflect the delay in water reaching this point of the basin. The flow data recorded in Figure 3 indicate that a small flow commenced at GS821017 (northern end of Jabiluka) on 13 December. Presumably soon after this the billabong topped its banks and water flowed to Nankeen. Water levels taken in Jabiluka Billabong (Figure 4) indicate that between 12 and 19 December there was a one metre increase in water level. After 19 December, the level increased about an extra 0.4 m and then remained almost constant to the end of the survey. The trend in water level in Nankeen followed closely that in Jabiluka.

In summary, Magela Creek commenced to flow past Jabiru on 30 November 1977 and crossed the main road below Mudginberri about 8 or 9 days later, at which time Island Billabong would have begun to fill. Subsequently water spread beyond Island Billabong and probably filled Jabiluka Billabong a day or so after 13 December. Flood waters had reached Nankeen Billabong by 19 December. The backflow billabongs would have received their first inflows between the latter part of November and 6 December. It is not possible to specify whether this inflow was runoff from the billabong catchment or backflow from Magela Creek.

4 RESULTS AND DISCUSSION

All results are recorded in Tables 1 to 8 and will be discussed under two headings, limnological features and nutrient status.

At the outset it must be recognised that the results from this present study provide information on the billabong systems over a time period when they are transformed from isolated standing waterbodies to part of a flowing stream system. In this respect we have surveyed only one part of their annual limnological cycle.

As was mentioned in the previous section, some billabongs had received initial runnoff before we were able to sample them. This would have resulted in major changes in water quality. We have therefore been rather cautious in giving too detailed an interpretation of the data.

4.1 Limnological Features

In this section the limnological features of the billabongs studied are discussed from the view point of changes in the physico-chemical parameters - conductivity, temperature, dissolved oxygen, redox potential and pH.

4.1.1 **Conductivity**

Conductivity is a measure of the total concentration of dissolved inorganic salts in the water. In a billabong, increases in conductivity are expected as the dry season progresses, owing to evaporation and concentration of the dissolved salts and/or to inflow of saline groundwater.

Data collected for Jabiluka Billabong by the Water Resources Branch, Department of the Northern Territory, show the typical annual pattern in conductance values expected (see Fig. 5). Between June and December there was a gradual increase in conductivity corresponding to an increase in the concentration of dissolved salts. Around mid-December 1977, Magela Creek waters reached Jabiluka, filled the billabong and eventually flushed it, resulting in low conductivity values of around 20 μS/cm by February 1978.

A generally similar seasonal trend was also noted in the concentrations of Na, K, Cl and SO_4 (Fig. 6). The concentration of both Na and Cl increased between three- and fourfold during the 1977 dry season. The concentrations of Ca and Mg also appeared to increase with the dry season, but to a lesser extent than Na.

There was little change in conductivity in the three backflow billabongs, Georgetown, Coonjimba and Corndorl, over the study period (Tables 1, 2 and 4). This no doubt reflects the fact that they were effectively flushed before our study commenced. The effect of dilution and flushing is shown by the data for Gulungul Billabong (Table 3) where conductivity was reduced from 67 μS/cm on 6 December to 27 μS/cm by 19 December.

The conductivity results for Island Billabong (Table 6) confirm our earlier statement that this billabong probably received its first runoff about 8 December. When surveyed on 4 December, Island Billabong contained surface waters with a conductivity of 60 μS/cm and bottom waters somewhat lower (48 μS/cm). On 13 December the water was considerably lower in conductivity (25 μS/cm) and was obviously well mixed vertically.

We have previously commented upon the changes in conductivity in Jabiluka Billabong waters as the billabong is flushed. The data in Table 7 show that surface water had values between 147 and 153 μS/cm until 12 December with a reduction to 80 μS/cm on 19 December and a further reduction to 37 μS/cm by 25 December.

A similar but more dramatic change in conductivity also occurred in Nankeen Billabong over this time period, conductivity decreasing from 240 μS/cm on 12 December to 40 μS/cm on 26 December.

4.1.2 **Temperature**

Standing waterbodies such as lakes and billabongs can become thermally stratified with a top warm layer (called the epilimnion) and a cold bottom layer (called the hypolimnion). A number of authors have classified lakes on the basis of the type of stratification with probably the most relevant to the present discussion that by Bayly and Williams (1973).

In lakes that are permanently stratified for extended periods the hypolimnion will usually become progressively lower in dissolved oxygen (this being used up by bacterial decomposition of organic matter) and increasingly more anaerobic.

It is possible to make several general observations regarding the temperature regimes in the billabongs studied.

(a) As a general rule water temperatures were found to be high. The range was from a minimum of around 28°C in bottom waters of some of the deeper billabongs, to a maximum approaching 40°C in surface waters of some of the turbid, shallow billabongs.

(b) An observable difference between the temperature of surface and bottom waters was found for most billabongs.

(c) The exact temperature profile depended in particular upon the time of day at which sampling was carried out. This is illustrated by the results from two sample runs on Corndorl Billabong on 14 December, one at 0900 h and the other at 1500 h. There was little evidence of thermal stratification at 0900 h (see Fig. 7), but by 1500 h the billabong was distinctly stratified with surface waters at a temperature of 36°C and bottom waters at 32°C.

    It seems clear that the penetration of radiation in this billabong was influenced by the turbidity (Secchi 0.8 m) since between 0900 h and 1500 h the surface water temperature increased by around 4°C while that of the bottom waters (1.5 m) only increased by 1°C.

(d) The influence of turbidity upon the temperature differential between surface and bottom waters is very markedly illustrated by Gulungul Billabong. Early in the study period (6 December) this billabong was very turbid (Secchi 0.1 m) and quite shallow (max. depth = 0.7 m). At 1500 h on 6 December there was a 10.5°C temperature difference between the surface water (40°C) and the water at 0.7 m (29.5°C).

(e) No temperature profiles were measured over a 24 h period during the study, hence it is not possible to draw definitive conclusions regarding the stability of the thermal stratification noted in most billabongs. It is possible, and indeed likely, that these systems could be thermally stratified during the day and, due to loss of heat, become destratified during the night. Whether this sequence occurs, or the billabongs remain thermally stratified over the 24 h period, will depend upon a number of factors including the billabong depth, the day and night temperatures and the wind regime. Waterbodies that do not exhibit persistent thermal stratification during the year, or which only stratify during the day, are classed as polymictic (Bayly and Williams 1973).

    Indirect evidence provided by the low dissolved oxygen concentrations found to occur at times in the bottom waters of some billabongs (and discussed fully in the next section) permits one to conclude tentatively that, at least for short periods (days), these billabongs may be persistently thermally stratified. Georgetown Billabong showed such a trend when sampled on 3 January (Table 1). Even as early as 1000 h on this day there was a 5.5°C temperature difference between top and bottom waters indicating that thermal stratification was well established. It seems likely that this thermal stratification had existed for several days, since bottom water (2.0 m) had a very low DO (0.2 mg/L; 3% sat., Eh -130 mV).

(f) The channel billabongs, Mudginberri and Island, are deeper and somewhat clearer than the other billabongs studied. The data collected in this study also suggest that the differences in temperature between surface and bottom waters are less than in the other billabongs. Thus for Mudginberri the maximum difference observed was 3.5°C, found on 8 December (see Table 5). Generally the difference was around 2°C.

The most significant temperature difference measured in Island Billabong was on 4 December when the surface water was 33.7°C and bottom water was 30.5°C. Interestingly this was before the billabong was flushed and it was quite turbid at the time (Secchi 0.4 m).

It seems that, with the exception of Island on 4 December, these two billabongs were studied under conditions which more resembled those in flowing streams than those in standing waterbodies. It is therefore not surprising that little thermal stratification was found. The temperature regime measured in Island Billabong on 4 December, before it was connected to the main Magela Creek flow, suggests that some thermal stratification probably occurs in these channel billabongs during the dry season. It is not possible to comment upon the stability of this stratification.

(g) In the period before waters reached them, both Jabiluka and Nankeen were extremely turbid (Secchi: Jabiluka 14 cm, Nankeen 6 cm). This would have significantly reduced sunlight penetration and resulted in only the very top water layers becoming appreciably increased in temperature during the day. This effect was very apparent in both billabongs (Fig. 8). The majority of this heat would be lost during the night. Thus these billabongs would be also classed as 'polymictic', since the thermal stratification occurring during the day would probably not persist during the night.

After flushing, the turbidity of these billabongs was significantly reduced. This resulted in modified temperature profiles (Fig. 8). Thus while the top 20-40 cm still showed the greatest temperature increase during the day, heating also occurred further down the water column. Presumably most of the heat from the surface layer is lost during the evening. This is certainly indicated by the temperature profile for Jabiluka taken at 0800 h on 5 January. At this early time of day, before appreciable surface heating had occurred, the temperature difference was only 1°C between top and bottom waters with the thermocline at about 2.5 m (Fig. 9). This small temperature differential, which obviously would be greater during the day, appears sufficient to prevent holomixis from occurring, since the DO and Eh data indicated that this billabong was well stratified and had anaerobic bottom waters (see Section 4.1.3).

4.1.3 **Dissolved oxygen and redox potential**

The oxygen dissolved in water is derived from the atmosphere and from photosynthetic reactions in algae and higher aquatic plants. The total amount that can dissolve is particularly dependent upon the water temperature and the salinity, and at any time the concentration will depend upon the relative rates of biochemical depletion and re-aeration (e.g. by algal photosynthesis).

In the billabongs studied, considerable diurnal (daily) fluctuation in DO levels are expected as a result of changes in water temperature and photosynthetic organisms, one expects an increase in DO concentrations (in surface waters) during the day and a depletion during the night when the aquatic plants are respiring. Because of these diurnal fluctuations, a DO measurement taken at one point during the day may not truly represent the situation existing in the waterbody.

In billabongs that are thermally stratified for a period of time, one would expect the hypolimnion to become depleted in DO as a result of bacterial decomposition of organic material.

Another useful comparative measurement of the condition of a waterbody is the redox (oxidation-reduction) potential. This is measured with a platinum electrode (coupled with a relevant reference electrode) and is usually expressed as Eh. In well oxygenated waters the Eh is normally in excess of 200 mV. As the water becomes progressively lower in DO so the Eh reduces until, in anaerobic waters or sediments, the Eh will normally be negative. The redox potential in a natural water will be influenced by a number of possible electroactive ions and compounds some of which do not yield reversible potentials (Stumm and Morgan 1970). As a result, Eh measurements in natural water cannot be quantitatively interpreted although they are quite valuable as a qualitative guide to the condition of a water (Wetzel 1975).

In the following discussion the Eh ranges used and the environments they apply to are those used by Jenne (1977), that is: Eh $<$ 0 mV, anaerobic environment; Eh $<$ 200 mV, reducing environment.

4.1.3.1 Backflow billabongs

With the exception of Georgetown Billabong on 3 January, it is unlikely that any of the four backflow billabongs contained anaerobic waters during the study period, although in a number of instances the waters could be described as reducing. The negative Eh values recorded at the bottom sampling position on a number of occasions almost certainly represent situations where the probe was actually positioned in the bottom muds. Once again it must be stressed that these billabongs had almost certainly received some runoff before our study commenced and it is possible that different conditions pertained before the runoff; that is, during the dry season.

The expected correlation between DO and Eh was generally found, that is, as DO decreases Eh also decreases and may become negative (see, for example, the data for Georgetown 15 December, 3 and 16 January; Coonjimba 3 and 16 January; Gulungul 3, 11 and 16 January: Tables 1, 2 and 3).

However, the Eh data collected in Georgetown Billabong on 23 December are somewhat perplexing. On this date, although the bottom waters were quite low in DO (approx. 3.4 mg/L, 43% sat.), the Eh was not correspondingly low (approx. 180-240 mV). Perhaps the following points are relevant:

(i) the surface water (approx. 10 cm) had a very low pH (approx. 1.8)

(ii) the rest of the waterbody, while not as acid as the surface film, nevertheless was more acidic than previously (pH 4.1-4.6)

(iii) there was a marked change in DO concentrations between 0.5 and 1.0 m depth (6.1 → 3.4 mg/L; 79 to 43% sat.)

(iv) the Eh values appeared to *increase* with depth.

At this stage it is not possible to explain this apparently anomalous situation.

As pointed out above, the waters in Georgetown Billabong on 3 January appeared to be anaerobic. In fact, from just below the surface to the bottom (2.5 m) the Eh was negative. There are, however, some anomalous results. For example, in the surface water (0-0.5 m) the Eh indicated anaerobic waters and yet the DO concentrations were still reasonably high (7.5-4.6 mg/L; 104-62% sat.). The relevant data are plotted in Figure 10 and indicate a thermocline at about 0.4 m depth. It is possible that the standardisation of the Eh meter was in error on this day and that all values are low by a constant amount. This hypothesis is somewhat supported by the similarity in the depth profiles of DO and Eh (Fig. 10).

4.1.3.2. Channel billabongs

The data do not indicate major reductions in the DO concentrations in Mudginberri Billabong through the study period (Table 5). The Eh data suggest there were times when bottom waters may have become slightly reducing (e.g. 30 December and 6 January).

On a number of occasions there was significant depletion in DO in bottom waters of Island Billabong; this was particularly noticeable on 30 December,and 5 and 12 January (Table 6). However, only on 5 January did the Eh results seem to reflect these low DO concentrations.

During the study period it seems that, perhaps with the exception of the very bottom water, the water in the two channel billabongs was not anaerobic.

4.1.3.3. Floodplain billabongs

The two billabongs studied almost certainly did not receive significant runoff until mid-December. However, by the end of December we consider they had been reasonably well flushed. It seems sensible therefore to divide the data into two groups: (i) before flushing (7 and 12 December) and (ii) during and after flushing (19 and 26 December, 4, 5, 12 and 17 January).

Before flushing: Both billabongs were extremely turbid during this period (Secchi: Nankeen 6 cm, Jabiluka 15 cm) and showed generally reduced DO concentrations in both surface and bottom waters (see Tables 7 and 8). This is also reflected in the Eh results which were generally less than 200 mV (except for Nankeen on 7 December) indicating reducing, but not anaerobic, waters.

After flushing: Both billabongs exhibited a quite marked DO profile on all occasions they were sampled. Generally the surface 0.5 to 1 m was reasonably well saturated with oxygen but there was significant reduction in the DO with depth (see Tables 7 and 8 and Fig. 8). Again the Eh values reflected these data. A number of negative Eh values were recorded; however in most instances they are for the very bottom sampling position and we cannot discount the possibility that the probe made contact with the bottom sediment on these occasions.

We have previously noted that in Jabiluka Billabong on 5 January, although the temperature profile showed a temperature difference of only 1°C between top and bottom water, the DO and Eh profiles clearly showed that the billabong was stratified, with quite anaerobic waters existing in the hypolimnion (see Fig. 9). The implications of this condition for release of nutrients to the water column is discussed in Section 5.

In the absence of data from 24 h sampling it is possible only to comment generally upon the persistence of stratification in these billabongs. From the limited data we have available, it seems likely that under certain conditions, such as those existing in Jabiluka Billabong around 5 January, DO stratification can be established, with thermal stratification only occurring during the day. Lakes which do not have persistent thermal stratification are classed as polymictic (Bayly and Williams 1973). Such lakes have generally been found to stratify during the day, much of the heat being lost during the night when holomixis takes place. In Jabiluka it seems that the thermal stratification could well have broken down during the night but, in view of the fact that the bottom waters were anaerobic, it is doubtful whether significant mixing occurred.

4.1.4 pH

4.1.4.1 Backflow billabongs

The water in these billabongs was generally slightly acidic. Prior to 23 December the pH ranges measured were Georgetown 5.6-6.4; Coonjimba approximately 5.7; Gulungul 5.2-6.5 and Corndorl 5.8-7.4. The high value of 7.4 was recorded in Corndorl on 14 December at 0.2 to 0.5 m depth (sampling time 1500 h) and corresponded to very high DO levels (approx. 10.2 mg/L, 140% sat.). A possible explanation is that high algal productivity, which caused the oxygen saturation and also disturbed the CO_2-HCO_3^--CO_3^{2-} equilibrium, resulted in the increased pH.

The pH profiles measured in Georgetown, Coonjimba and Corndorl Billabongs around 3 to 6 January are interesting (see Fig. 11). In each billabong the pH initially increased with depth and then decreased. This trend must remain unexplained until further work is done.

4.1.4.2 *Channel billabongs*

Early in the study, the water in the two channel billabongs was slightly acidic with Island Billabong being the more acidic (Mudginberri 5.5-6.8; Island 4.3-5.6). Between late December and early January, both billabongs exhibited rather unusual pH profiles (Fig. 12) with the surface water being considerably lower in pH than the rest of the waterbody. For example, on 6 January in Mudginberri Billabong the surface 20 cm had a pH of 6.0-6.8, while from 0.5 m to the bottom (4.5 m) the pH was between 8.2 and 8.5. Similar unexpectedly high pH readings were also recorded below 0.5 m in Island Billabong; in fact at 1 m depth on 5 January a value of 8.9 was recorded.

Data collected in Mudginberri Billabong on 11 January and in Island Billabong on 12 January indicate 'normal' pH profiles with values between 6.0 and 6.3 in Mudginberri and between 5.6 and 6.2 in Island.

4.1.4.3 *Floodplain billabongs*

The two flood plain billabongs show similar trends to the channel billabongs. Early in the study, before Magela Creek reached the flood plain, both Jabiluka and Nankeen contained slightly acidic water with pH values in the range 4.2-5.9. The first flush of Magela Creek water that entered Jabiluka Billabong may have been rather acidic, since the pH in this billabong changed from between 5.7 and 5.9 on 12 December, to between 4.2 and 4.9 on 19 December. Obviously much more frequent samplings will be required in the future if the nature of this first flush is to be adequately determined.

In early January both billabongs showed pH profiles similar to those previously discussed for the channel billabongs. In Nankeen on 4 January the surface 20 cm of water had pH values in the range 5.0-5.7 and between 0.5 m and 4.0 m the pH ranged between 7.6 and 8.0. Similarly in Jabiluka on 5 January the surface 0.5 m had pH values between 5.1 and 5.8 and from 1 to 5 m depth the pH was considerably higher (6.9-7.8). Once again we are unable to explain this trend.

However by 12 January, one week later, the pH profile in each billabong was essentially back to normal with the pH of the bulk of the water in the range 5.3-6.7.

4.1.4.4 *Acidic 'slug'?*

A most intriguing observation made during the study was that around 23 to 26 December 1977 a 'slug' of extremely acidic water appeared to pass down the system from Georgetown to Nankeen Billabongs. The sampling program was such that this low pH water was detected in all billabongs with the exception of Gulungul, Mudginberri and Jabiluka.

The most acidic water appeared to be confined to the top 10 to 15 cm of each billabong. The pH of the rest of each billabong also appeared to be somewhat more acidic than recorded on earlier samplings. In Georgetown on 23 December (1000 h) the surface 10 cm had a pH of 1.8 and between the depths 12 and 20 cm there was a noticeable change in pH from 2.5 to 4.6 (footnote b, Table 1). This low pH surface water did not appear to have a significantly different conductivity from the rest of the waterbody.

Also in Coonjimba Billabong on 23 December (1130 h), the surface 10 cm was extremely low in pH (Table 2).

Corndorl Billabong was sampled the following day at 0930 hours and was found to have a surface layer 0.1 m thick with a pH of approximately 1. The rest of the water column was also somewhat lower in pH than expected (pH 3.0-4.1). Island Billabong was sampled on 23 December and had a surface pH of 1.3, the pH of the rest of the waterbody being between 3.7 and 4.1 The surface water of Nankeen Billabong, sampled on 26 December, had a pH of approximately 1, with the other water varying between pH 3.9 and 5.4.

In the previous section we have noted that rather alkaline conditions were found in the bottom waters of most billabongs in the two week period after 23 to 26 December. It is not known whether there is a causal link between this and the very low pH surface film observed around 23 to 26 December.

Initially it was thought that this acidic layer could have been due to a natural flush of highly acidic material such as sulphuric acid (from the oxidation of sulphide minerals) or humic acids (from the breakdown of organic debris from paperbarks and other vegetation). Several samples were analysed for both SO_4^{2-} and total organic carbon (TOC). The results are tabulated in Table 9 and indicate that the levels of both these parameters are much too low to have caused such a pH drop.

Of course it is possible that the pH meter calibration was in error around the time in question. This seems unlikely as the meters were standardised before each sampling run. However, even if the absolute pH values are in error, the very striking pH change between the top 10 to 20 cm layer and the rest of the waterbody still remains unexplained.

Another perplexing observation we can report, but not explain, was that in a number of cases there were quite significant differences between the in situ pH measurement and the starting pH of samples taken from the same depth, transported back to the laboratory and titrated potentiometrically for alkalinity. The samples when tested in the laboratory would have been at a somewhat lower temperature (23°C) than when taken from the field (30-34°C).

No doubt this change would have had an effect on the CO_2-HCO_3^--CO_3^{2-} equilibrium, but not to the extent noted in some samples where changes in excess of 5 pH units occurred (Table 10).

At this stage we are unable to determine whether a surface film of acid water was present in the study billabongs around 23 to 26 December or whether the observations were due to an instrumental malfunction. However it is clear that this feature should be studied during the 1978-79 change from dry season to wet season.

5 NUTRIENT STATUS

Algal productivity in a standing waterbody is dependent upon a number of factors of which the most important are probably light and nutrient availability. In this section we discuss the results pertaining to the levels of the two main algal nutrients, nitrate (NO_3-N) and phosphate (PO_4-P).

The data relating to Secchi, chlorophyll *a* and nutrients will be discussed in two time periods; before and after flushing of each billabong. Obviously, the conditions pertaining in these two periods will be different.

5.1 Secchi Depth

The Secchi disc is used as an approximate measure of the transparency of a waterbody to light. Briefly a white (or white and black) disc, approximately 20 cm diameter, is lowered into the water column to the point where it is no longer visible from the surface. Studies have shown that the light penetration at the point where the Secchi disc can no longer be seen corresponds to about 5-10% of the surface light (Wetzel 1975; Golterman 1975). The Secchi depth gives a qualitative measure of the depth of light penetration and hence the depth of the euphotic zone.

Before flushing: By the end of the dry season, the backflow and floodplain billabongs were very turbid. For example, Nankeen had a Secchi depth of only 6 cm, Jabiluka about 14 cm and Gulungul 10 cm. The one reading we have for a channel billabong before flushing, Island on 4 December with a Secchi of 40 cm, suggests that the water in the channel billabongs is somewhat clearer than that in the other billabongs, which confirms visual observations.

After flushing: After the initial flushing, the water clarity in all billabongs improved markedly (see Fig. 13). In the case of Jabiluka, the Secchi depth had increased from 13 cm on 12 December to 1.29 m by 19 December. There was a trend towards somewhat lower Secchi depths in the backflow billabongs, probably a reflection of their shallower depths. Secchi depths between 1.0 m and 1.7 m were recorded in Mudginberri and Island Billabongs after they became part of the flowing Magela Creek system. This reflects the very low suspended solids levels in the water flowing down Magela Creek.

5.2 Chlorophyll *a*

Chlorophyll *a* measurements are most useful in providing an estimate of the algal biomass present in a waterbody. Chlorophyll *a* is present in all photosynthetic organisms and may be extracted from the cells and measured spectrophotometrically. Of course chlorophyll *a* measurements do not permit the algal species present to be identified, nor do they provide a measure of the algal productivity.

Two different environmental habitats for algae existed during our survey. These were a lentic environment in the period before flushing and, perhaps with the exception of the backflow billabongs, a lotic environment after Magela Creek was flowing.

Chlorophyll *a* data for all billabongs are plotted in Figure 14. The data show that chlorophyll *a* concentrations in all billabongs were generally lower than 20 µg/L. The highest values tended to be recorded at the commencement of the study, that is, at the end of the dry season. This is best illustrated by the data for Island and Jabiluka Billabongs (Fig. 14). In the former billabong, the initial chlorophyll *a* value was 19 µg/L and this was reduced to less than 8 µg/L after it became connected to Magela Creek. Similarly, chlorophyll *a* values in Jabiluka were reduced from between 18 and 24 µg/L to 10 µg/L or less. The chlorophyll *a* values in Nankeen Billabong were reduced from between 10 and 15 µg/L at the end of the dry season to 5 µg/L or less by January.

There was a general trend towards low chlorophyll *a* levels (<10 µg/L) in Mudginberri, Island, Jabiluka and Nankeen Billabongs after they had become part of the flowing Magela Creek system. The rather high value of 26 µg/L found in Mudginberri Billabong on 15 December is somewhat surprising since, on this occasion, water was flowing rapidly through the billabong. The high value may simply reflect plant material washed down by Magela Creek.

The chlorophyll *a* levels in the backflow billabongs were, with the exception of Corndorl, below 10 µg/L. It must be remembered that all our data are for the period after these billabongs had been flushed. Hence it is not surprising that the biomass was low, since it was probably washed from the billabongs in the initial flush.

Corndorl appears to sustain a higher algal biomass than the other three backflow billabongs. This may be due to a higher nutrient input to this billabong, since there is considerable agricultural use of land in the Corndorl catchment. However, it may simply be that the habitat is more conducive to algal growth, in that there is less water flow through this billabong.

With the limited data available it is extremely difficult to draw conclusions relating to the trophic status of these billabongs. If however one takes as a guide the maximum chlorophyll *a* concentrations found (approx. 20-25 µg/L), this would suggest that, at the end of the dry season, the waters are probably *mesotrophic*.

5.3 Nutrients

In this section we discuss the analytical results for both NO_3-N and PO_4-P. Both these forms are the preferred, but by no means the only, nutrient sources for algae (Golterman 1975).

The changes in NO_3-N concentration over the dry season are shown in Figure 15. These data were supplied by Water Resources Branch, Department of the Northern Territory (DNT). The graph has a similar shape to that for conductivity (Fig. 5) with a maximum concentration around October-November which is reduced as the billabong is filled by rainfall and local runoff, and is later flushed by Magela Creek. These data suggest that the increase in NO_3-N levels through the dry season is due mainly to evaporative concentration.

Also marked on Figure 15 are the results obtained during our study for NO_3-N concentrations in Jabiluka Billabong. It appears that our results are considerably *lower* than those obtained by the DNT. For example on 5 January 1978 our result was 7 μg/L NO_3-N while that obtained by DNT was 680 μg/L. There are two differences between the methods used. Firstly we used a UV absorption method (Standard Methods 133B) while DNT presumably used either the Cd reduction technique (Standard Methods 213B) or the Brucine method (Standard Methods 213C). Secondly we analysed samples within 24 h, whereas DNT samples were not analysed until two to six weeks after they had been taken. In fact in the case of the sample quoted above, it was not received into the DNT laboratories until 23 February, some six weeks after sampling. It is most likely that such a delay would lead to high NO_3-N levels as a result of bacterial oxidation of organic material in the water.

The UV absorption method is regarded, at best, as a useful screening method for NO_3-N and consequently we regard our values as indicative of trends only. The method was used only because of its convenience at the time. In future, we recommend that samples be analysed within 24 h of sampling using a more reliable analytical method.

In general the surface billabong waters had quite low PO_4-P concentrations with values being less than 20 μg/L (Tables 1-8). One high reading (103 μg/L) was found in Nankeen Billabong before flood waters reached it. The NO_3-N concentrations appeared to be somewhat elevated in Nankeen (218, 2221 μg/L), Jabiluka (467, 475, 71, 90 μg/L) and possibly Island (71 μg/L) be ore they were flushed. After flushing occurred, the NO_3-N concentrations in all waters were very low (<7-25 μg/L).

Unfortunately our study commenced too late to catch the initial runoff into the backflow billabongs and hence it is not possible to comment definitively about the nutrient status of this initial runoff water. However it is possible from the observations made on Jabiluka and Nankeen Billabongs before and after Magela Creek water flowed into them, to suggest that the first flush is considerably lower in NO_3-N and PO_4-P than the water in these billabongs at the end of the dry season. For example the NO_3-N concentrations measured in the surface waters of Jabiluka Billabong before Magela Creek flowed into it were 467 to 475 μg/L and this was reduced to 71 μg/L on 19 December and to 7 to 25 μg/L by January. A noticeable reduction was also found in Island Billabong which had a NO_3-N concentration of 71 μg/L on 4 December and this was reduced to levels below 7 μg/L after 13 December.

A number of samples of near bottom waters were taken during the study and the results are recorded in Tables 1 to 8. There is some evidence that when bottom waters were anaerobic, PO_4-P concentrations were high (see data for Island and Jabiluka Billabongs on 5 January, Tables 6 and 7). In Jabiluka Billabong the water from about 3.5 m to the bottom (5.2 m) was anaerobic, with DO levels less than 0.5 mg/L and negative Eh values. Water at 5.0 m contained a PO_4-P concentration of 47 μg/L compared with the surface water concentration of 5 μg/L.

A similar situation existed in Island Billabong where water at 5.5 m (DO 0.4 mg/L; Eh -10 mV) contained a PO_4-P concentration of 50 μg/L compared with the surface water concentration of 7 μg/L. The implication of these elevated nutrient levels in the bottom waters is that the additional nutrients can become available for algal growth when mixing occurs.

6 CONCLUSIONS

A six week survey of the physico-chemical limnology of eight billabongs in the Magela Creek system of the Northern Territory was conducted between 4 December 1977 and 17 January 1978. This period corresponded to the end of the dry season and the early part of the wet season. Sampling of each billabong was carried out approximately weekly and included depth profiles of conductivity, temperature, pH, DO and EH, Secchi depth and analysis of both surface and bottom water samples for alkalinity, PO_4-P, NO_3-N and chlorophyll *a*.

The eight billabongs consisted of four backflow billabongs (Georgetown, Coonjimba, Gulungul and Corndorl) situated in the region of the Ranger uranium deposits, two channel billabongs (Mudginberri and Island) and two floodplain billabongs (Jabiluka and Nankeen). Unfortunately the backflow billabongs had probably received some runoff a few days before the study commenced and there were fewer limnological changes in these than in the billabongs that were flushed during the study.

Conductivity values for Jabiluka Billabong, supplied by the Water Resources Branch, Department of the Northern Territory, showed an increase from June to December, the dry season, followed by a reduction in values, which corresponded with Magela Creek water reaching the billabong about mid-December, then filling and subsequently flushing it. In fact the surface water conductivity changed from 153 μS/cm immediately before flushing to 60-20 μS/cm by February 1978.

This change in conductivity between the end of the dry season and commencement of the wet is indicative of the similar dramatic changes in other water quality parameters. For example Secchi depth was generally very low at the end of the dry season, but increased after Magela Creek commenced to flow; in Jabiluka the change was from about 14 cm to between 1.2 and 1.5 m. Nitrate-N (and to a lesser extent PO_4-P) was also reduced.

All billabongs contained slightly acidic waters with pH ranging from 4.2 to 6.8. In a number of billabongs the surface pH was apparently affected by the level of algal productivity. For example in Corndorl Billabong on 14 December the surface pH was 7.4. At this time the water was supersaturated (DO 140% sat.).

During the period 23 to 26 December 1977 all billabongs sampled apparently had a surface layer (10-20 cm deep) of very low pH water. This was not due to high sulphate or organic carbon concentrations. At this stage no plausible explanation for this observation can be advanced. It is clear however that this feature should be further studied during the 1978-79 transition period between dry season and wet season.

In the two week period after 23 to 26 December the billabongs were generally found to have rather unusual pH profiles with slightly acidic water (pH 5.0-7.0) near the surface and more alkaline water (pH 7.0-8.5) below this. It is not known whether this was linked with the very low pH surface water observed earlier.

Water temperatures were, as expected, quite high and ranged from a minimum of around 28°C in bottom waters of the deeper billabongs to a maximum approaching 40°C in surface waters of the turbid, shallow billabongs. There was evidence that all billabongs were thermally stratified on most occasions profiles were taken. The exact temperature profile was dependent upon the time of day sampling was carried out. For example Corndorl Billabong on 14 December showed little evidence of thermal stratification when sampled at 0900 h but by 1500 h the billabong was distinctly stratified with a surface water temperature of 36°C and a bottom water temperature of 31°C.

A lack of 24 h profile data prevents us from commenting definitively upon the stability of this stratification. Our tentative conclusion (based largely upon corresponding DO and Eh data) is that these billabongs are probably *polymictic,* that is, they may become thermally stratified during the day but, due to heat loss, will undergo holomixis during the night. This behaviour is typical of many tropical lakes.

No doubt under certain conditions the thermal stratification may continue for short periods of time (days). There is evidence that this was the case in Georgetown and Jabiluka Billabongs around 3 to 5 January 1978. Both these billabongs showed obvious DO and Eh stratification with very low oxygen concentrations in the hypolimnion. It is most unlikely that mixing in these billabongs had taken place for some time. Interestingly, when sampled early in the morning of 5 January (0800 h) Jabiluka Billabong showed a temperature difference of only 1°C between top and bottom waters. Thus while considerable heat is obviously lost from the surface waters of these billabongs it appears that under calm conditions stratification is sufficiently stable to prevent mixing occurring.

Given the high water temperatures and high levels of sediment organic matter in these billabongs one would expect the bottom waters to be rapidly deoxygenated (anaerobic) if mixing were prevented even for a short period of time.

One consequence of stratification would be that nutrients, particularly phosphate, could be remobilised from the sediments back into the water column to be made available for algal growth when holomixis next occurs. Elevated PO_4-P concentrations (47 and 50 µg/L) were found in the anaerobic bottom waters of Jabiluka and Island Billabongs respectively when they were sampled on 5 January 1978; surface water contained only 5 and 7 µg/L PO_4-P. Both billabongs had been well flushed by Magela Creek waters by this time.

A limited number of chlorophyll *a* levels were obtained from these billabongs before they were flushed. The levels ranged from 10 to 24 µg/L and suggest mesotrophic conditions. However we previously noted that at the end of the dry season most billabongs were quite turbid. It must be considered therefore that the algal biomass in such billabongs would be somewhat limited by the depth of the euphotic zone. After flushing, the chlorophyll *a* levels were generally less than 10 µg/L. Corndorl Billabong showed the highest levels of the backflow billabongs.

In general the surface waters of all billabongs had quite low PO_4-P concentrations, with values less than 20 µg/L. One high reading (103 µg/L) was found in Nankeen before flood waters reached it. Except for this case, little difference was found in PO_4-P concentrations before and after flushing. Some higher PO_4-P concentrations (approx. 50 µg/L) were found in the bottom anaerobic waters of Island and Jabiluka Billabongs.

Nitrate-N concentrations appeared to be elevated in billabong waters at the end of the dry season. For example levels in Nankeen were as high as 2221 µg/L, in Jabiluka they were up to 475 µg/L and in Island 71 µg/L before the billabongs were flushed. After flushing, all waters had low NO_3-N concentrations (<7-25 µg/L).

Unfortunately we were not able to obtain samples of initial runoff water for nutrient analysis. However, from the observations made on Island, Jabiluka and Nankeen Billabongs before and after Magela Creek water flowed into them, it would seem that the first flush is considerably lower in NO_3-N (and PO_4-P) than the waters in these billabongs at the end of the dry season.

7 ACKNOWLEDGMENTS

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APPENDIX FIELD EQUIPMENT AND ANALYTICAL METHODS

Field Equipment

Conductivity was measured using a Yellow Springs model 33 S.C.T. meter.

Temperature was measured using the above meter.

Dissolved Oxygen was measured using a Yellow Springs model 57 oxygen meter. Standardisation was effected by the air saturated with water technique.

Redox Potential was measured with a probe consisting of a bright platinum spade coupled to a silver/silver chloride reference electrode. The meter was standardised regularly against Zobells solution.

pH was measured using a submersible combined glass electrode supplied by Titron coupled to a Townson model 1850/S/P pH meter. The meter was checked against reference pH buffer solutions the evening prior to each sampling run.

Analytical Methods

Alkalinity was measured by potentiometric titration of the sample with acid (Standard Methods 102 4d).

Nitrate-Nitrogen was measured by the UV spectrophotometric method (Standard Methods 133B). The method involves measurement of the UV absorbance at 220 nm correcting for any absorbance at 275 nm. The method is particularly susceptible to interference by dissolved organic matter. Quantification of results was by comparison with a standard curve (known nitrate concentration in de-ionized water). Spiking of two natural samples with known amounts of nitrate gave curves with the same slope as the standard curve.

Phosphate-Phosphorus was determined by the phosphomolybdo-blue method of Murphy and Riley *(Anal. Chim. Acta* **27,** 31-36 (1962)) using antimony-ascorbic acid as the reducing agent.

Chlorophyll a was determined by the trichromic method (Standard Methods 602A) which involves filtration of the sample, extraction of the chlorophyll with 90% acetone and measurement of the absorbance.

TABLE 1 LIMNOLOGICAL DATA FOR GEORGETOWN BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (°C)	Cond. (µS/cm)	pH	Eh[a] (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
1977														
9 Dec	0830	3.17	0.2	0.0	28.5	25	5.7	130	5.4,5.5	2.35	18	17	2	0.30
				0.2	28.5	25		140						
				0.5	28.0	23		155						
				1.0	27.5	21		165						
				2.0	27.0	21	5.8	178	5.8,5.9					
				3.0	26.7	20		183						
				3.3	26.0	21		140						
15 Dec	1400	2.66	0.08	0.0	35.5	27	6.2	225	5.8	283	nd	8	8	0.64
				0.2	36.0	27	6.4	159	5.9					
				0.5	32.0	27	6.4	160	7.3					
				1.0	30.5	27	6.1	150	3.4					
				2.0	29.5	24	5.9	120	2.5	2.85	nd	7	10	
				2.5	29.0	25	5.9	100	2.0					
				2.6	29.0	27	6.0	-100	1.7					
23 Dec	1000	2.76	0.4	0.0	30.0	23	1.8[b]	90	7.1					0.37
				0.2	30.0	23	4.6	130	6.6					
				0.5	29.5	22	4.4	160	6.1					
				1.0	28.5	22	4.3	180	3.4					
				1.5	28.0	23	4.2	200	3.4					
				2.0	28.0	23	4.2	220	3.4					
				2.5	28.0	25	4.2	240	3.4					
				2.7	28.0	27	4.1	230	3.1					

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. ($\mu S/cm$)	pH	Eh[a] (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N ($\mu g/L$)	PO_4-P ($\mu g/L$)	Chlor *a* ($\mu g/L$)	Secchi Depth (m)
1978														
3 Jan	1000	2.50	(*c*)	0.0	34.0		5.8	0	7.5	8.0	7	17	2	0.43
				0.2	34.0		6.8	-20	6.2					
				0.5	31.5		7.5	-80	4.6					
				1.0	30.0		7.4	-90	2.3					
				1.5	29.5		8.2	-90	0.3					
				2.0	28.5		7.3	-130	0.2					
				2.5	28.5		5.4	-210	0.2					
9 Jan	1000	2.86	0.30	0.0	31.5		5.8	200	6.2	9.9	4	6	5	0.50
				0.2	31.5		6.5	195	5.4					
				0.5	30.0		6.5	190	5.3					
				1.0	29.5		6.4	200	6.0					
				2.0	29.0		6.4	210	7.0					
				2.5	29.0		6.3	230	7.0	3.8	4	14	4	
				2.8	29.0		6.3	-40	7.1					
16 Jan	1000	3.17	0.43	0.0	31.0		5.9	110	7.1					0.85
				0.2	30.5		6.5	100	6.6					
				0.5	29.5		6.4	90	4.8					
				1.0	29.0		6.3	80	5.2					
				2.0	28.5		6.3	80	5.0					
				3.0	28.5		6.4	90	4.3					
				3.2	28.5		6.5	-50	4.3					

a Relative to silver/silver chloride
b Marked change in pH (2.5 → 4.6) around 12 cm below surface
c Below gauge
nd = not detectable
Blanks indicate no readings taken

TABLE 2 LIMNOLOGICAL DATA FOR COONJIMBA BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^oC)	Cond. (μS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N (μg/L)	PO_4-P (μg/L)	Chlor *a* (μg/L)	Secchi Depth (m)
1977														
13 Dec	1200	1.55	1.05	0.0	32.0	30	5.8	230	5.6,6.1	2.71	nd	8	8	0.49
				0.2	32.5	30		230						
				0.5	30.5	32		230						
				1.0	29.0	30	5.7	230	1.3,1.2					
				1.5	28.0	37		235						
23 Dec	1130	1.46	1.14	0.0	31.5	25	~1[a]	370	5.2	2.64	nd	11	6	0.76
				0.2	31.5	27	4.6	260	5.1					
				0.5	30.0	27	4.5	250	3.6					
				1.0	29.0	22	4.6	280	2.3	1.93	nd	6	14	
				1.45	28.0	33	3.8	100	1.6					
1978														
3 Jan	1200	1.41	1.06	0.0	35.0		5.6	220	8.6	3.30	36	5	4	0.74
				0.2	34.0		6.3	210	8.6					
				0.5	32.0		6.3	220	6.9					
				1.0	32.0		6.3	100	5.8					
				1.4	32.0		6.4	0	4.0					
9 Jan	1200	1.50	1.05	0.0	31.5				7.8		14	12	8	0.75
				0.2	31.5				7.7					
				0.5	31.5				7.3					
				1.0	31.5				6.6					
				1.5	31.5				6.1					

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. ($\mu S/cm$)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N ($\mu g/L$)	PO_4-P ($\mu g/L$)	Chlor *a* ($\mu g/L$)	Secchi Depth (m)
10 Jan	1330	1.40	1.05	0.0	33.0		6.7	50	8.5					0.99
				0.2	32.0		6.6	50	8.3					
				0.5	32.0		6.6	60	7.7					
				1.0	32.0		6.6	60	6.5					
				1.4	31.5		6.5	60	5.9					
11 Jan	1000	1.50	1.05	0.0	31.5		4.4[a]	350	7.4					0.98
				0.2	31.5		6.0	180	7.0					
				0.5	31.5		6.0	160	6.3					
				1.0	31.0		5.9	160	5.1					
				1.5	31.0		5.9	90	5.4					
16 Jan	1100	1.50	1.16	0.0	31.0		5.6	180	6.9					1.00
				0.2	31.0		6.4	120	6.0					
				0.5	30.5		6.4	110	4.9					
				1.0	30.0		6.4	100	4.6					
				1.5	30.0		6.3	60	4.1					

a Sharp pH change at 0.12 m
nd = not detectable
Blanks indicate no readings taken

TABLE 3 LIMNOLOGICAL DATA FOR GULUNGUL BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
1977														
6 Dec	1500	0.65	0.32	0.0	40.0	67		240	6.1,5.5					0.1
				0.2	32.0	60		260						
				0.3	30.0	56		270						
				0.6	29.5	56		270						
				0.7	29.5	73		160						
9 Dec	1300	2.03	0.70	0.0	34.0	43	5.8	90	5.6,5.5	1.71	136	7	10	
				0.2	33.0	42		100						
				0.5	28.5	43	5.6	110	3.9,4.0	1.23	11	13	15	
				1.0	27.5	37		125						
				1.5	27.0	38		75						
19 Dec	1200	2.23	1.43	0.0	30.0	27	5.2	180	4.7	1.35	nd	7	4	1.13
				0.2	30.5	25	5.9	185	4.6					
				0.5	29.0	25	6.0	225	4.2					
				1.0	28.5	25	6.1	130	4.2					
				1.5	28.0	27	6.1	170	3.8					
				2.0	28.0	27	6.2	175	3.6					
				2.2	28.0	27	6.5	-30	2.8					
1978														
3 Jan	1400	2.01	1.40	0.0	35.0		5.8	230	6.5	4.70	nd		4	1.23
				0.2	35.0		6.4	230	6.4					
				0.5	32.5		6.4	120	6.4					
				1.0	32.0		6.3	100	6.4					
				1.5	31.5		6.4	70	2.0					
				2.0	31.0		7.0	20	0.5					

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
11 Jan	1100	2.06	1.42	0.0	31.5		5.7	170	5.4	4.50	nd	7	7	1.15
				0.2	31.5		6.1	120	5.1					
				0.5	31.5		6.1	110	4.8					
				1.0	31.0		6.1	110	4.2					
				1.5	30.5		6.1	110	3.9					
				2.1	30.5		6.1	30	3.4					
16 Jan	1230	2.41	1.65	0.0	31.0		5.5	140	5.0					
				0.2	31.0		6.4	100	4.7					
				0.5	30.0		6.4	90	4.2					
				1.0	29.0		6.4	80	3.9					
				1.5	28.5		6.4	70	4.0					
				2.0	28.5		6.5	70	4.0					
				2.4	28.5		6.5	10	3.5					

nd = not detectable

Blanks indicate no readings taken

TABLE 4 LIMNOLOGICAL DATA FOR CORNDORL BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^oC)	Cond. (μS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N (μg/L)	PO_4-P (μg/L)	Chlor *a* (μg/L)	Secchi Depth (m)
1977														
8 Dec	1600	1.28		0.0	34.0	27	6.3	220	7.3,7.5	2.88	7	10,11	8	0.7
				0.2	34.0	27		190						
				0.5	32.0	30		190						
				1.0	31.2	30		195						
				1.4	30.5	30		200						
14 Dec	0900	1.78	0.35	0.0	31.5	30								0.8
				0.2	31.0	30								
				0.5	31.0	30								
				1.0	30.5	30								
				1.5	30.0	30								
				1.9	30.0	30								
	1500			0.0	36.5	37	6.3	235	9.4	4.07	nd	nd	15	
				0.2	35.0	37	7.4	185	10.0					
				0.5	32.5	35	7.4	200	10.2					
				1.0	31.0	32	6.2	220	7.7					
				1.5	31.0	32	5.8	235	6.3					
				1.7	31.0	32	5.8	220	5.6					
24 Dec	0930	2.33	0.75	0.0	30.0	25	~ 1	180	6.0	4.50	11	14,16	13	0.8
				0.2	30.0	27	3.4	180	6.0					
				0.5	30.0	28	4.1	180	5.5					
				1.0	30.0	27	3.8	190	4.9	4.10	nd	5	13	
				1.5	29.5	28	4.0	120	4.7					
				2.0	29.5	30	3.9	160	4.5					
				2.3	29.5	40	3.0	30	3.4					

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. (μS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	No_3-N (μg/L)	PO_4-P (μg/L)	Chlor *a* (μg/L)	Secchi Depth (m)
30 Dec	1300	1.84	0.38	0.0	36.5	37	5.8	230	8.2	4.09	25	18	4	0.4
				0.2	36.5	35	6.7	220	8.0					
				0.5	32.0	40	9.4	170	6.4	64.35	21	13	12	
				1.0	30.0	30	7.7	170	5.6					
				1.5	29.0	30	7.5	80	5.4	124.5	nd	14	13	
				1.8	27.5	30	6.4	40	5.4					
1978														
6 Jan	0900	1.54		0.0	31.0		5.7	120	6.3	8.4	11	13	15	0.4
				0.2	31.0		6.5	120	6.0					
				0.5	31.0		7.9	140	5.2					
				1.0	30.5		7.8	130	5.2					
				1.5	30.5		6.6	30	5.0					
11 Jan	1200	1.93	0.21	0.0	34.5		6.0	90	8.2	4.5	nd	7	5	0.6
				0.2	34.5		6.4	60	7.6					
				0.5	32.5		6.3	60	6.9					
				1.0	31.0		6.2	60	4.6					
				1.5	31.0		6.2	60	4.6					
				1.9	31.0		6.2	0	4.6					
16 Jan	1400	2.02	0.52	0.0	35.0				9.4					0.6
				0.2	35.0				8.7					
				0.5	30.5				7.0					
				1.0	30.5				4.3					
				1.5	30.0				3.8					
				2.0	30.0				3.1					

nd = not detectable

Blanks indicate no readings taken

TABLE 5 LIMNOLOGICAL DATA FOR MUDGINBERRI BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. ($\mu S/cm$)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N ($\mu g/L$)	PO_4-P ($\mu g/L$)	Chlor a ($\mu g/L$)	Secchi Depth (m)
1977														
8 Dec	1400	5.4	1.72	0.0	32.0	25	5.6	270	6.4	1.47	14	10,5	2	0.95
				0.2	31.5	23								
				0.5	31.0	20								
				1.0	31.0	20		290						
				2.0	30.0	20								
				3.0	29.0	20								
				4.0	28.5	20		240						
				5.0	28.5	20	5.5	230	5.3,5.4					
				6.0	28.5	22		230						
				7.0	28.5	23								
				7.8	28.5	23		200						
15 Dec	1000	3.28	1.70	0.0	30.5	21	5.7	330	5.6	1.13	nd	5	26	1.45
				0.2	30.0	22	6.2	325	5.5					
				0.5	30.0	22	6.1	205	5.5					
				1.0	30.0	22	5.8	200	5.3					
				2.0	30.0	23	5.8	210	5.3					
				2.5	29.5	23	5.7	210						
				2.9	29.5	23								
				3.0					5.3					
				3.3	29.0		6.8	230						

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (°C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
30 Dec	1200	4.16	1.83	0.0	31.0	30	6.1	210	9.0	1.74	nd	7		0.94
				0.2	31.0	30	6.9	190	8.8					
				0.5	30.5	30	7.0	100	8.7					
				1.0	30.5	30	7.0	45	8.1					
				2.0	30.0	24	7.0	45	8.0					
				3.0	30.0	25	7.0	50	6.8					
				3.5			8.5	80	6.7					
				3.7	29.5	25								
1978														
6 Jan	1100	4.63	1.6	0.0	32.0		6.0	230	7.0	3.45	14	12	3	1.24
				0.2			6.8	180	6.4					
				0.5	32.0		8.5	90	7.4					
				1.0	31.5		8.5	80	7.8					
				2.0	31.0		8.2	90	7.9					
				3.0	30.5		8.3	80	6.8					
				4.0	30.5		8.3	130	6.9					
				4.5	30.5		8.3	80	7.0	3.25	nd	16	nd	
				4.6	30.5				7.1					
11 Jan	1400	2.99	1.80	0.0	32.5		6.0	180	9.4	1.80	nd	7	1	1.50
				0.2	32.5		6.3	170	9.2					
				0.5	32.0		6.3	160	8.2					
				1.0	32.0		6.2	150	6.7					
				2.0	32.0		6.2	150	4.9					
				3.0	30.5		6.2	140	4.5					

nd = not detectable
Blanks indicate no readings taken

TABLE 6 LIMNOLOGICAL DATA FOR ISLAND BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (°C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
1977														
4 Dec	1500	4.30	1.82	0.0						0.61	71	11	19	0.4
				0.2	33.7	60	5.3	360						
				1.0	31.8				4.8,5.1					
				2.2	31.8	57	4.3	395						
				3.0					2.6,2.4					
				3.2	31.0	50	4.4	385						
				3.7	30.5	48	4.5	388						
				3.8			4.4	328						
				4.2	30.5	48	4.5	-100						
				4.3	30.5	48	4.4	-100						
13 Dec	0900	5.35	2.38	0.0	30.0	25	5.6	220	3.6,4.0	1.46	nd	8	4	1.59
				0.2	30.0	25		180						
				0.5	30.0	25		180						
				1.0	30.0	25		180						
				2.0	30.0	25		185						
				3.0	29.5	25		195						
				4.0	29.0	25		200						
				5.0	29.0	27	5.5	207	3.1,3.0					
				5.5	29.0	33		110						
23 Dec	1500	6.30	2.82	0.0	28.0	21	1.3	260	5.9	nd	nd	9,6	7	0.96
				0.2	29.0	20	3.9	300	5.8					
				0.5	29.0	21	4.0	320	5.6					
				1.0	29.0	21	4.0	310	5.4	0.95	nd	6	6	
				2.0	29.0	22	4.1	320	5.5					
				3.0	29.0	22	4.0	310	5.3					
				4.0	29.0	23	4.1	320	5.3					

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^oC)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N (µg/L)	PO_4-P (µg/L)	Chlor a (µg/L)	Secchi Depth (m)
				5.0	29.0	23	3.7	340	5.3					
				6.0	29.0	25	4.0	250	5.3					
				6.2	29.0	27			4.9					
				6.4			4.0	70						
30 Dec	0900	5.53	2.66	0.0	31.0	27	4.7	270	4.2	2.67	nd	8	3	1.13
				0.2	31.0	27	6.1	270	3.8					
				0.5	31.0	27	8.4	270	3.6					
				1.0	31.0	27	8.2	210	3.5					
				2.0	31.0	27	8.0	200	3.4					
				3.0	31.0	28	7.8	185	2.3					
				4.0	30.0	28	7.6	180	1.6	2.43	nd	11	2	
				5.0	30.0	30	6.9	180	0.7					
				5.5	30.0	30	7.0	100	0.5					
				5.7	30.0	33	6.5	-80	0.4					
1978														
5 Jan	1000	5.66	2.6	0.0	32.5		5.4	230	4.5	3.05	nd	7	6	1.26
				0.2	32.5		8.4	300	4.0					
				0.5	32.0		6.6?	290	3.8					
				1.0	32.0		8.9	280	3.8					
				2.0	32.0		8.6	240	1.7					
				3.0	31.0		7.5	80	1.7					
				4.0	31.0		7.5	90	1.2					
				5.0	31.0		8.3	70	0.5					
				5.5	30.5		8.3	-10	0.4	4.15	nd	50	8	
				5.7	30.5		7.0	-170	0.5					

TABLE 6 LIMNOLOGICAL DATA FOR ISLAND BILLABONG (ctd)

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
12 Jan	0900	5.80	2.78	0.0	31.0		5.6	250	6.0	1.50	nd	9	2	1.67
				0.2	31.0		5.8	230	5.6					
				0.5	31.0		5.8	210	5.7					
				1.0	31.0		5.8	210	4.6					
				2.0	30.5		5.8	200	3.0					
				3.0	30.5		5.8	190	2.8					
				4.0	30.5		5.9	180	2.1					
				5.0	30.5		6.0	180	0.9					
				5.8	30.5		6.2	-30	0.5					
17 Jan	1000	6.06	3.03	0.0	30.0				6.8					1.63
				0.2	30.0				6.4					
				0.5	29.5				6.3					
				1.0	29.0				5.6					
				2.0	29.0				4.4					
				3.0	29.0				4.1					
				4.0	29.0				4.0					
				5.0	29.0				3.7					
				6.7	29.0				3.4					

nd = not detectable
Blanks indicate no readings taken

TABLE 7   LIMNOLOGICAL DATA FOR JABILUKA BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (°C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
1977														
7 Dec	0900	3.26		0.0	31.0	148	5.8	175	4.2,4.5	1.92	467	8	24	0.15
				0.2	30.0	148		170						
				0.5	29.5	147	5.9	165						
				1.0	29.5	147	5.8	160						
				1.5	29.5	147								
				2.0	29.5	147		157						
				2.5	29.5	147	5.8		3.4,3.8					
				3.0	29.5	148		165						
				3.4	29.5	155								
				4.0	29.5			55						
12 Dec	1200	3.69		0.0	32.0	162	5.9	185	6.1,6.1	0.78	475	10	18	0.13
				0.2	31.0	153		185						
				0.5	29.0	152		180						
				1.0	28.5	150		185						
				2.0	28.5	150		190						
				3.0	28.5	150	5.7	190	4.3,4.3					
				3.5	28.5	152		140						
				3.75	28.5	190		-40						
19 Dec	0900	4.65		0.0	29.5	80	4.2	300	5.7	nd	71,90	5	8	1.29
				0.2	30.0	80	4.6	265	5.6					
				0.5	30.0	80	4.6	320	5.5					
				1.0	29.5	80	4.7	340	4.8					
				2.0	29.0	80	4.7	350	4.1	nd	39	10	3	
				3.0	29.0	73	4.6	360	3.6					
				4.0	29.0	70	4.8	360	3.5					

TABLE 7 LIMNOLOGICAL DATA FOR JABILUKA BILLAGONG (ctd)

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. (µS/cm)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N (µg/L)	PO_4-P (µg/L)	Chlor *a* (µg/L)	Secchi Depth (m)
1977														
19 Dec (ctd)				4.5	29.0	68	4.9	360	3.5					
				4.6				20						
				4.8			5.8	-80						
				4.8	29.0	7.3			2.5					
26 Dec	1500	5.11	0.92	0.0	35.0	27	5.0	250	7.2					1.50
				0.2	35.0	37	8.8	250	7.1					
				0.5	34.0	33	9.3	310	6.6					
				1.0	34.0	33	9.0	260	5.7	0.29		15	12	
				2.0	33.0	40	8.7	160	4.3					
				3.0	32.0	37	7.0	200	3.3					
				4.0	31.0	40	7.0	160	2.2	1.59		13	10	
				5.0	30.0	43	7.0	-150	0.4					
				5.1	30.0	73		-150	0.2					
1978														
5 Jan	0800	5.23	0.80	0.0	32.0		5.1	190	6.9	0.45	7	5	9	1.12
				0.2	32.0		5.7	190	6.8					
				0.5	32.0		5.8	195	6.8					
				1.0	32.0		6.9	200	6.6					
				2.0	32.0		6.9	180	3.5					
				3.0	31.0		6.9	160	2.1					
				4.0	31.0		7.7	-40	0.4					
				5.0	31.0		7.8	-80	0.5	2.0	39	47	6	
				5.2	31.0		7.1	-140	0.5					

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^oC)	Cond. ($\mu S/cm$)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N ($\mu g/L$)	PO_4-P ($\mu g/L$)	Chlor *a* ($\mu g/L$)	Secchi Depth (m)
12 Jan	1100	5.30	0.80	0.0	34.0		4.9	280	7.3	0.95	25	8	2	1.28
				0.2	34.0		5.4	240	7.3					
				0.5	32.5		5.3	220	7.0					
				1.0	32.0		5.3	210	6.4					
				2.0	32.0		5.3	200	4.6					
				3.0	31.0		5.5	190	2.9					
				4.0	31.0		5.8	190	1.4					
				5.0	31.0		6.6	180	1.3					
				5.3	31.0		6.6	-90	0.5					
17 Jan	1200	5.36	1.04	0.0	32.0				6.8					
				0.2	32.0				6.8					
				0.5	31.0				5.2					
				1.0	30.5				5.7					
				2.0	30.0				4.2					
				3.0	30.0				3.0					
				4.0	29.5				2.5					
				5.0	29.5				1.8					
				5.4	29.5				1.4					

nd = not detectable
Blanks indicate no readings taken

TABLE 8 LIMNOLOGICAL DATA FOR NANKEEN BILLABONG

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. ($\mu S/cm$)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N ($\mu g/L$)	PO_4-P ($\mu g/L$)	Chlor a ($\mu g/L$)	Secchi Depth (m)
1977														
7 Dec	1500	2.90		0.0	34.0	240	5.4	350	3.5,3.4	1.78	218		10	0.06
				0.2	32.0	235								
				0.5	30.0	220		450						
				1.0	29.5	220								
				2.0	29.5	225		320						
				2.8	29.0	283		30						
12 Dec	0900	2.66		0.0	30.5	240	5.4	185	3.5,3.2	1.59	2221	103	15	0.06
				0.2	29.0	237		180						
				0.5	28.5	235		180						
				1.0	28.5	235		180						
				2.0	28.0	237	5.6	180	3.0,2.8					
				2.5	28.0	237		185						
				2.9	28.0	249		120						
26 Dec	1100	4.00		0.0	33.0	27	5 1	80	6.2	1.52	nd	4	14	1.11
				0.2	33.0	40	3.9	90	6.1					
				0.5	32.0	40	4.8	90	5.4					
				1.0	31.5	40	5.1	60	5.3					
				2.0	31.0	42	5.0	50	5.3					
				3.0	30.0	43	5.4	65	4.4					
				4.0	27.5	40	5.0	-250	4.4	0.95	nd	9	10	

Date	Time	Water Depth (m)	Gauge Read.	Depth (m)	Temp. (^{o}C)	Cond. ($\mu S/cm$)	pH	Eh (mV)	Dissolved Oxygen (mg/L)	Alk. (mg/L)	NO_3-N ($\mu g/L$)	PO_4-P ($\mu g/L$)	Chlor *a* ($\mu g/L$)	Secchi Depth (m)
1978														
4 Jan	1100	4.40		0.0	34.5		5.0	150	8.6	1.8	11	11	5	0.82
				0.2	34.5		5.7	200	8.5					
				0.5	33.0		8.0	190	8.1					
				1.0	32.0		7.8	180	5.1					
				2.0	31.0		7.8	170	3.5					
				3.0	31.0		7.6	150	3.0					
				4.0	31.0		7.6	165	2.3					
				4.5	31.0		7.0	-170	2.3					
12 Jan	1300	4.24		0.0	37.0		5.5	260	9.2	1.30	nd	9	3	0.60
				0.2	37.0		5.9	230	8.9					
				0.5	33.0		5.7	200	6.0					
				1.0	32.0		5.6	180	4.1					
				2.0	31.0		5.7	180	3.2					
				3.0	30.5		5.9	180	2.5					
				4.0	30.0		6.7	170	1.7					
				4.2	30.0		6.7	-40	1.3					
17 Jan	1400	4.40		0.0	30.0				6.2					
				0.2	30.0				6.1					
				0.5	30.0				5.7					
				1.0	30.0				4.7					
				2.0	29.0				3.2					
				3.0	29.0				3.2					
				4.0	29.0				3.2					
				4.4	29.0				2.9					

nd = not detectable
Blanks indicate no readings taken

TABLE 9 TOTAL ORGANIC CARBON AND SULPHATE CONCENTRATIONS IN BILLABONG WATERS

Billabong	Date	Sample Depth (m)	TOC[a] (mg/L)	Sulphate (SO_4^{2-}) (mg/L)	pH (in situ)
	1977				
Corndorl	24 Dec	1.0	-	<0.2	3.8
	30 Dec	0	9.0	~0.2	5.8
		0.5	-	~0.2	9.4
		1.5	8.0	<0.2	7.5
Island	23 Dec	0	4.0	2.7	1.4
		1.0	4.0	<0.2	4.0
	30 Dec	0	6.0	~0.3	4.7
		4.0	6.0	<0.2	7.6
Jabiluka	26 Dec	0	4.0	4.5	5.0
		4.5	6.0	5.8	7.0
Nankeen	26 Dec	0	5.0	5.5	~1
		4.0	7.0	5.8	5.0

[a] Analyses by State Rivers and Water Supply Laboratories using Beckman TOC Instrument

TABLE 10 VARIATIONS BETWEEN IN SITU AND LABORATORY pH MEASUREMENTS[a]

Billabong	Date	Depth (m)	pH in situ	pH laboratory
Georgetown	3 Jan 1978	0	5.8	6.8
	9 Jan 1978	0	5.8	6.5
		2.5	6.3	6.3
Coonjimba	23 Dec 1977	0	~1	6.2
		1.0	4.6	6.0
	3 Jan 1978	0	5.6	6.4
Gulungul	19 Dec 1977	0	5.2	6.1
Corndorl	24 Dec 1977	0	~1	6.5
		1.0	3.8	6.2
	30 Dec 1977	0	5.8	7.2
		0.5	9.4	7.6
		1.5	7.5	7.4
	6 Jan. 1978	0	5.7	6.5
Mudginberri	6 Jan 1978	0	6.0	6.0
		4.5	8.3	5.9
Island	23 Dec 1977	0	1.3	4.2
		1.0	4.0	4.3
	30 Dec 1977	0	4.7	5.7
		4.0	7.6	5.9
	5 Jan 1978	0	5.4	6.2
		5.5	8.3	5.8
Jabiluka	26 Dec 1977	1.0	9.0	5.4
		4.5	7.0	6.9
	5 Jan 1978	0	5.1	5.3
		5.0	7.8	5.6
Nankeen	26 Dec 1977	0	~1	6.1
		4.0	5.0	5.6
	4 Jan 1978	0	5.0	6.0

[a] Data omitted where differences were $\leq \pm$ 0.5 pH units

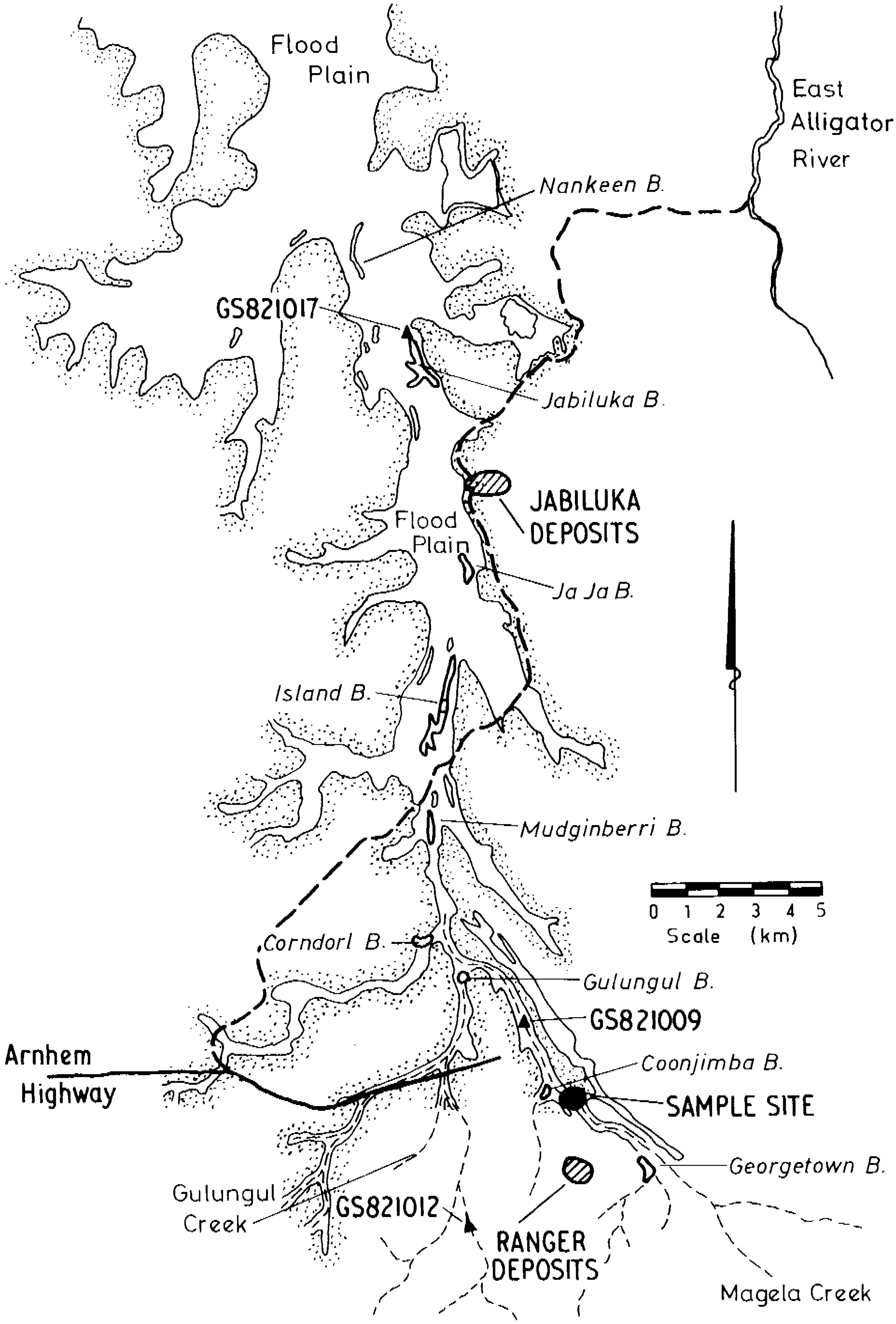

FIG. 1 STUDY AREA SHOWING LOCATION OF BILLABONGS STUDIED

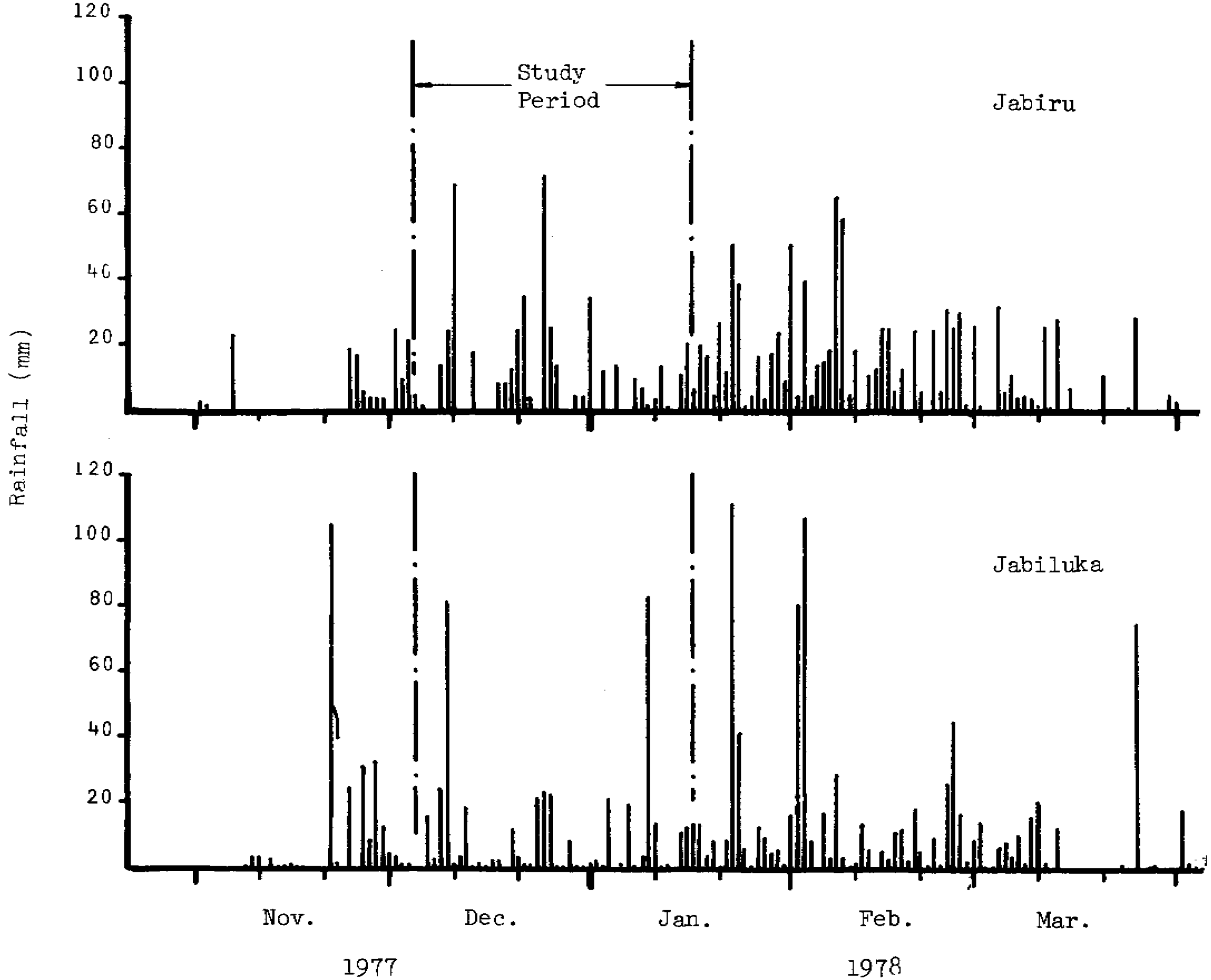

FIG. 2 RAINFALL AT JABIRU AND JABILUKA, NOVEMBER 1977 TO MARCH 1978

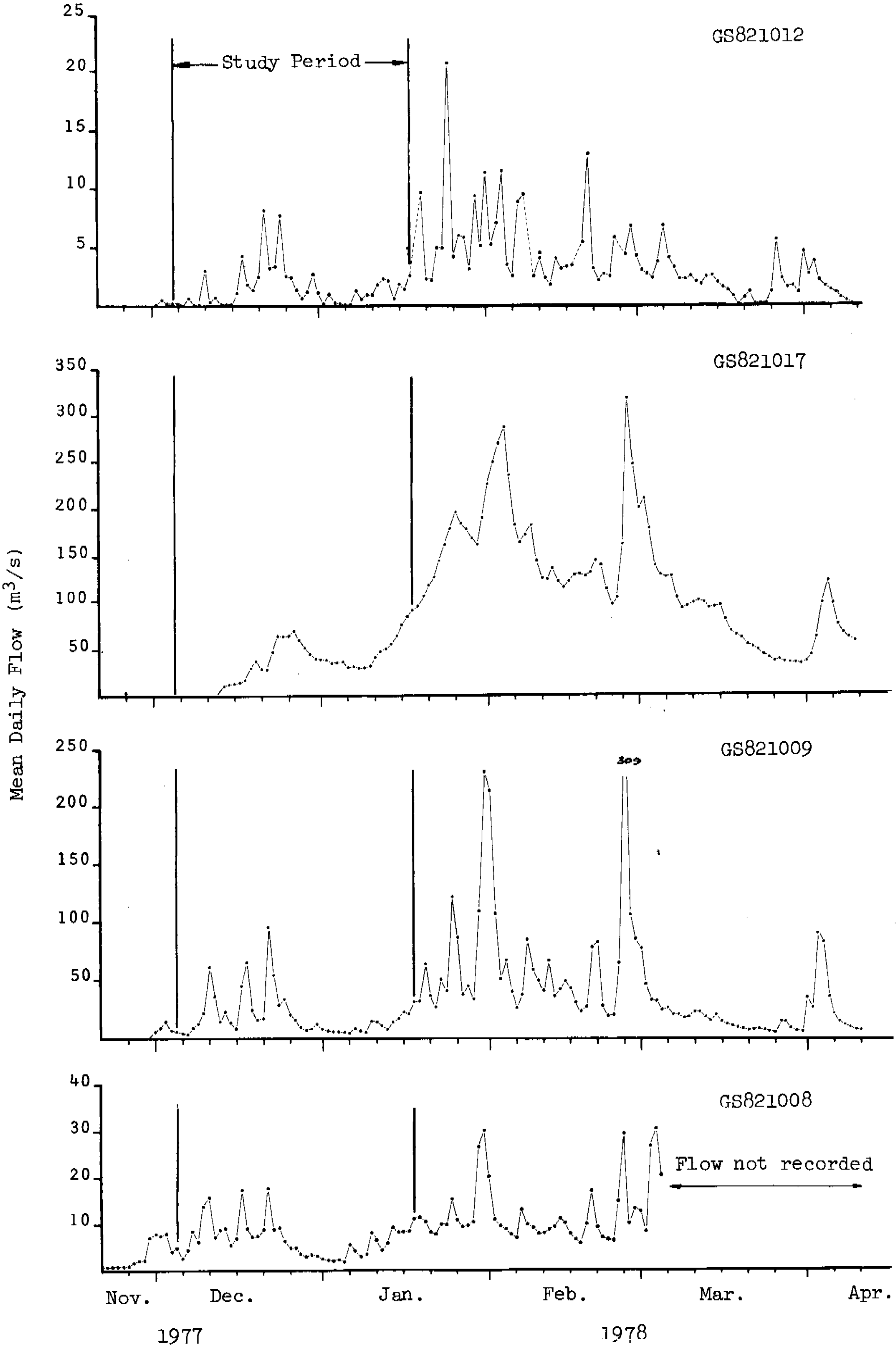

FIG. 3 MEAN DAILY FLOWS IN MAGELA CREEK CATCHMENT, NOVEMBER 1977 TO APRIL 1978

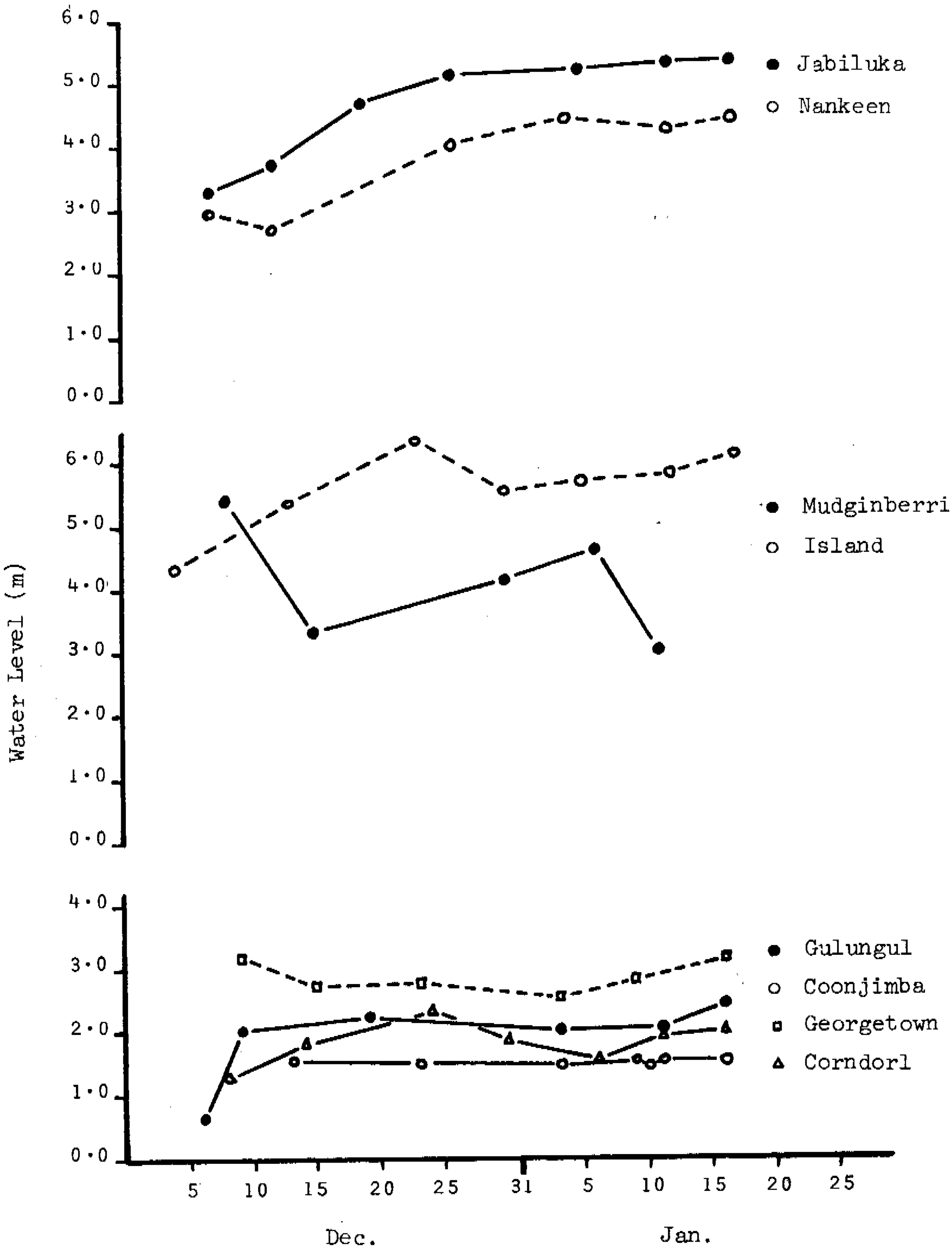

FIG. 4 WATER LEVELS IN BILLABONGS DURING STUDY PERIOD

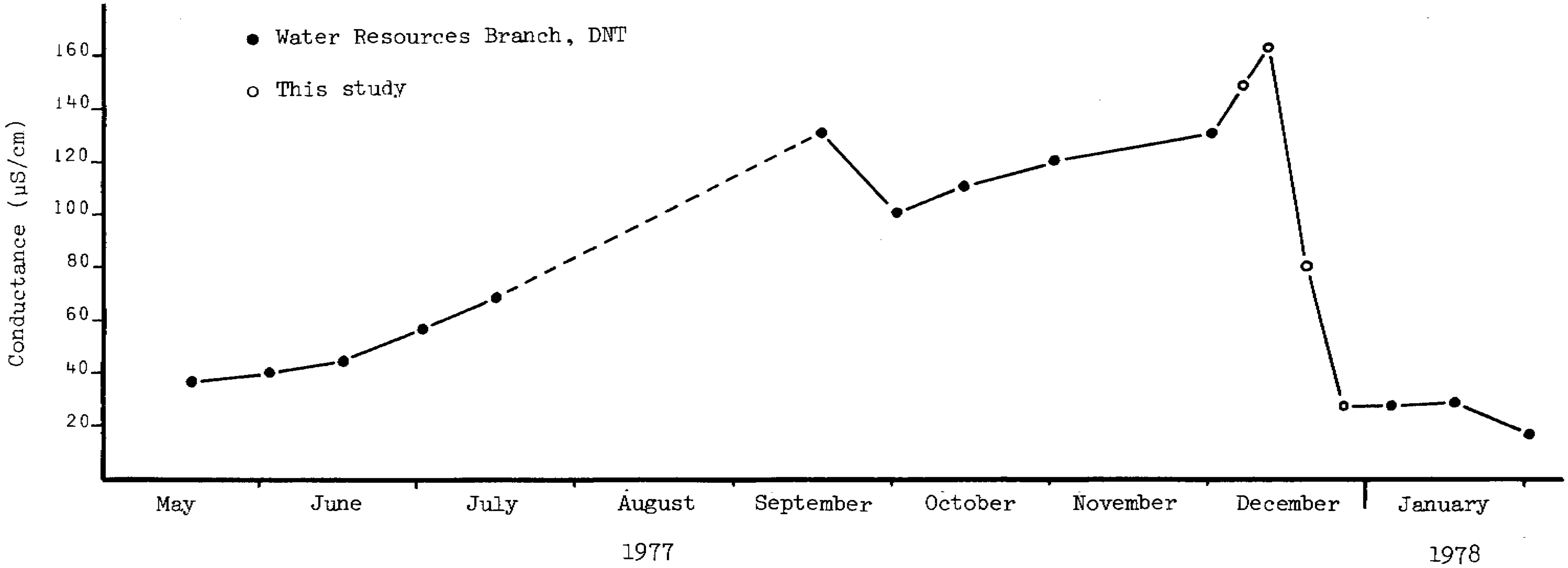

FIG. 5 CONDUCTIVITY IN JABILUKA BILLABONG BETWEEN MAY 1977 AND JANUARY 1978 - DRY TO EARLY-WET SEASONS

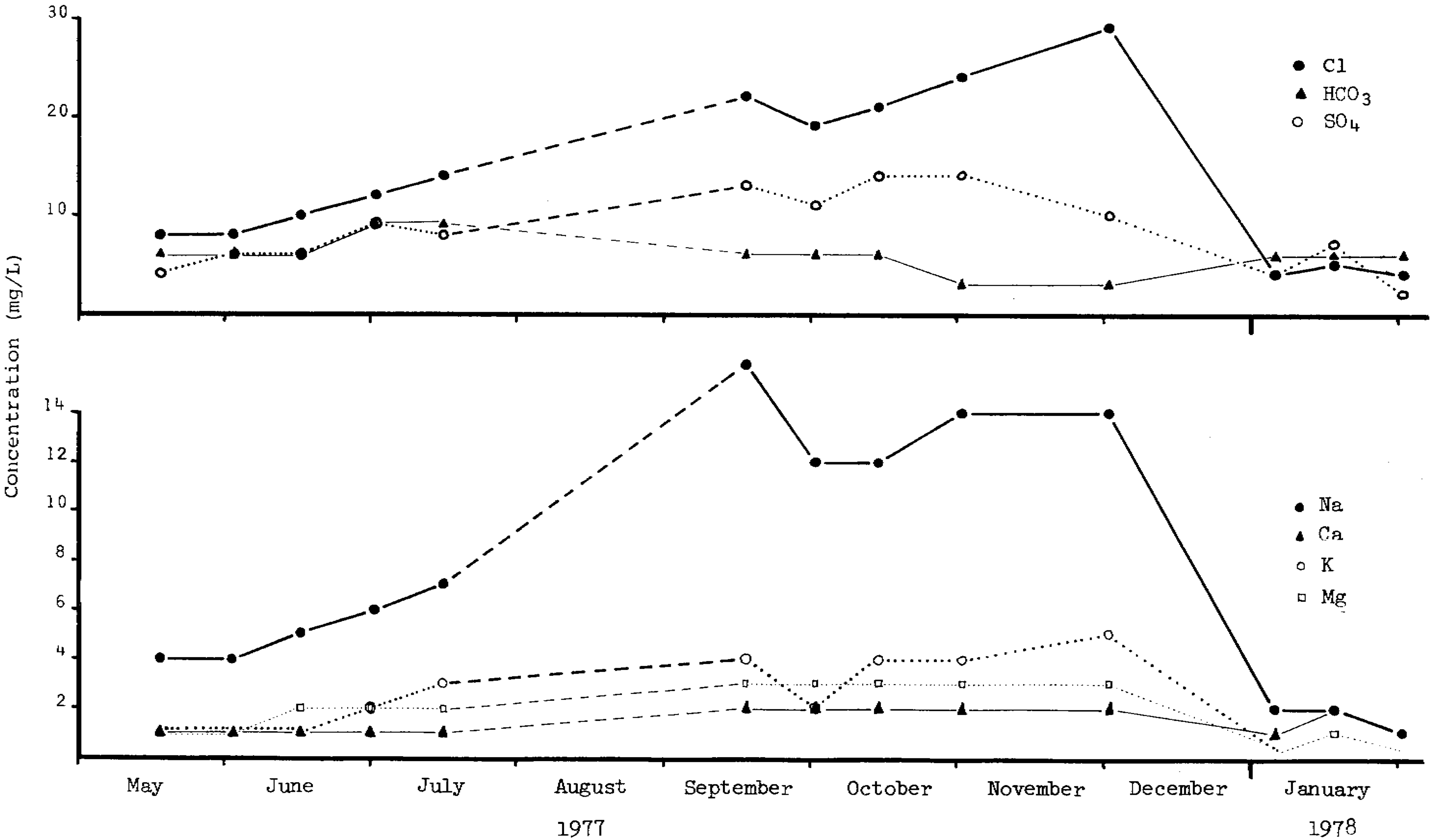

FIG. 6 MAJOR CATION AND ANION CONCENTRATIONS IN JABILUKA BILLABONG, MAY 1977 TO JANUARY 1978

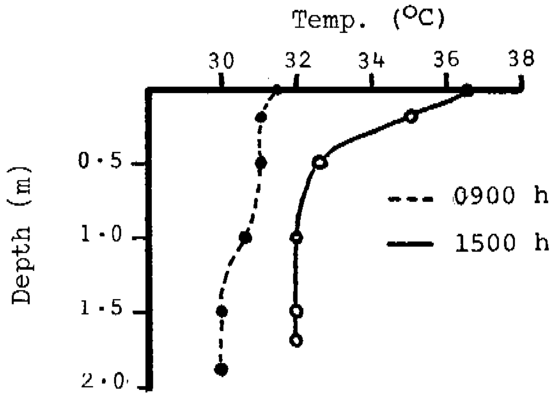

FIG. 7 TEMPERATURE PROFILE FOR CORNDORL BILLABONG ON 14 DECEMBER 1977

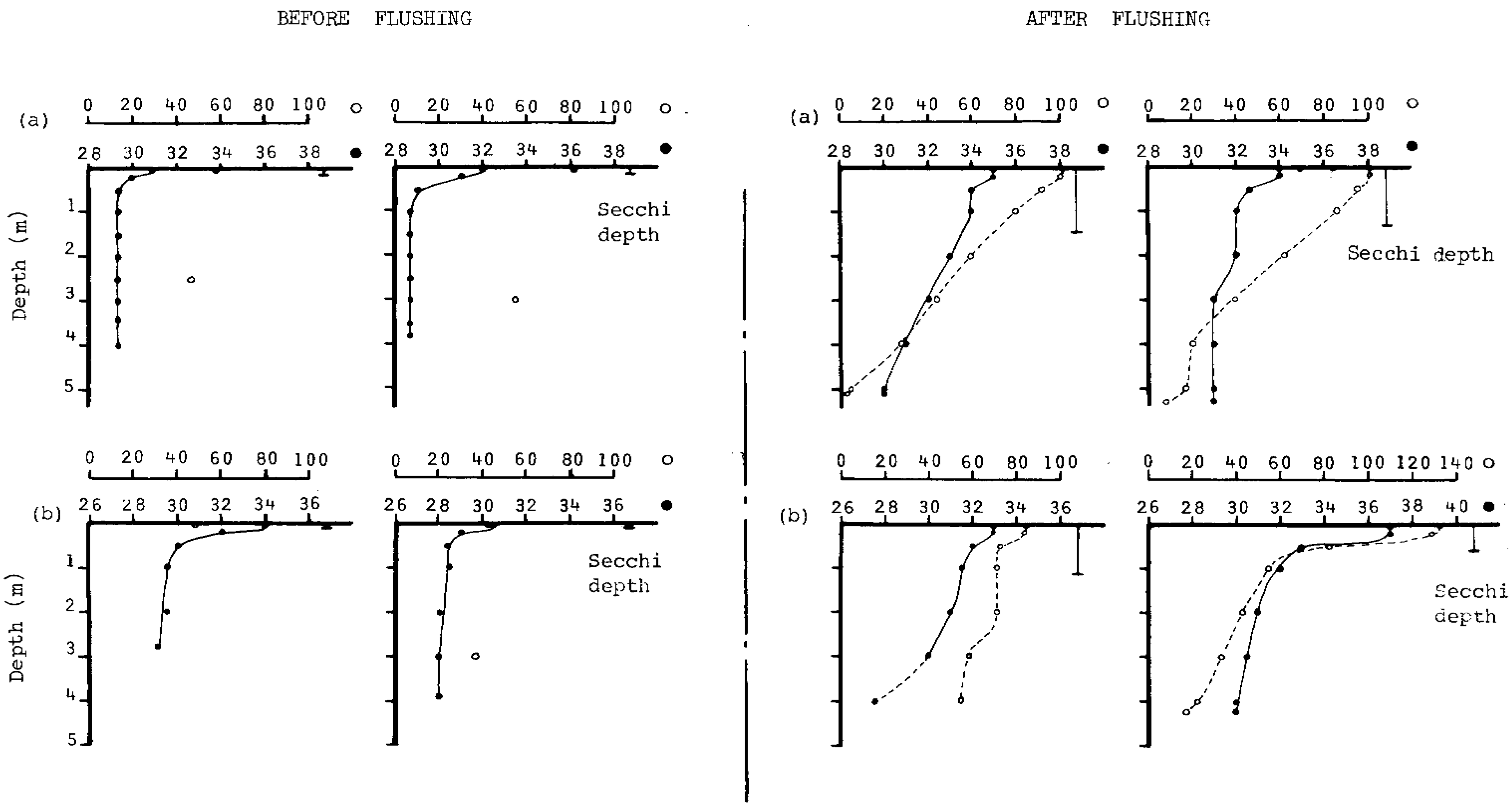

FIG. 8 TEMPERATURE PROFILES FOR JABILUKA AND NANKEEN BILLABONGS BEFORE AND AFTER FLUSHING

∘ DO (% sat.) • Temperature (°C)

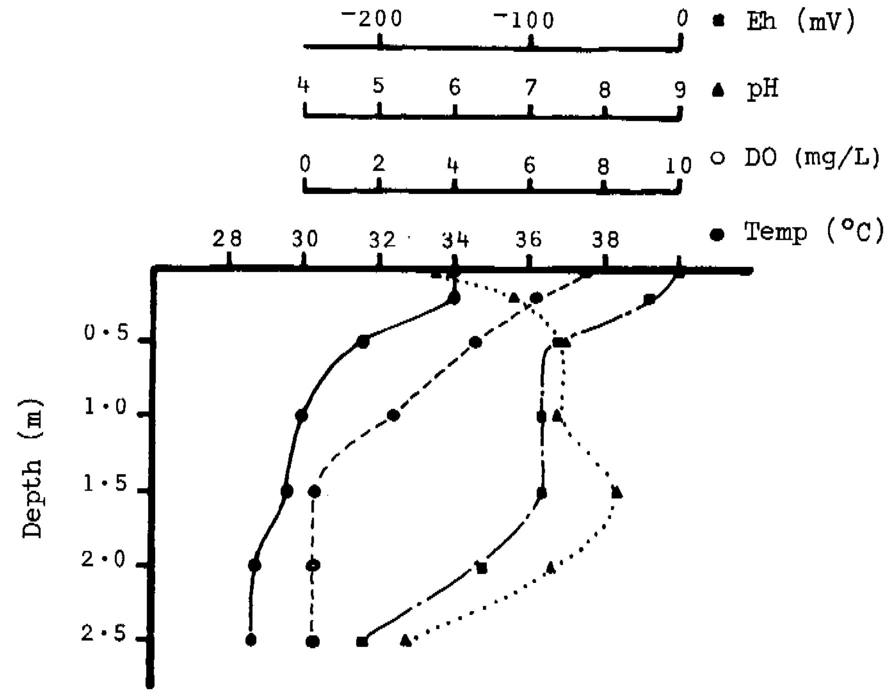

FIG. 9 TEMPERATURE, DO AND Eh PROFILES FOR JABILUKA BILLABONG ON 5 JANUARY 1978

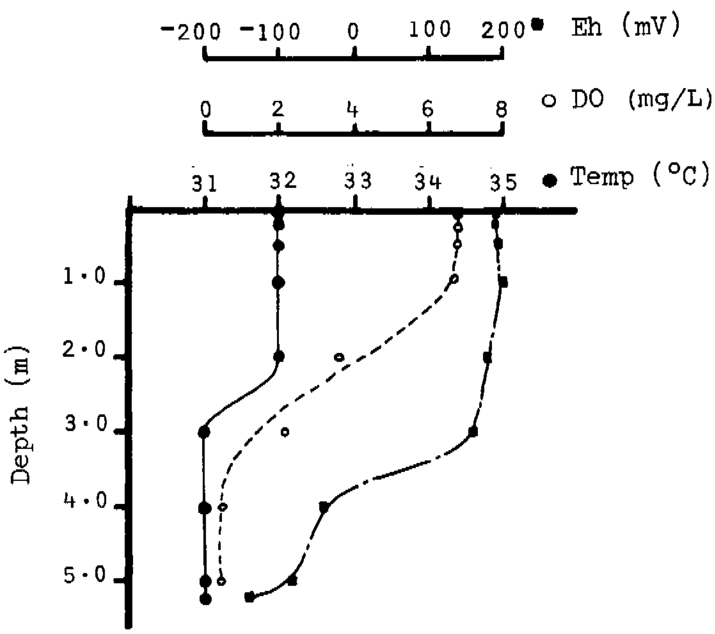

FIG. 10 TEMPERATURE, pH, DO AND Eh PROFILES FOR GEORGETOWN BILLABONG ON 3 JANUARY 1978

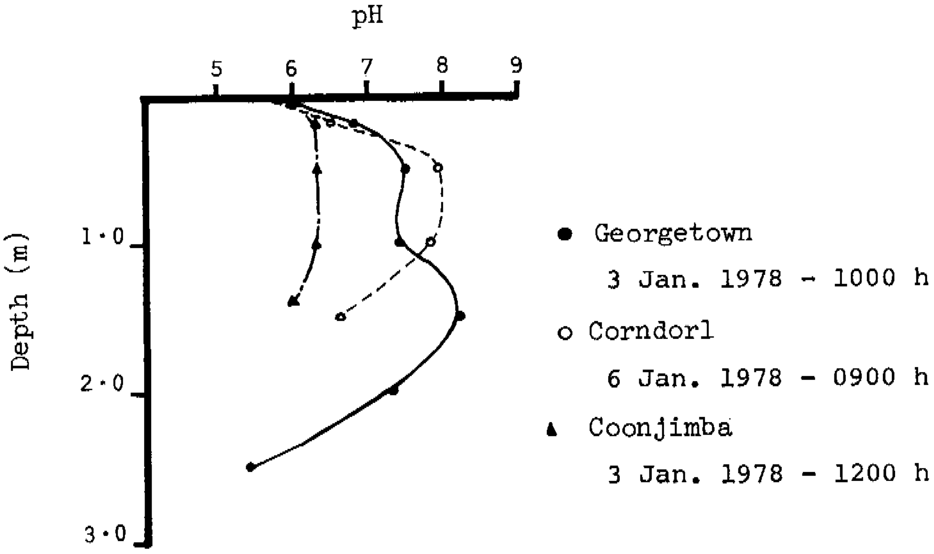

FIG. 11 pH PROFILES FOR BACKFLOW BILLABONGS, GEORGETOWN, COONJIMBA AND CORNDORL, JANUARY 1978

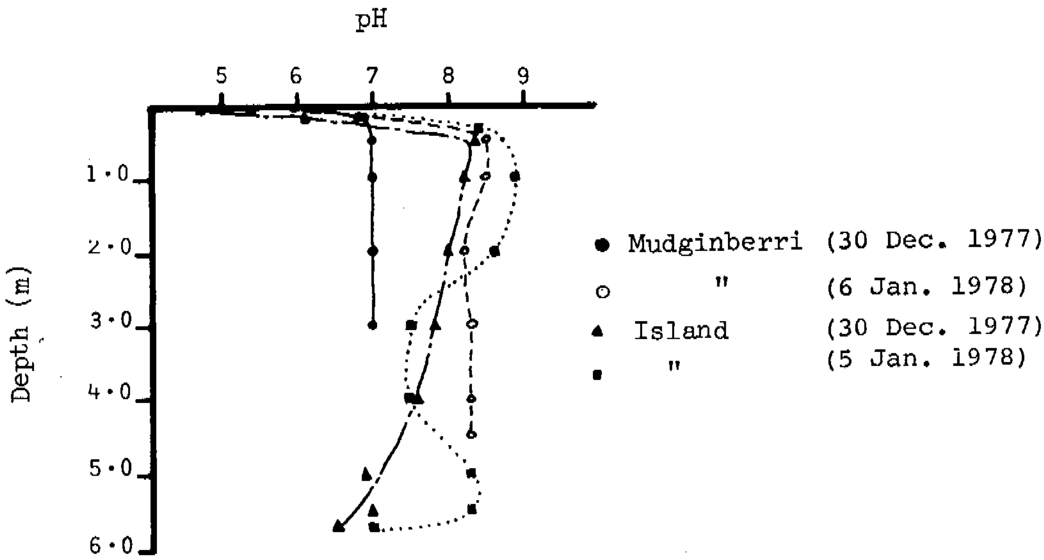

FIG. 12 pH PROFILES FOR CHANNEL BILLABONGS, MUDGINBERRI AND ISLAND, DECEMBER 1977 TO JANUARY 1978

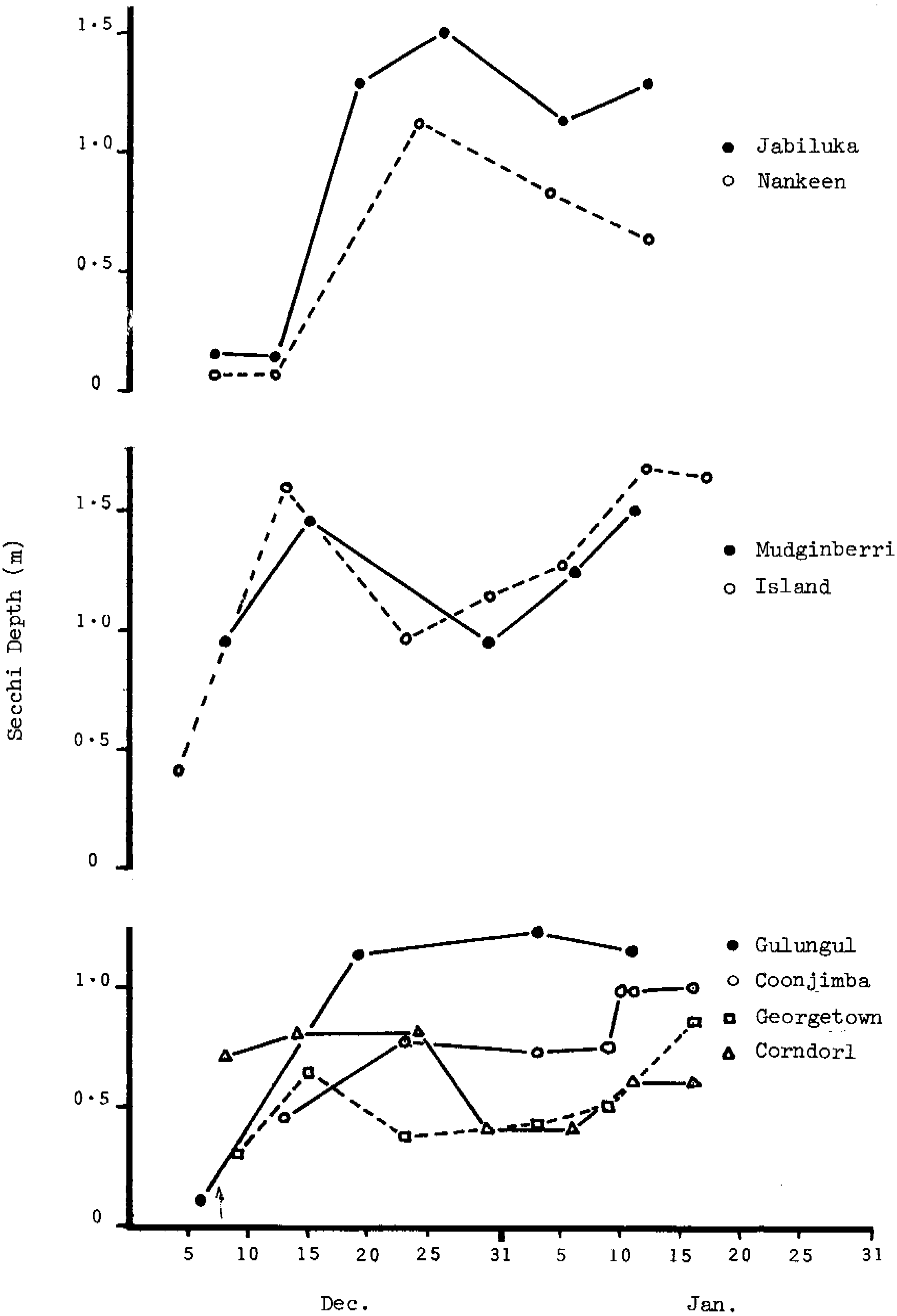

FIG. 13 SECCHI DEPTHS IN BILLABONGS OVER STUDY PERIOD

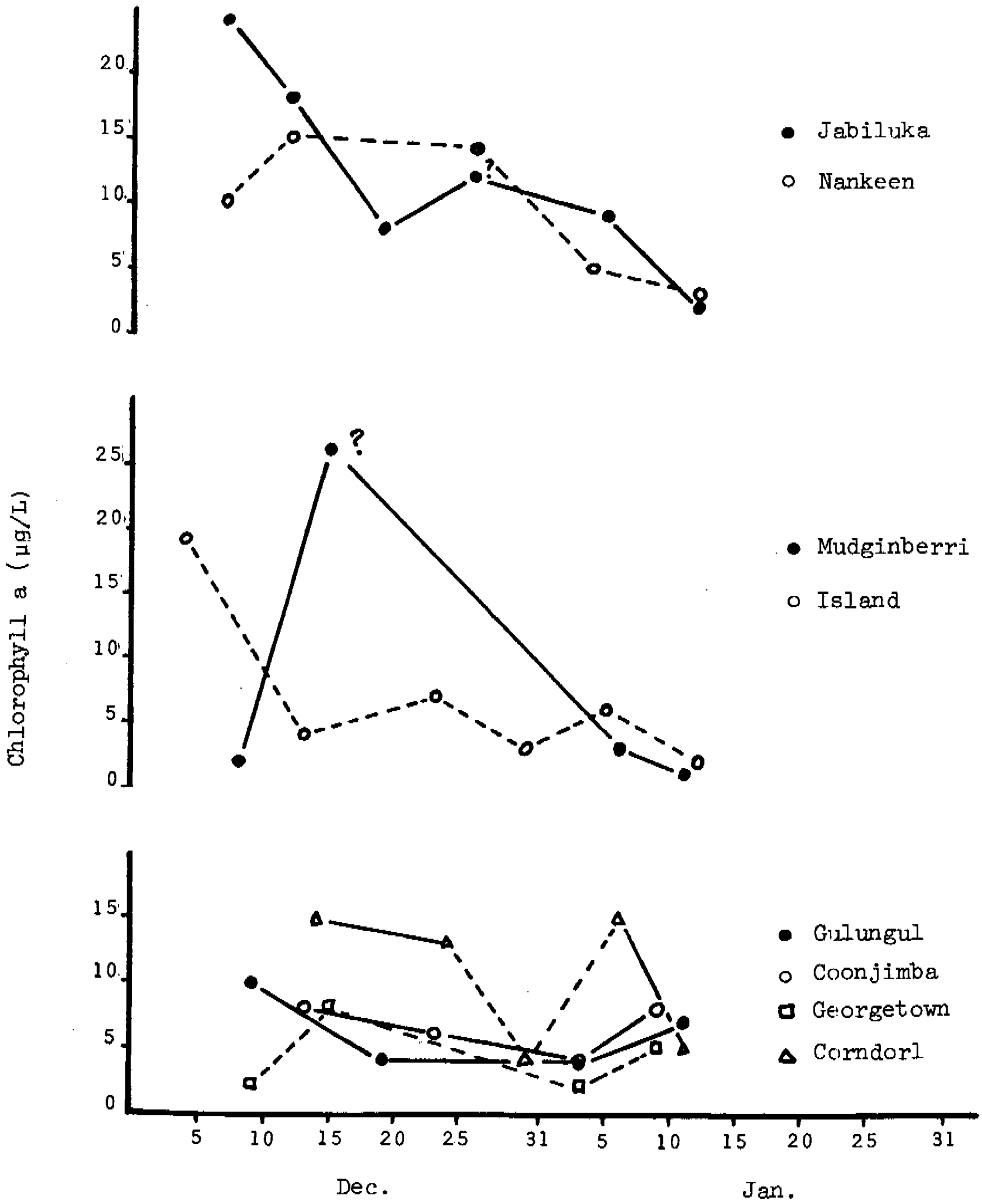

FIG. 14 CHLOROPHYLL *a* CONCENTRATIONS IN BILLABONGS OVER STUDY PERIOD

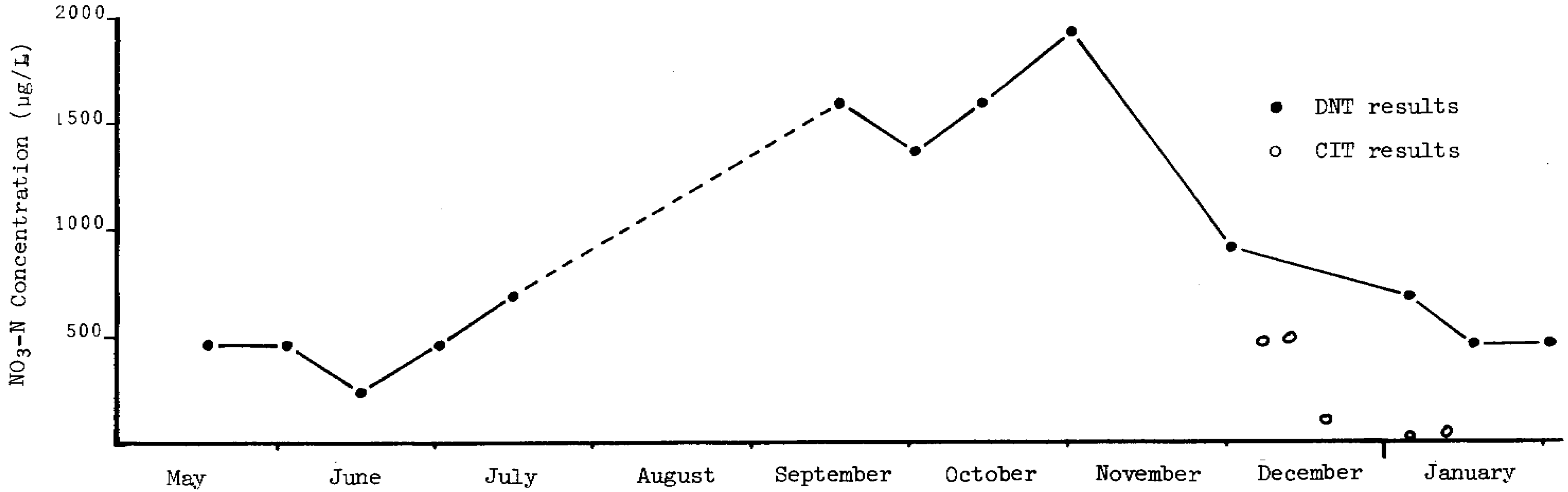

FIG. 15 NITRATE-NITROGEN CONCENTRATION IN JABILUKA BILLABONG FROM MAY 1977 TO JANUARY 1978

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RESEARCH PUBLICATIONS

Research Reports (RR) and Technical Memoranda (TM)

TM 1	Transport of trace metals in the Magela Creek system, Northern Territory. I. Concentrations and loads of iron, manganese, cadmium, copper, lead and zinc during flood periods in the 1978-1979 wet season. December 1981	(pb - 26 pp)	Hart, B.T., Davies, S.H.R, Thomas, P.A.
TM 2	Transport of trace metals in the Magela Creek system, Northern Territory. II. Trace Metals in the Magela Creek billabongs at the end of the 1978 dry season. December 1981	(pb - 23 pp)	Davies, S.H.R., Hart, B.T.
TM 3	Transport of trace metals in the Magela Creek system, Northern Territory. III. Billabong sediments. December 1981	(pb - 23 pp)	Thomas, P.A., Davies, S.H.R., Hart, B.T.
TM 4	The foraging behaviour of herons and egrets on the Magela Creek flood plain, Northern Territory. March 1982	(pb, mf - 20 pp)	Recher, H.F. Holmes, R.T.
RR1	The macroinvertebrates of Magela Creek, Northern Territory. April 1982	(pb, mf - 46 pp)	Marchant, R.
TM 5	Flocculation of retention pond water. May 1982	(pb, mf - 10 pp)	Hart, B.T. McGregor, R.J.

pb = paperback; mf = microfiche