LAKE CLAREMONT RESEARCH (1987-88)

REPORT

SECTION 1 LAND USE
SECTION 2 LAKE PHOSPHORUS BUDGET
SECTION 3 BIRDS OF THE AREA

BY

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August 1989

Cover: Lake Claremont from the north.
(I.Lantzke)

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Department of Science.

August 22, 1989

The Mayor
Town of Claremont
308 Stirling Highway
CLAREMONT WA 6010

Dear Sir,

Re: Lake Claremont Research (1987-88) Report.

On behalf of our research group I have pleasure in submitting our report on Lake Claremont and its present use. In it we present the results of an intensive study of water quality and use of Lake Claremont and surrounding open space over a twelve month period. The information is presented in three parts; land use, lake chemistry and biology, and birds of the region. Accompanying the report are the Lake Claremont Research Officer's field records. Aquatic invertebrate specimens have been lodged with the Western Australian Museum under the general title "Lake Claremont Project" with the identifications of P.W.G. 1 to 49.

This report had its genesis in a recommendation of the ad hoc citizen's committee (Keogh, Scollary-MacKay, Haynes) which reported in 1985. The committee recommended that basic research be carried out on Lake Claremont and Claremont Council applied for a Commonwealth Employment Project grant in 1987 and was awarded $21,530. This grant was supported by $5,000. from Claremont Council and $5,000. from Western Australian College of Advanced Education.

A major portion of the research has been concerned with the world wide problem of eutrophication of the lake, and the findings are of considerable scientific value. Also because this has been a pioneering study for Western Australia it provides guidance for other managers of the metropolitan wetlands.

Aspects of the study we consider important are its integration of all aspects of the investigation of the lake and its surrounds over the same twelve months, and the scope of the project, with quantitative data obtained for land use, as well as the phosphorus compartments of the lake.

Results of importance are :

- Determination of the quantities of phosphorus in storm water and the temporal pattern of storm events.
- The quantities of phosphorus associated with the sediments.
- The chemistry of phosphorus removal from the water column, and the change with season in the controlling factors.
- That the rate of release of sediment phosphorus was not limiting to algae growth (in summer).

The relevance and importance of these, and the other findings are highlighted by a recent listing of priority research areas for metropolitan wetlands (McComb, A.J. (ed.) (1988), 'Workshop on Biological Needs for Management of Metropolitan Wetlands'. Western Australian Water Resources Council, Leederville). The research areas judged of highest priority were "(a) Deteriorating water quality (sources and amounts of nutrients and contaminants, relevant wetlands processes, species sensitivity, botulism and algal toxins, effects of pesticides)".

The study has achieved the first two of these for Lake Claremont, and contributed to the next two. The study has also contributed to the second priority area by contributing data relevant to ".... more biological and ecological information including species and habitat requirements."

There are, we suggest, a number of actions the Council should now take towards establishing a management plan for the lake.

1. Forward copies of the report to the Environmental Protection Authority, and the Western Australian Water Resources Council.

2. Making a general (press) release to the citizens of Claremont of the major findings and the Council's intentions with respect to a land management plan. This should be supported by making copies of the report available to interested ratepayers.

3. Setting in place methods for the long term protection of the lake. These must include establishing methods for keeping informed of, and participating in groundwater planning. Of particular concern at the moment should be discussions with :-

   - Councils to the north and north-east on methods of protecting the groundwater that will eventually flow to Claremont.
   - Western Australian Water Resources Council on their plans, and the Hollick Report (which, inter-alia, suggests pumping groundwater lower in the metropolitan area).
   - Environmental Protection Authority on "green-house" effects.

4. Making decisions about the personnel who will be responsible for:

- Handling public discussion and resolution of differences of opinion.
- Planning; implementing; and subsequently monitoring a land management plan.

5. Deciding on any immediate action to be taken with the lake and its surrounds, such as the annual influx of phosphorus in storm water, fertilization of the grass surrounding the lake, and the establishment of a monitoring programme (against which to judge the effects of a management programme).

It would also be relevant to consider if there is need to commence any applied research, such as methods of removing phosphorus from the sediments.

Because of its compact size, known history, and the baseline data in this report, Lake Claremont offers excellent research opportunities. These include chemical studies of the sedimented phosphorus - its forms, variation with depth, diffusion, and rates of solution and/or inactivation, either by microbial mediation, or as insoluble residues. There are important questions about the forms and sources of drainage phosphorus, and the long term effects of re-directing drain water into sumps. There are also interesting questions related to the water chemistry and phosophorus removal, the rehabilitation of natural vegetation, and the control of exotic plants (weeds) around the lake.

In submitting our report we would also like to express our own interests in the care of Lake Claremont as an important local biological and educational resource, and to indicate our availability to meet with members of Council who wish to discuss aspects of the project.

We also wish to gratefully acknowledge financial support from the Commonwealth Government and Claremont Town Council and a grant from the Western Australian College of Advanced Education; the co-operation and assistance and help of all Claremont Council staff; and help from many lake users, officers in Government and Council Instrumentalities, Perth's limnological community and our colleagues and families.

Yours sincerely,

Ian Lantzke

Ian Lantzke.

LAND USE AND CAR PARKING

CONTENTS

LAKE CLAREMONT LAND-USE SURVEY 1987 - 1988.

SUMMARY :

During the period September 28 1987 to June 14 1988, a survey was undertaken to assess the diversity and significance of the land use undertaken by the community, of the Lake Claremont environs. district.

Essentially, the results clearly indicated several major patterns and effective variables in the type and intensity of use.

The Lake Claremont region is predominantly an open space area catering for recreational needs, mainly for active recreants. During most survey periods active recreants made up 80% or more of users. Given the abundance of open space in the region (82% excluding lake) it may be surmized that active recreation is generally well catered for and that there is an accompanying demand.

The region has several topographhical features which create some diversity in land use. The land surface, apart from the open grassed areas, includes an area of disturbed remnant bushland to the north-west of the lake, the lake itself and two small parks - Stirling Road and John Mulder Park.

It is apparent that these areas are comparatively under-used for passive recreation, although their collective area excluding the lake is also comparatively small and not connected.

The lake and the bushland areas need some kind of promotion that would raise their importance to the general public but in such a way that would not unduly compromise their character. Along with this promotion some form of native vegetation restoration to the bushland and lake margins would enhance their intrinsic values and their profile in the region.

INTRODUCTION :

Lake Claremont is surrounded by land zoned and used for recreation. This land area is made up of mainly open grassed areas which fall under two separate land tenures; those of the Claremont Town Council and Scotch College (see Map 1). As a result, the region offers opportunities for mainly active and, to a lesser degree, passive recreation.

As part of the multi-faceted Lake Claremont Project, a land use survey was conceived by the authors to assess the diversity and significance of recreational land uses in the region. The resulting information will provide baseline data for council management purposes and is presented in the following.

LAND USE

SURVEY METHODS

The surveys were to be undertaken by P. Gabriel with the following objectives :

1. To establish statistical data illustrating the number of people using the region and in what ways, over a year, with emphasis on overall trends as well as discreet events.

2. To determine, by way of the survey, the major and minor land uses especially where areas and accompanying uses were under-catered for or under-used.

3. To quantify the extent of car park use at certain points within the project boundaries so as to highlight periods of access space and space limitation.

The boundaries of the project area were set between Davies, Alfred, Narla, Shenton and Stirling Roads, the western boundaries of Cresswell Park and Scotch College.

Direct observation of the land users was to take place on an anti-clockwise route around the lake, the central physical feature at 5 to 6 points from which certain parts of the area could be viewed. The land use survey was to take place in conjunction with the bird observation work outlined in Section   of this report. Car parking statistics were to be accounted at the end of each observation session.

It was decided, given the topography and area, that a number of set observation points and observation times were required to obtain useful data. Also, it was perceived that weekday and weekend activities may show distinct differences in activity and population/activity. Thus the following general observation schedule was organized :

> For the first week of each month for seven days, three sessions of observation per day of duration three and a half hours each were to be undertaken. The following time periods were allocated:
>
> 1) Morning (a.m.) 6.30 - 10.00 a.m.
> 2) Afternoon (p.m.) 11.30 - 3.00 p.m.
> 3) Evening (p.m.+) 3.30 - 7.00 p.m.

During these sessions both bird populations and human land use were to be assessed for 30 minutes at six observation sites.

The observation sites are hereby described (see Map 1).

Site 1:

Near the small jetty at the southern end of the lake, in the Stirling Road park. Observation embraced the southern third of the Lake Claremont Golf Course, Stirling Road Park, John XXIII playing fields, the southern half of Scotch College playing fields and the southern half of the cycle path running along the western side of Lake Claremont.

Site 2:

Facing the central part of the golf course and looking around to Scotch fields over the Lake Cresswell Park and the cycle path skirting the western perimeter of the lake margins.

Site 3:

A point near the drain entering the very north eastern point of the lake and taking in that area of the golf course, John Mulder Park and over the lake to Scotch fields and the cycle path.

Site 4:

Standing in the eastern part of the bushland in the north-west near the western extremity of the golf course.

Site 5:

Taking in Cresswell Park, the western half of the bushland and the northern half of Scotch fields from the very western point of the lake.

Site 6:

The point at which a right angle occurs in the cycle path running along the western side of the lake adjacent to Scotch fields and covering the golf course and all of Scotch fields.

Car parking was to be assessed at seven points in the study area. These were at :

1. Stirling Road, where the road meets the Stirling Road Park. This area being a section of grassed land enclosed with copper logs and with no marked car bays. The most comfortable capacity was deemed to be four cars.

2. Cresswell Park car park adjacent to the park in the north-west of the region. A bitumenized area with no marked bays and bounded by grassed areas with shade trees. Bitumenized capacity is about 35 car bays.

3. Elliot Road western side, abutting the golf course. It was perceived that this road along with the adjacent Lapsley Road would experience heavy public use during times of large events such as football at the nearby Claremont Football Oval and the Royal Agricultural Show. This area has no marked bays and an appropriate capacity of 60.

4. Lapsley Road southern side facing the golf centre and its car park. There are no marked car bays and a capacity of 40.

5. Claremont Golf Course Centre car park. This area consists of 52 marked bays and a bitumenized area unmarked that could accommodate approximatley 70 more cars.

6. The Claremont Aquatic Centre (the swimming centre) car park running off Davies Road and opposite the Claremont Football Oval. This car park has a bitumenized area with 135 marked bays and a large expanse of enclosed grass which could account for about 115 more cars at most.

7. Claremont Tennis Club. The car parking facilities here consist of a grassed area for about 50 cars, on the corner of Shenton Place and Shenton Rod. This region offered the greatest chance of capacity variability. The arbitrary figure of 50 was settled on, on the basis of possible access and availability of even ground. Effectively, the observation times were to be :

   1. 10.15 a.m.
   2. 3.15 p.m.
   3. 7.15 p.m.

   The authors believed that these three time periods would give diurnal variation and potential for accounting for maximum and minimum counts depending on recreation, residential and other car parking events. Furthermore, because it was perceived that bird observation would need a significant time period for accuracy and that observation periods be about 3½ hours long, hence the above car parking observation periods were chosen.

Central to the project rationale was to establish significance and magnitude of land uses performed in the area. The observation site descriptions listed above allude to this need, that is, that several (open grassed) regions could be viewed entirely from several points. Furthermore, this would give a greater weighting to those activities that make use of the region for prolonged periods. It was perceived that regardless of this weighting, the types of uses were predictable given the landscape makeup and that the weighted uses would occur to a reasonable significance.

The observation of land uses over a long period would give increased weighting to certain prolonged activities which would indicate their more significant long term impacts on the regions facilities. This would provide an indication of some major management/development needs for the region.

Given the size, topography, facilities and proximity of this region to other recreation areas, schools and the Claremont commercial precinct, there would be many transient visitors as well as local residents and organized groups. The long observation periods were expected to illustrate the transient uses far better than quick spot checks.

SURVEY RESULTS

The following tables are a summary of all the raw data collected for land use and car parking during the Lake Claremont Project. Appendix 1 and 2 present complex data tables from which these tables were extracted.

Table 1:

Land use statistics for the Lake Claremont Region details in percentage form the monthly breakdown of activities as part of the total number of users per total activities down the vertical. It also presents, on the horizontal line, the percentage per month of each activity over the sum total of users for each particular activity. On the far right of the table, the total gross numbers per activity and activity type group (e.g. transient) are presented along with their percentage of the total project quantity of land users. The bottom of the table shows the total monthly gross figures for all activities and their corresponding percentage portion of the final total. The percentage per month per activity and the percentage per year per activity, presented in the monthly columns bear no direct relationship to each other. The percentage monthly figure comes out of the monthly gross figures at the table bottom and the % yearly figures are derived from the reference number for the total yearly quantity per activity. See discussion section on land use below for further explanations of figures.

Tables 2.0 to 2.2:

\- form a quantitative summary of car parking during the survey. Table 2.0 illustrates the maximum and minimum extremes per month per time of day as percentages of each car park's capacity and total car park capacity for the project area. On the right hand side column the average percentages of capacity used per car park per period are presented. On the bottom line the average daily total car parking capacity is presented for each month, ending in an average capacity used for the region at any day of the year.

Tables 2.1 and 2.2:

\- act to define Table 1 further. Table 2.1 identifies the car parking capacities for each car park and for the total car parks. The figures used to define the percentage capacities in Table 1 are those in the far right column of Table 2.1 The figures in Table 2.2 represent times when the percentage car parking capacity of each car park was exceeded, based on the figures in column four in Table 2.1.

The results for car parking are discussed further on in this and the following section. In general, all raw statistics were recorded in a large exercise book in situ and coverted to complex tabular form as presented in the Appendices.

LAKE CLAREMONT REGIONAL LAND USE

DISCUSSION OF RESULTS

Before describing the trends and significant events that occurred during the survey, it is important to note several changes to the operating methods during the survey.

During August and September of 1988 the preparations were made, thus the first month sampled was October. February 1988 was missed due to changes in other sampling timetables and July 1988, was left out for the purposes of data collation.

The following is a list of the sampling periods undertaken for land use appraisal.

MONTH			DATES		
1.	October	1987	28. 9.87	-	6.10.87
2.	November	1987	2.11.87	-	8.11.87
3.	December	1987	30.11.87	-	6.12.88
4.	January	1988	11. 1.88	-	17. 1.88
5.	March	1988	29. 2.88	-	6. 3.88
6.	April	1988	4. 4.88	-	10. 4.88
7.	May	1988	2. 5.88	-	8. 5.88
8.	June	1988	5. 6.88	-	11. 6.88

All weeks were sampled on a Monday to Sunday basis. Hence, eight months were effectively sampled and it was anticipated that they would present an adequate cross-section of the variations in yearly activity, embracing seasonal changes and their relationship to formal and casual activities in the Lake Claremont region.

There were two distinct changes to the survey method. It was perceived after the first two months sampling that the majority of people used the area during the following time periods within the sampling sessions :

1. a.m. (6.30 - 9.00)
2. p.m. (12.00 - 2.00)
3. p.m.+ (4.30 - 6.30)

Also, from the results of the bird population surveys it appeared as though the number of birds for most species were observed during each period. Hence, due to the above two factors and pressures on the survey logistics, especially time, it was decided to shorten the survey to two sessions per day for six days in December. The results for both land use and bird populations were proportinately similar to those of October and November (refer to Appendix 1, this sub report and Appendices in the Bird Survey sub report).

In view of these results, it was decided to reassess land use and bird observation. Given the apparent consistency of bird survey results, a total of three sessions of observation were designated to cover morning, afternoon and evening periods, of 3½ hours duration. For land use sampling the following timetable was settled on.

Morning	:	6.30 - 8.45
Afternoon	:	11.30 - 1.45
Evening	:	4.30 - 6.45

Sampling occurred at the same sites and for 15 minutes per site, for the seven day sampling week. For the purposes of consistency and accuracy, the results for the remaining hours that were sampled from October to December were not included in the results (in Appendix 1) and thus have no impact in Table 1.

Although the shortened survey may have lent a certain bias toward times when major activities such as organized sports, the results as anticipated after December showed significant numbers for a diverse array of uses. In any case, it was too difficult for one observer to do so for most of a day.

Before actual discussion of results, there was another minor point of change in the organization of survey sampling. Just prior to survey initiation it was learnt that the John XXIII playing fields were to be subject to residential development and this proceded almost immediately. Thus, the decision was made to exclude them from observation as they were no longer open to direct public access.

Table 1, is a statistical summary of the land uses at Lake Claremont over the survey period. Over this period a total of 35 different activities were noted. For the sake of organization, some of these were grouped together in relation to their specific and general type of activity. In effect, this reduced the number to 21 as presented in Table 1. The activities were further subgrouped into three general categories, that is :

1. Transient visitors
2. Sustained passive recreants, and
3. Sustained active recrants

Transient visitors were those deemed to be those moving a defined path around or adjacent to the Lake or recreation ground, regardless of whether they definitely appeared to be using the area as a travel route or whether they were there to appreciate the scenic amenity of the region.

Sustained passive users were those people who maintained a presence in a particular area over a period of time but who did not apply a highly active physical effort.

Sustained active users included, sportspeople, golfers, children at play as well as people disturbing the Lake environs and uncontrolled domestic pets.

One category of activity not included was that involving the ground staff of the Claremont Golf Course, Scotch College and Cresswell Park. Their activities were very predictable and it was decided that, as they were responsible for maintenance, they were quite separate from the other users. It is worth noting however, that during times where heavy machinery (e.g. tractors, lawn mowers) were in use, the ground staff created a noise and sometimes a physical barrier in some parts of the golf course and Scotch College. However, it was observed that golfers and other major users simply skirted around these obstacles and as such, no particular attention was paid to relative changes in land uses caused by this activity. In general they accounted for about 5% of population overall.

It was hypothesized at the beginning of the project that, given the landscape make-up, the principal uses for the area would be active recreation such as adult and child sport and golf; adult sport such as cricket and hockey occurring at Cresswell Park; child sport occurring at Scotch College and golf being played on the extensive Claremont Public Golf course.

It was also expected that casual, more passive uses would occur, principally due to the presence of both large areas of open space and natural features such as the Lake and remnant woodland.

An assessment of the areas available to the public in terms of % size is as follows (excluding the lake) and the Lakeway Drive-in site.

ZONE	% TOTAL LAND AREA
Golf Course	57.5
Scotch College	27.5
Cresswell Park	6.2
Remnant Bushland	5
Stirling Road Park	2.5
John Mulder Park	1.2

Total open grassed fields = 91.2%

This information gleaned from aerial photograph circa 1975, (S.A. Lands and Surveys Department) C/O Claremont Town Council.

(The Lake is approximately the same area as the golf course. However, due to its central location, it is the most notable physical feature in the landscape.)

Hence, we can see that the facilities for active recreation are the largest. It was felt that the survey would confirm this and also define any paucity or excess use of other area types not specifically designed for active recreation.

Overall, as can be seen in Table 1, the various active passtimes mentioned above were overwhelmingly the most popular and significant.

It is important to reiterate at this point that by the very nature of the observation methods the sustained active recreation was further 'weighted' by the fact that these activities were counted two to three times over. It is estimated that approximately 30-40% of the gross data for these activities came from this 'weighting'. However, a quick calculation from the gross total figures on the right hand vertical column of Table 1 would see an average increase of about 9% in transient activity and a drop of 5% for active recreation, if an average 35% of active numbers were removed from the data.

Throughout the year the sustained sporting activities made up about 60% of land users with peaks in May and June due to high activity at Scotch College fields during weekday afternoons.

The passive recreants made up less than 5% overall with most activity in the seasons of spring 1987 and autumn 1988.

The transient users overall represented about 30% of users in any month and the general trend of the statistics suggest that warmer weather attracts most of these people with the exception of those simply travelling through the area such as cyclists.

The total populations per month were fairly similar throughout the survey and major differences could be attributed to the number of golfers, adult and child sporting events.

Golf was the most significant use of the region. The course makes up nearly 60% of the land surface, the percentage composition of measured populations that golfers made up was between 19 and 40%. Golfing was observed at early as 6.30 a.m. and as late as 7.00 p.m. (night golf was observed at these times). The major effect limiting golf was possibly excessively hot, dry days in December and cool, moist days of June.

The course underwent a renovation from a cramped 18 hole course to a more spacious 9 hole course. By February a golf tournament was held to commemorate the opening. It may be possible to surmise that the change in quality of the course and its promotion, caused an overall increase in golfers, in spite of the reduction in the number of holes.

Fluctuations in weather and season had definite influences on magnitude and type of activities throughout the survey. The generally warm to hot conditions that existed from November to April provided a conditional 'water shed' for sporting activities whether formal or casual. Indeed, the first occasion that rainfall occurred in a survey week was in June on one day where very light drizzle occurred. This homogeneity in conditions presided over some general trends. The morning periods began at cool conditions light to brisk easterly or southerly breezes sometimes semi overcast but generally quite clear skies; during midday, with temperatures in the high 20's or more sparse high clouds or clear skies with little or no breeze; evening periods were marked by warm conditions which were ameliorated occasionally by later cool south westerly breezes. Sunrises were at approximately 6.00 a.m. and sunsets about 7.00 to 7.30 p.m.

October 1987 endured a generally milder version of the above whereas May and June 1988 were quite cooler, cloudier with sunrises at 7.00 a.m. and sunsets as early as 6.15 p.m.

As can be seen from Table 1, the highest numbers per activities with some exceptions, occurred in the November to April period. Transient users generally, on weekdays, used the region in the cooler morning and evening periods. These people tended to use the area for light exercise or travel and at least ostensibly because of its open space and visual amenity. In the cooler months these user groups occurred more towards the later morning, midday and early in the evening due to limited light and cooler conditions.

Passive recreants were more variable in occurrence and this reflection was probably intensified by the spasmodic appearance of these activities. Activities such as photography, bird watching and walking occurred mostly in the morning or evening periods when light and weather were appropriate. Picnics, along with children at play, occurred in mainly the afternoons during cooler months or mornings and evenings in the warmer months.

Seasonal and weather conditions produce several notable effects on activities in the region. The most striking impact was the drying and flooding of the lake. In terms of land use, this event must have changed the perspective of the region for the users.
Indeed, several people walking through the region were noted as voicing comments about rehabilitation, quality of amenity values. For those who particularly enjoyed feeding the water fowl, the drying of the lake (which was very severe) attracted attention to the lake and the region to the extent that people were feeding the remaining birds and even leaving water for them. This happened often in March, especially, just before the first rains. The first rains brought more water but stirred up powerful odors from the moistening mud; this also attracted comments to the observer P. Gabriel.

The lowering of water levels also allowed for the access to sensitive parts of the lake, such as the stands of bushrushes (Typha orientalis). Stray dogs and children playing or collecting miss-hit golf balls formed a small but environmentally significant user group noted in Table 1, simply as lake disturbances. Lake disturbances would have included (if they had been seen)person(s) who started several fires in the bulrushes along the eastern margins of the lake. These events occurring in March and April were flagged by the early morning presence of policemen and fire brigade workers.

The maintenance of the vast grassed areas by the various groundstaff required, as mentioned above, the use of regular watering, fertilizing, sanding and mowing of grass which sometimes offered a disturbance to users especially in the warmer months. However, this did not seem to effect the overall figures to any great degree.

The appearance of waterfowl was a definite attraction for many people and such sentiments were conveyed to the observer throughout the project. Hand feeding occurred at several places especially at the small jetty protruding into the lake from Stirling Road. Members from the Royal Australasian Ornithological Union noted taking population counts for birds in March and June.

As rain and cooler conditions set in the region began to assume the modified European-style lake-landscape, a reduction in lake disturbance, along with a reduction of passive and transient users.

Perhaps, in some instances, a more significant driving force than climatic conditions was the factor of timing for certain formal and casual events. The organization of the lifestyles must have played a significant role in the choice of activity for some users.

The transient activities, for example, were made up of many performing active (jogging, riding) and passive (walking, walking the dog) recreation and mainly in the mornings and evenings. It is quite probable that some of these people used the area prior to beginning formal employment for the day, or school. Indeed, many of the riders were school children, especially during the months when primary and secondary schools, near the area, were operating.

Child sporting activities occurred from October to December and March to June as part of the school curriculum. Adult sport followed a familiar pattern regardless of season with formal training sessions on several weekends. (In both these cases, spectators and staff were included in statistics for these activities.)

The groundstaff were of course following a formal timetable also. The role of weekends and public holidays becomes important in terms of activity determination. Although there were no great increases in overall people numbers from week days to weekends and public holidays, the kinds of activity changed.

During these periods there were more people found in picnics, casual sport on playing fields, such as kite flying, frisbee throwing, etc. and children playing.

Organized sporting matches occurred on weekends as previously mentioned.

There were some areas and activities which seemed under used, at least by comparison with the heavily used areas. These areas included the woodland, John Mulder Park set between Davies Road and the central eastern part of the golf course, and for various reasons, the lake.

Activities at these areas varied between each of these areas. The woodland is separated into two parts by a cleared area which contains derelict BBQ facilities. There is also a sharp incline up to the abandoned Lakeway Drive-in site. Because the major footpath runs through this area (from Strickland Road around and south to Stirling Road) most people used it to pass through in some fashion. As with the lake there appeared to be few people (n 1.0%) overall who visited the region to use these natural areas specifically.

John Mulder Park has similar park facilities to Stirling Road Park but is approximately half the size. It also has the only skateboard track in the region. It appeared as though the users were from surrounding dwellings and streets. Parents taking children to use the playground facilities and picnic as well as young skateboarders were the major user groups.

It is significant to point out at this point that, as mentioned above, the region caters very well for active recreation with areas for passive recreation being smaller and disparate. Furthermore, although from Table 1, we can see that overall passive recreation formed less than 4% and walking and walking the dog made a total of 12.4%, passive recreation by its very nature requires a certain solitude, usually created by a varied topography and lack of general disturbance. Hence, although the percentage use for passive recreation in some areas and overall was low, we may deduce two things :

1. Passive recreation has possibly been observed at its current limit.

2. That some areas and the region as a whole may need sympathetic alterations to encourage more passive use.

DISCUSSION : PART B

CAR PARKING IN THE LAKE CLAREMONT REGION

Table 2.1 is most significant in a discussion of the car parking of the Lake Claremont region. The figures displayed therein constitute a summary (from left to right) of the process for the interpretation of the raw data collected in the project lifetime. The figures in the fourth column were determined on the following basis :

1. Stirling Road car park, as described in Section 2, had a 'comfortable capacity of four'. There was room for eight vehicles but in that situation four vehicles would have been inhibited from access out to the road.

2. The car parks at Cresswell Park, the swimming centre and the Golf course have areas of bitumen for car parking. The former two have grassed areas in addition. Cresswell Park (entirely), the swimming centre and the Golf course car park have unmarked bitumen areas. It was decided by the authors that although the unmarked grass and bitumen areas are used during times of need at each centre, the most important car parking requirements are met by properly designated car parking. Hence, in terms of future car parking policy and development, the maximum car parking capacities were defined to provide an indication of potential needs, especially in the face of pressures for space in and from the surrounding recreational and commercial areas.

3. The Tennis Club car park consists of an undulating semi-grassed area of approximately 1200 square metres in size. It has one access way of Shenton Place. During the survey it reached a capacity of 60 in October 1987, in cramped conditions due to the annual event of the Royal Agricultural Show, held nearby. The capacity of 50 was settled on as the maximum comfortable figure, given the physical makeup of the area.

4. The remaining parking areas, Elliot Road and Lapsley Road, are not genuine parking areas as such, but were believed to provide parking in times of high needs. Both areas are adjacent to the Golf course and its car park. An estimate of their capacities is presented in Table 2.1.

The analysis of car parking may be split into two parts :

1. Description of the variation in the status quo of car park use as depicted from the survey results.

2. The implications from the above in regard to possible management and development directions for car parking in the region and adjacent car parking pressure.

1. **THE SURVEY:**

As described in the land use discussion above, changes occurred to the survey method in December 1987 and January 1988. The effect upon car parking was to change the observation times from:

a) 10.00 a.m. to 8.45 a.m.
b) 3.00 p.m. to 1.45 p.m.
c) 7.15 p.m. to 6.45 p.m.

Given the extremes of figures obtained regardless of events, as shown in Table 2.0, it was decided that due to logisitic pressures, the survey could be changed without unduly favouring any kind of car parking events. Indeed, the figures display quite an array of monthly, individual variation per car park sites and sampling sessions.

The major observable variable over the year that did affect observation and corresponding car park use, was probably the seasonal variation in local weather conditions and the fluctuation in dawn and dusk times.

During different seasons there were different major uses and for some their occurrence was limited by the available natural light (although there were probably other factors involved in the organization of the particular events that precluded night or early morning activity). For example, in the cooler months of May and June 1988, a number of cars at the Golf centre at 6.45 p.m. were less than in summer due to earlier sunset and cooler conditions.

The figures at the bottom of Table 2.0 are perhaps the most notable for car parking. In October, the greatest average use of the total car parking occurred. The figure obtained is nearly double the next closest figure. This was caused by the annual explosion in car parking requirements caused by the Royal Agricultural Show, which ended on Friday October 3, 1987.

Indeed, it was events with similar significance to this that caused major pertubations for available car parking space throughout the survey. This is indicated statistically in Tables 2.0 and 2.2. In May and June of 1988 the occurrence of football matches and associated club training at the Claremont Football Club training at the Claremont Football Oval caused a distinct increase in car parking at the swimming centre (closed for swimming in May), the Tennis Club, Elliot and Lapsley Roads during week days and weekends.

There were a number of trends that are exemplified in Tables 2.0 and the Appendiced raw data. These include the following :

1. The swimming centre and Golf Club car parks were the most used both in reality and in percentage capacity. Stirling Road car park was understandably well used at times given its small size. Other car parks such as Cresswell Park and Lapsley Road, were dependent upon time of observation and accompanying events to reach significant capacity.

2. Golf as a land use along with adult sport, was one of the few land uses that could be related to car parking events. It proved to be one of the most significant activities in both areas. Indeed (along with residential use), its car parking requirements overflowed to the adjacent Lapsley and Elliot Roads.

3. The major land uses for Cresswell Park were adult sporting activities: men's cricket in summer and men's hockey in the winter months. Training and match situations occurred on week evenings and weekends respectively.

4. Stirling Road car park was generally used by passive recreators using the adjacent parkland and adjoining foot-path near the southern end of the lake. On average, it carried about 1 car per day or less.

5. The Tennis Club car parking was subject to several sources of cars (by deduction). It seems that during the construction of the 'Heritage Fields Estate Development' workers used the area for parking. This car park was possibly used also by nearby residents and/or visitors as well as shoppers or retail workers from the shopping precinct south of the railway line.

6. The swimming centre car park probably fulfils to a lesser extent the car parking needs of people using the rail service, shopping or working in the shopping precinct.

7. Weather effects had indirect impacts on car parking. Weather conditions as mentioned in the section dealing with land use analysis were generally homogenous, that is, mild to warm temperatures, occasional strong winds and rain occurring very slightly in June 1988. Extremes of temperature in the summer months possibly influenced sporting activities during the week days, such as golf, especially in the midday sessions.

   During the cooler months when sunrises were later and sunsets earlier, the amount of activity related to car parking such as golf, passive recreation and tennis for example, decreased, as can be seen from the overall daily capacities per month and the maximum and minimum percentage capacity utilization per session per month per zone.

8. Using the figures for average daily capacity per month and per year, we come to gross average limits of car parking demand for the total car parks. Table 2.3 illustrates these figures as well as average daily gross limits of each car park for the project period.

TABLE 2.3 :

CAR PARK	Average daily limits per year		Maximum daily limits per year		Minimum daily limits per year	
	Figure	%	Figure	%	Figure	%
Stirling	1<	20.3	10	250	0	0
Cresswell Park	>4	13.0	56	160	0	0
Elliot Road	5	8.3	52	87	0	0
Lapsley Road	6	15.0	47	117	0	0
Golf Centre	17	33.3	89	171	0	0
Swimming Centre	30	22	190	141	0	0
Tennis Club	5	9.3	60	120	0	0
TOTAL CAR PARKING	68	18.0	143	38		

The percentages are taken from Table 2.0 and represent percentages of maximum capacity as defined in 2.2. The figures for actual cars using the car parks are presented in terms of whole cars, hence no decimal places given. For example, the average daily limit per year for Cresswell Park was n 4.5, given as >4.

Ultimately, we may draw several conclusions from Table 2.3 about how well car parks within the survey boundaries are utilized. The average daily figures would indicate that overall there is ample space whether marked or not in all car parks. However, the maximum figures, along with those high-lighted in Table 2.2, indicate that there can be periods of paucity of space.

To the south of the project region there are car parking areas on either side of the railway line. These are used by shoppers, retail and other workers for the Claremont shopping precinct and people wishing to use the rail service to go to their respective work places. No statistical analysis was applied to these areas. However, they form along with car parking in project region and the shopping areas, a network of car parking in great demand for shoppers, workers and recreants. There appears to be a capacity of approximatley 600 car bays.

During periods of high pressure on the project area car parking, these car parks were also used totally. This was evident during the Royal Agricultural Show in October 1988, a Home-Show at the same grounds in March and during the winter sporting season at the Claremont Football Club.

At this point we may define the above as conclusive statements, however, it is important to discuss the implications of future developments in the Lake Claremont region in the light of our findings.

2. IMPLICATIONS FOR FUTURE MANAGEMENT

There are several possible changes to land uses in and around Lake Claremont. These include:

1. Resumption of the railway reserve land by the State Government body Land Corp.

2. Provision of heated swimming pool facilities at the Claremont Aquatic Centre.

3. The re-development of the Lake Way Drive-in site.

4. The upgrading of the BBQ area just south of the Drive-in site, in the remnant native woodland.

5. Development of an observation centre near the lake to tie in with the environmental and historical 'renovation' of the Claremont district, organised by B. Haynes and the Claremont Museum.

Briefly and in turn:

1. The resumption of railway reserve land by the State Government will mean the loss of about 600 car bays used intensively by a variety of user groups. As indicated above, there are times when the carparking space at the Swimming Centre, Tennis Club, Lapsley and Elliot Roads are used up by both recreants and others attending specific short term events. The loss of the railway reserve parking would clearly force the regular workers, shoppers, etc. to encroach on the recreational zone carparks constantly. For the Claremont Town Council, large scale alternatives would need to be found to cater for this imbalance.

2. Provision of heated swimming pools at the Swimming Centre would allow it to remain open all year, whereas at present it closes in May and re-opens in about September. This would increase carparking, especially during early mornings and cool evenings.

   During the cooler months of May and June 1988 in the survey, when the Swimming Centre was closed to the public the only major use for its car parking was for football training and spectator parking on weekends. This indicates that extra parking space for heated swimming pool users may not be required, given the large area of grassed parking space referred to in Table 2.1. However, if the railway reserve land is resumed as mentioned above, there will be greater pressure for space in the Swimming Centre carpark.

3 & 4. The re-development of the Lake Way Drive-in site <u>may</u> provide some parking space for the upgraded BBQ area and perhaps for spectators of sporting events at Cresswell Park and general passive recreants. The upgraded BBQ area would need some carparking provided nearby and if it was not supplied with the redevelopment, then it may come from an area adjacent to the nearby end of Strickland Road.

5. Development of an observation centre for greater appreciation of the conservation, education and recreation value of the remnant natural features of the region - the lake and remnant bushland - would require car parking. Whether that means increasing an existing car park, for example at Stirling Road Park, would depend on its siting.

CONCLUSIONS:

In general, several conclusions about regional land use in the Lake Claremont recreational zone may be drawn.

1. As predicted, active recreation is the prominent feature for the areas. These pursuits are well catered for and constitute a successful, desirable public resource.

2. Some of the less well used areas such as the remnant native woodland to the north-west of the lake, the lake itself would benefit from some sympathetic rehabilitation such as revegetation with native plants of that region. This, along with some kind of promotion such as static information displays and perhaps key observation point(s) or major observation centre, may help to bring a greater balance to the land uses by encouraging interest in the natural areas. School groups (which were lacking during the survey) and other tour groups could be enticed because of the conservation, education and passive recreation values of these areas.

IMPLICATIONS FOR FUTURE DEVELOPMENTS IN THE REGION

During the project lifetime it came to the notice of the authors that several changes to the regional land uses may occur via the Claremont Town Council. These included :

1. Redevelopment of the Lakeway Drive-in site for residential development.

2. Upgrading of the BBQ area that exists in the woodland near the north-western corner of the lake.

3. The creation of an observation centre for education and conservation purposes for the public.

In lieu of the general conclusions drawn from the land use survey we may consider the first two and possibly the third option together.

The Drive-in site and the BBQ area are adjacent to each other. Residential development at the former could see a small increase in the number of users especially passive recreation. It may see accelerated degradation of the nearby woodland. However, although the woodland is quite degraded at present, this process may reduce the visual and ecological value of the region and would require monitoring and maintenance.

The BBQ area would attract more family groups and others to an area that seems to have little use. As long as it contributes to degradation of the woodland and lake areas, particularly by way of fire hazard, it may act to focus attention to the landscape values of the region. Along with some kind of static information display as suggested in the above and revegetation of the woodland and lake margins, the natural areas could be promoted adding further incentive for passive recreants, school groups and others to visit the region. Furthermore, the development of an observation centre with the services of a ranger perhaps, near the BBQ area or at Stirling Road Park may also attract attention to the lake and the region as a whole.

TABLE 2.0 : LAKE CLAREMONT CAR PARKING 1987 - 1988 P.W.G.

PERCENTAGE, CAPACITY:

MORNING SAMPLING

CARPARK	Oct.		Nov.		Dec.		Jan.		Mar.		Apr.		May		June		Average daily % Capacity use
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	
Stirling Rd	75	0	100	0	50	0	75	0	25	0	50	0	50	0	25	0	21
Cresswell Pk	65	0	2	0	2	0	9	0	11	0	2	0	16	0	2	0	3
Elliot Rd	67	0	8	2	10	2	13	2	28	0	5	0	5	0	3	0	7
Lapsley Rd	100	0	27	5	25	5	35	0	27	2	17	5	10	5	15	0	16
Golf Centre	67	23	90	7	74	14	81	16	78	16	60	12	81	7	69	2	39
Swim Centre	100	4	20	4	19	6	78	19	22	17	37	4	6	0	13	0	16
Tennis Club	48	0	48	0	24	0	6	0	66	0	10	0	20	0	8	0	8
Monthly % Total Capacity a.m.	87	5	33	3	20	5	47	9	37	3	26	3	20	1	20	0.3	16

AFTERNOON SAMPLING

CARPARK	Oct.		Nov.		Dec.		Jan.		Mar.		Apr.		May		June		Average daily % Capacity use
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	
Stirling Rd	100	0	50	0	50	0	75	0	50	0	75	0	75	0	50	0	25
Cresswell Pk	57	0	69	0	91	0	73	0	5	0	2	0	5	0	100	0	12
Elliot Rd	87	0	7	0	3	2	13	0	13	3	40	0	13	2	28	0	10
Lapsley Rd	100	0	12	0	27	0	27	0	20	5	92	5	25	2	100	5	18
Golf Centre	100	25	46	14	44	14	97	5	58	28	97	18	100	14	100	35	47
Swim Centre	100	2	46	7	26	7	50	22	96	17	70	9	17	0	93	0	30
Tennis Club	100	0	76	0	16	0	28	2	20	2	82	0	60	0	28	2	13

EVENING SAMPLING

CARPARK	Oct. Max	Oct. Min	Nov. Max	Nov. Min	Dec. Max	Dec. Min	Jan. Max	Jan. Min	Mar. Max	Mar. Min	Apr. Max	Apr. Min	May Max	May Min	June Max	June Min	Average daily % Capacity use
Stirling Rd	0	0	75	0	50	0	50	0	50	0	100	0	0	0	50	0	15
Cresswell Pk	46	0	80	0	96	0	71	0	62	0	25	0	48	0	100	0	24
Elliot Rd	47	0	7	0	3	0	12	2	7	0	8	0	8	0	2	0	8
Lapsley Rd	100	0	10	0	5	2	12	0	7	0	7	0	5	0	2	0	9
Golf Centre	100	0	14	5	42	5	46	7	88	2	35	2	7	0	42	0	14
Swim Centre	100	2	33	0	11	4	39	0	59	2	54	0	54	0	76	0	20
Tennis Club	80	0	4	0	24	4	24	0	24	0	36	2	16	0	32	0	7
Monthly % Total Capacity a.m.	91	1	26	05	23	3	34	1	44	1	34	0.5	27	0	54	0	14
Average % Total Capacity/day/month	99	4	34	3	23	4	43	5	44	5	43	3	27	1	55	3	
Average daily % capacity used.	38		13		14		21		22		16		10		13		18% Da /Year

TABLE 2.1 : CAR PARKING CAPACITY IN THE STUDY AREA

CAR PARK	No.Marked Car bays	Approx. No. Car bays extra	Total Car bays	Total used * in Analysis
Stirling Road	-	4	4	4
Creswell Park	35	45	80	35
Elliot Road	-	60	60	60
Lapsley Road	-	40	40	40
Golf Centre	52	70	122	52
Swim.Centre	135	115	250	135
Tennis Club	-	50	50	50
TOTAL CAR BAYS	222	384	606	376

TABLE 2.2 : SURVEY PERIODS WHERE MAXIMUM CAR PARKING CAPACITY EXCEEDED ACCEPTED ANALYTICAL MAXIMUM CAPACITIES OF EACH CAR PARK.

	MONTH PERCENTAGE CAPACITY								
	October 1987			May 1988			June 1988		
	a.m.	p.m.	a.m.+	a.m.	p.m.	p.m.+	a.m.	p.m.	p.m.+
Stirling Road		250							
Cresswell Park								160	154
Lapsley Road		117	102					107	
Golf Centre		171	135		112			133	
Swimming Centre	124	141	113						
Tennis Club	120	120							
Monthly % Total Capacity		120							

THE PHOSPHORUS BUDGET OF
LAKE CLAREMONT 1987 - 1988

A REPORT TO CLAREMONT TOWN COUNCIL

BY PHILIP GABRIEL (Lake Claremont Research Officer) and
IAN LANTZKE (WACAE, Claremont Campus)

June 1989
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4043X

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SUMMARY

1. Average ground water levels at Lake Claremont fell during the 1970's, and summer levels over recent years have been close to 1m (A.H.D), ie below some, or all, of the lake bottom.

2 The lake contains sufficiently large quantities of phosphorus (P) for its waters to be hyper-eutrophic - that is over-enriched.

Peak P concentrations measured in the study were:-

Soluble reactive phosphorus ($P-PO_4$) 420ug/L (Site 1: 8/6/88)

and soluble organic and polyphosphates ((total P)-($P-PO_4$)) 250ug/L (Site 2: 4/1/88)

Total soluble P in the water column varied from 30.4kg (on 13/10/87) to 0.2kg (on 22/2/88)

3. The phosphorus in the water column is in a highly dynamic situation. Concentrations and forms can change rapidly. The largest change observed was the decrease in total P concentration of 290µg/L over the 14 days between 13/10/87 and 27/10/87 (at Site 2) and the $P-PO_4$ concentration change of 210µg/L over 14 days (23/5/88 to 7/6/88 : Sites 1 and 2). The largest total phosphorus change observed was from 30.4kg to 5.3kg over 14 days (13/10/87 to 27/10/87).

4. There is a significant inflow of phosphorus in the storm water draining into the lake, especially from summer and autumn rains.

The annual inflow is estimated at about 12.5kg total soluble P, containing about 60% soluble reactive phosphorus (PO_4^{3-}), together with a significant, but undetermined amount of plant detritus and humus.

5. The bulrush and lake clubrush mobilized about 57kg of P annually, and about 37% of this (21kg) is shed into the lake each year in dead leaves.

6. A mat of dried algae left in the western arm of the lake in late summer contained an estimated 33kg of P.

7. The sediments act as the main source and sink for the P in the water body.

   Approximately 3 tonnes of P is held in the surface 1 cm of the lake bed.

8. Groundwater, at present low in P, enters the lake from the NE. The groundwater leaving on the west and southwest, is slightly richer in P, than the incoming ground water (when the lake contains water), but the concentration is not as great as in the lake water.

   It was not possible to estimate groundwater volumes either entering or leaving the lake, nor the quantities of P involved, but we think they are relatively small.

1.0 INTRODUCTION

1.1 Reason for the Project

Lake Claremont is a part of the coastal plain's diminishing wetland resource, and is a freshwater area close to the saline Swan Estuary. It is also an important and historical component of Claremont's recreation resource. However in recent years some problems with the lake's health have been perceived.

Firstly the lake now dries out during most summers.

Secondly at several stages of the year it carries blooms of algae, often the blue-green types such as *Anabaena* sp. and *Anacystis* sp. which cause odour problems and are toxic to waterfowl and other animals.

Thirdly there is the spread of the bulrush (*Typha orientalis*), encroaching on previously open water, formerly used by open water species of waterfowl.

The expectation was that, if the underlying causes for these effects could be determined, the Council would then be in a position to design an effective management plan for the lake and its surrounds.

1.2 Project Purpose

The purpose of the project was to obtain a year's cycle of quantitative information on as many aspects of the use and health of the lake as possible. Since this type of wetland degradation is a world wide problem, it was also expected that a better understanding of the Lake Claremont problem would help other wetlands' managers.

Preliminary data (Lantzke, unpublished) strongly suggested that the underlying problem at Lake Claremont arose from an excess of phosphorus compounds (abbreviated to P hereafter) in the lake, in conjunction with the low summer water levels. (See also Section 2)

The first priority of the project therefore was to determine lake water volume over the seasons, and establish a water budget. The second priority was to determine the P already present in the lake (again over the whole year):- in the sediments; and in the animals and plants. It was also necessary to determine the P flow between these locations, and the amounts entering in drain water; in ground water and as general detritus, as well as amounts of P removed in ground water. (Details are in Section 3 and appendix 8.2). It was hoped that as a result of this, the "feed back" mechanism that normally maintained the lake's P in balance would be identified.

The third priority was to obtain information on the seasonal variations in other plant nutrients; potassium (K); magnesium (Mg); nitrogen (N); sulphur (S, as sulphate SO_4^{2-}) and carbon (as carbonate CO_3^{2-} and bicarbonate HCO_3^-); in minerals capable of interacting with phosphorus;- calcium (Ca) and iron (Fe); and of chemicals influencing aquatic animals:- pH; dissolved oxygen (DO ;O_2); chloride (Cl^-), and salinity (NaCl); (Experimental details in Section 3 and appendix 8.2)

The fourth priority was to monitor lake and land use by ;- aquatic animals; birds; and people. Human use of the lake and its environs past and present is discussed separately in the report by P Gabriel.

1.3 Scope of Project and of Report

1.3.1 The project concentrated on obtaining data related to the phosphorus balance in the lake over the period August 1987 to August 1988. There was no intention, or attempt, to investigate such other issues as potential management options; mechanisms controlling the supply or release of specific minerals; the microbiology of the lake; or other possible lake materials such as heavy metals or other toxic substances. However because the project was co-funded by the Commonwealth Government through a CEP grant there was also a training requirement, and this meant that some stages and processes had to be learned and practised before they could be applied. For this reason new operations had to be phased in gradually, and some important events were missed, such as the determination of the 1987 maximum in bulrush growth. (Fortunately the 1988 data provides sufficiently similar data.)

The point also should be made that this project was a noteworthy first in several ways.

It was, we believe, the first time in WA that a local government authority set out to determine for itself the annual cycle of phosphorus in a wetland. It also constituted the rare, but scientifically better approach to lake management, of acquiring significant quantitites of relevant data, before commencing planning.

Also, by combining a Commonwealth Government training grant (CEP) with the traditional community involvement of academics (Western Australian College of Advanced Education; Claremont Campus), and its own infrastructure the Claremont Council provided both post-graduate experience and training for an environmental scientist, and considerable fundamental data of value to all wetland managers. This shared approach also meant that the Council's portion of the cost was effectively offset by in excess of $14,800, the cost that would have been incurred just for the laboratory chemical analyses done.

This project was only the second time in W.A. that a lake P budget has been calculated, and is the first to systematically make high frequency analyses of inflowing storm water. Previous, related Australian studies are those of R.A. Congdon (1979, 1986); Congdon and McComb (1976) on Lake Joondalup, and Cullen, Rosich and Bek (1979) on Lake Burley Griffin.

It should be borne in mind when interpreting the data obtained, that it applied to the one season 1987-1988, and every season is different.

1.3.2 The report concentrates on issues relating to the P budget and of relevance to lake management. In an attempt to avoid distractions, the full data is only appended (Appendix 8.3), and other aspects of the study will be published subsequently. There is no attempt to propose any particular management plan.

2.0 HOW PERTH'S WETLANDS FUNCTION

In order to understand Lake Claremont better it is desirable to consider the known general characteristics of Perth's unique wetlands.

First is their biological inter-relatedness. The wetland system functions as a whole, the individual lakes complementing one another as water and food sources for mobile animals, and as refugia for aquatic animals and plants. This is possible because they constitute a wide diversity of chemical, physical and biological habitats.

Second is their importance to the whole south west corner of the state. Without them there would be insufficient available water for many biota, nor would food supplies (such as midges or rush seeds) be available at crucial times for others.

(For these reasons it is irresponsible to modify any one wetland without a detailed consideration of its roles in the total system).

There are three sources of water for the metropolitan freshwater lakes, swamps and seasonally damp areas: direct rainfall; runoff from the surrounding basin; and the groundwater. On Perth's permeable sands the groundwater controls the lake level, since surface water rapidly moves down to the water table, and only when this is above ground level does a pool persist. (It is important to recognize, however, that even having the water table close to the surface produces a highly productive location, with species different from those of both free water and dry sand habitats.)

The minerals, and some of the humus, that occur in the wetlands come in small part in the direct rain, in part in the groundwater, and in large part from the runoff. (How much phosphorus [P], and what forms are in runoff, had not been elucidated prior to this work: we now know that a large amount of phosphorus drains from the suburban slopes around Lake Claremont).

In general it has been clear for some years now that the soil around a lake, and the vegetation growing on it, contribute to the chemistry of the lake water. The importance of the drainage basin, and of natural vegetation upon it, in maintaining the health of Perth's lakes, is emphasized by the changes in lakes such as Claremont that are now in urbanized areas.

At present, lakes retaining a broad band of fringing vegetation are in better health than those heavily cleared (Chambers, 1984:1) probably because of the ability of vegetation to intercept and hold phosphorus moving in detritus, run-off, or shallow ground water. Whether this state of affairs will persist over long periods, is unknown.

In a normal (stable) lake there are many checks and balances to maintain its conditions within bounds. In the case of Lake Claremont it was suspected that excess P had overloaded the feedback mechanisms of the lake, resulting in such excess plant growth that the rest of the lake could not handle it.

Phosphorus does not form a volatile compound in natural situations, and there are only limited ways for it to escape from a lake, which in effect acts as a P sink. Phosphorus can only leave in outflowing water - surface or ground, and in small amounts as wind blown aquatic plants and seeds and the bodies of animals that feed in the lake and then migrate, such as midges, mosquitos or dragonflies. The importance of birds for phosphorus removal could not be quantified.

The plants of lakes are specialized to handle the lack of free oxygen in the sediments, and the fluctuations in water level, while using the abundance of water to grow rapidly. The floating plants get their P from the water and are capable of taking up large amounts. But with extra P (fertilizer) there is more growth, and much more plant matter to be dealt with. The rooted plants normally draw their P from the sediments, but many species of reeds will also assimilate large amounts of P from the water column if it is nutrient rich. Most of these plants recycle portion of their phosphorus by withdrawing it from the leaves as they die. Nevertheless the dead leaves, which fall into the water, contain significant amounts of phosphorus, as well as other nutrients. The P leaches rapidly into the water, although there is evidence that over subsequent months leaf detritus accumulates considerable quantities of P, probably through microbial activity. The P in the sediments is historic phosphorus, having come into the lake in the past. In a normal (low P) lake, drawing P from the sediments is a mechanism for using the usually scarce P over and over, but when a lake is overloaded with phosphorus it just helps to perpetuate the problem.

The possible fate of plant matter is either to be eaten (green or dead) or fall to the bottom and rot and possibly contribute to the peat layer. If too much falls to the bottom and rots there is potential for all the oxygen in the region to be consumed, in which case the aquatic animals will suffocate. A lesser problem with excess dead plant matter can be the growth of large populations of detritus feeders such as midge and mosquito. In a natural system this would help to restore balance as they would leave the lake and be mostly eaten by birds and spiders, but in the meantime if houses are built too close, mosquitos and midges will have their well known effects on people. In a well balanced lake the green plant eaters consume much of the plant material, and are themselves in turn eaten by various animals all the way up to the birds. In this way a relatively large amount of P is held in animal tissue.

Another effect of excess P is to change the nitrogen-phosphorus ratio, favouring the blue-green algae against the green alga and the diatoms. Many of the blue-green algae release toxic chemicals, and some are also considered to produce a strong smell akin to that of γ-hexane.

The most important P control mechanism is now considered to be adsorption of P compounds onto the sediments. This adsorption is reversible, so that if more P is added to the water, more adsorbs onto the sediments. If P is removed from the water, some of the adsorbed P is released by the sediments. When the system is in equilibrium for long periods (probably years) some of the adsorbed

P ceases to be available; it can no longer be desorbed, and the sediments can presumably take up more P. This appears to be the natural fate of P in Perth's lakes, but is being overridden by the extra phosphorus entering the lakes.

It is important to note that any action that disturbs the sediments (containing phosphorus from past times) is likely to lead to P re-release, so that dredging may increase a phosphorus problem, at least for a period of years.

The impact of phosphorus in a lake also depends upon its chemical form. The usual operational division of the total phosphorus (Tot. P), is based on its analytic detection as either "reactive" or "non-reactive" forms and largely parallels its biological availability. Reactive phosphorus is orthophosphate (PO_4^{3-} ion and its protonated relatives, HPO_4^{2-}; $H_2PO_4^-$ and H_3PO_4), usually referred to as $P-PO_4$ when the quantities are expressed as weight of phosphorus. This is the form most readily available to plants.

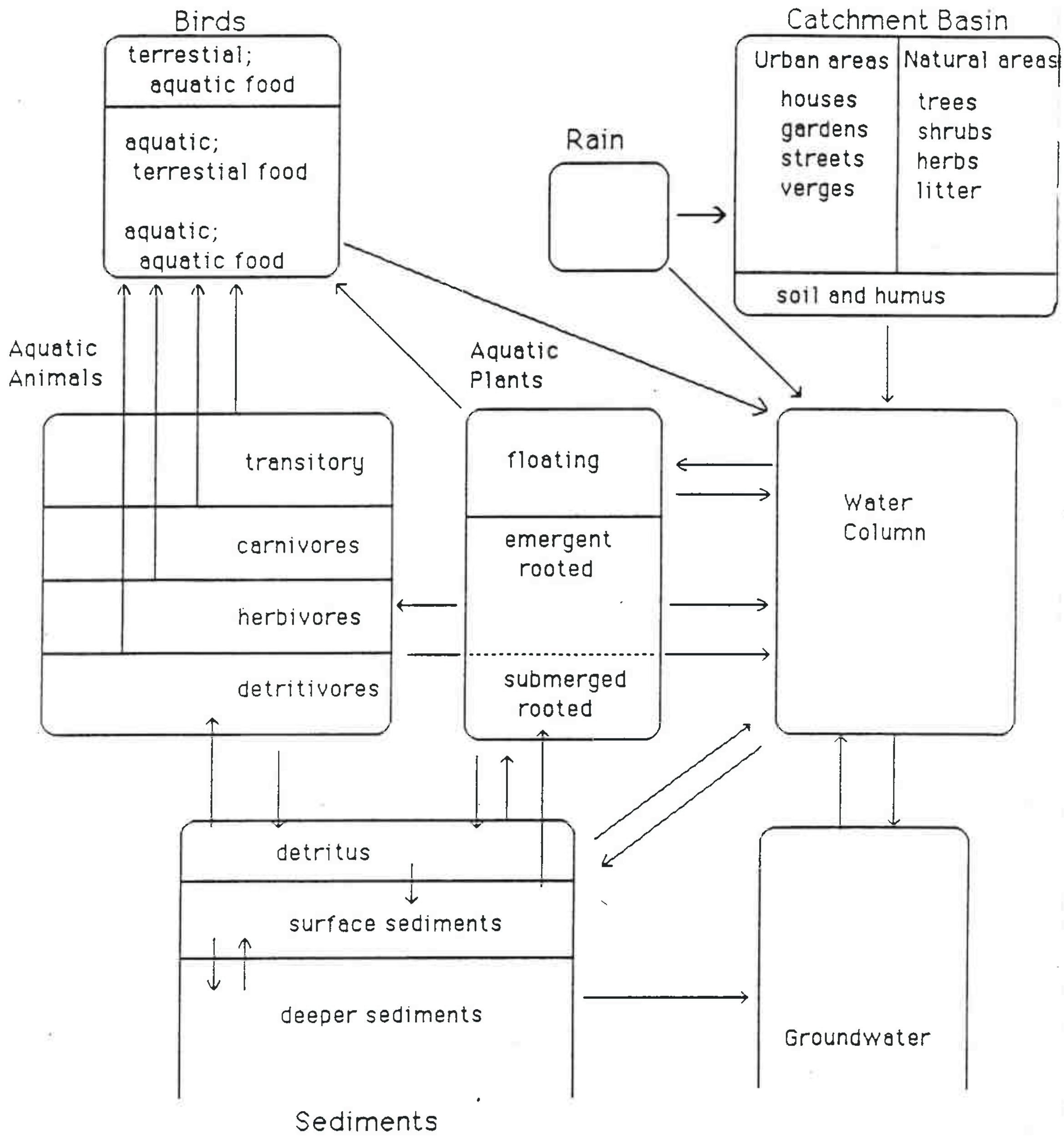
Non-reactive phosphorus (nr P) can consist of either, or both, condensed phosphates (such as the polyphosphates), and phosphorus combined in organic (plant and animal) compounds. In general it is this latter organic phosphorus that is assimilated by animals. The concentrations of the two forms of nr P can be determined separately, but for the primary purpose of this project the time required to do this could not be spared, and total nr P was obtained by difference between Tot. P and $P-PO_4$.

"Natural" supplies of phosphorus are slight, coming from weathered phosphatic rocks; from plant and animal material, and traces in rain. The material may be in the form of PO_4^{3-}; extractable poly - or organic phosphates; or insoluble inorganic or organic compounds. Man can contribute large amounts of PO_4^{3-} in phosphatic fertilizers and rust inhibitors, and various polyphosphates in detergents and water softeners.

For convenience in discussing the P budget of a lake, and to assist in planning for lake management, it is helpful to consider each location of P as a "compartment" as represented in Figure 1.

The basic P budget then becomes the quantities of P in each compartment. However there is a flow of P from one compartment to another and the rates of these flows are also important. (The difference between a slowly released P fertilizer such as blood and bone and a rapid release one like superphosphate is well known by native plant gardeners). This flux of P from one compartment (location) to another makes obtaining accurate data in the field and laboratory very demanding, and also means that the P values obtained at any given instant only apply to that time.

Fig. 1 **Phosphorus Compartments of Lake Claremont**



3.0 HOW THE DATA WERE OBTAINED

The precise methods used for all measurements and analyses are given in Appendix 8.2.

Four lake water monitoring sites and six bird observation positions were selected, and four ground water bores were sunk at the places marked on the map (Figure 2).

The jetty at the south end was used as Site 1 for water and bird observation, as it provided a convenient depth reference point (the NE pylon) and representative conditions in the open waters of the deeper southern arm of the lake. Bore 1, adjacent, was expected to give information on outflowing ground water chemistry.

Bird site 2 gave views of the tree stumps; the young paperbarks (*Melaleuca rhaphiophylla*); and the inner edge of one bulrush (*Typha orientalis*), and one lake club rush (*Schoenoplectus validus*) stand.

Bird site 3 provided views of the bulrush stand on and around the small island as well as of Cresswell Park and much of the bushland.

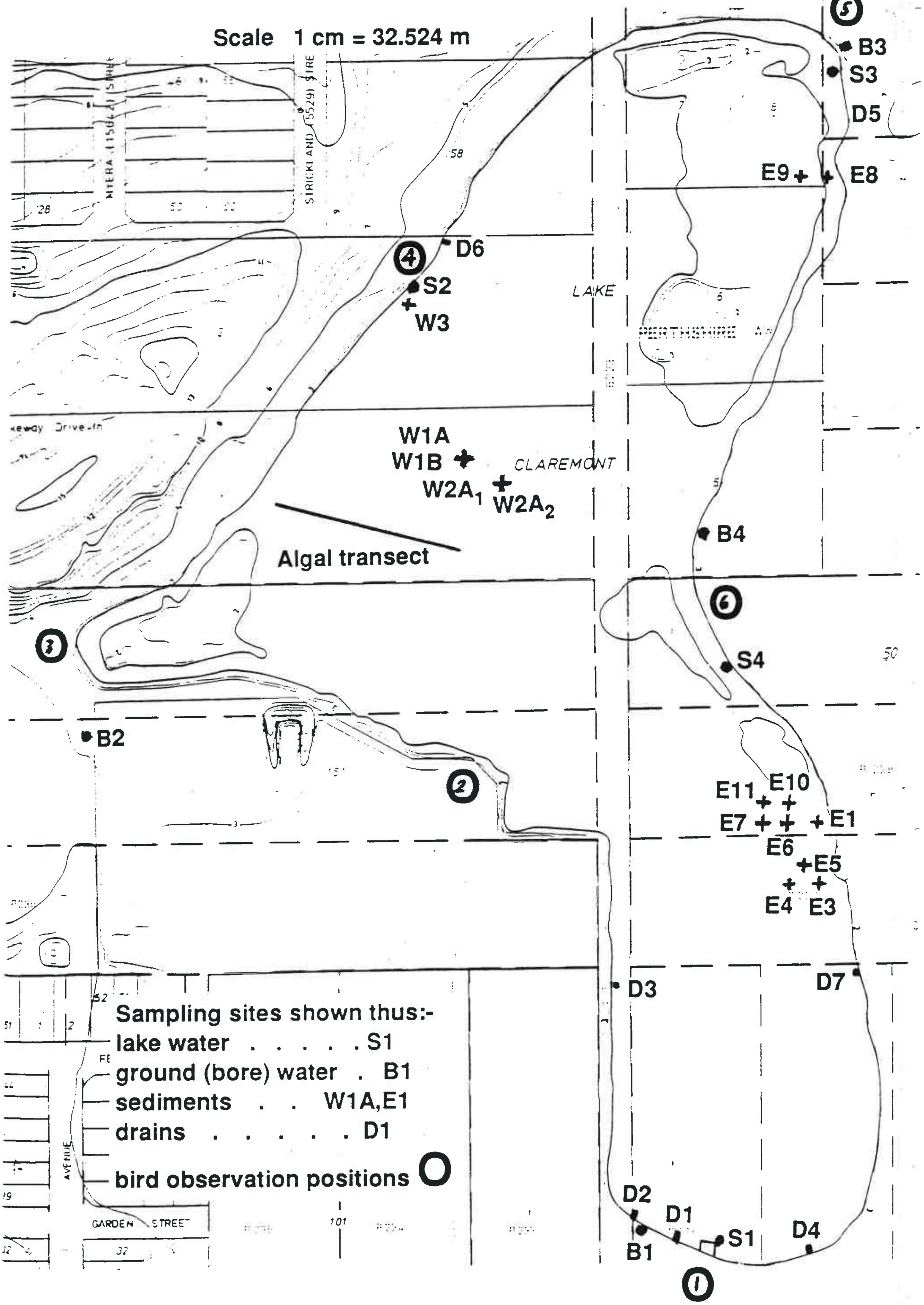
Bore hole 2 was also located near this bay (20m SW of water) as this was the general location of the old lake shore line, and was also expected to indicate the chemistry of water leaving the lake.

Water site 2 and Bird site 4 were on the Western edge, to obtain measurements from the open water of the western arm of the lake.

Water site 3, Bore 3 and Bird site 5 were all in the NE corner to give information on conditions in the "sea" of bulrush, and the effects of groundwater inflow.

Water site 4, Bore 4, and Bird site 6 were on the east side of the lake and were also expected to give information on the effects of groundwater and of reeds.

Figure 2 Map of Lake Claremont.
(Based on map PERTH 2000 BG 34/ 08.22
reproduced by permission of Dept. of Land Administration)



Field work was organized on a 4 week cycle. Every first and third week the lake and bore sites were sampled for water quality. Every second week was spent observing and recording bird and human use of the lake and its surrounds. The fourth week was used for detailed sampling and laboratory processing of plants and sediments.

Lake and bore visits involved measurement of lake water depth, pH, temperature, dissolved oxygen (DO), clarity and conductivity, and collection of two 1 litre water samples. On occasions three samples were taken, one of the surface water and one of bottom water to check for water stratification, and the third for small animals. Bore holes were monitored for water depth, pH and conductivity, and one sample collected. The water used was that already present in the bore. There was not enough time available to pump out each bore and wait for it to refill. We believe the water obtained was sufficiently representative of the surrounding soil water, as measurements showed that P concentrations could change significantly over the two weeks between samplings.

Collected water samples were always analysed within six hours for soluble reactive phosphorus ($P-PO_4$) and total dissolved phosphorus (tot. P), after filtration through 0.45 um filters. Phosphorus present in, or adsorbed on, particulate matter (other than phytoplankton) was not sampled for several reasons.

Firstly the undisturbed water was generally quite clear although brownish coloured, and contained very little particulate matter. (The depth of water to absorb 90% of the incident light at 440nm (blue), 550nm (green) and 660nm (red) were approximately 20cm, 55cm and 100cm respectively, and the absorption coefficient was about $10m^{-1}$ at 440nm (Kirk, 1986)).

Secondly any adsorbed PO_4^{3-} was expected to be in equilibrium with dissolved PO_4^{3-}, so would have contributed to the soluble reactive phosphorus concentration. Thirdly, particulate analyses would have lengthened each analysis time (and cost) by another day, thereby excluding other work judged of higher priority.

On the first sampling session of each cycle the water was also analysed for bicarbonate (HCO_3^-); chloride (Cl^-); sulphate (SO_4^{2-}); calcium (Ca^{2+}) potassium (K^+) and magnesium (Mg^{2+}).

Initially after every sampling session the second lake water sample was analysed for small aquatic animals (water fleas; backswimmers etc) but from November, when the spring flush was thought to be declining, only samples from the first sampling session were analysed.

During the second week of the sampling cycle the Lake Claremont Research Officer spent every morning (0630 to 1015 hours), midday (1130 to 1520 hours) and afternoon (1530 to 1920 hours) systematically observing and recording the aquatic and terrestrial birds and the activities of people at the lake, spending 30 minutes at each site.

To evaluate the significance of the rushes in the cycling of P and other nutrients, these were sampled by randomly selecting 50cm by 50cm squares (quadrats) within the rush beds and collecting all above-ground material in each. These aerial parts were then dried, weighed and analysed in the laboratory. The average weight of plant matter; phosphorus; potassium; and selected trace metals was then calculated per square meter of reeds.

In a similar fashion the floating algae (phytoplankton) found in the lake between 18 February and 12 April (1988) were sampled on four occasions by collecting water and algae in a measured number of collecting tubes 32mm in diameter, and filtering this liquid. In every case a total volume of 1 litre was collected. The algae was dried, weighed and analysed. Pipe sampling was used in order to collect algae resting on the bottom: many blue-green algae are noted for their property of rising or sinking in the water, dependent on conditions.

Samples of sediments were collected from representative sites: Site 2 (sandy); middle of tree stump area (old peat); Site 4 (young *Typha* peat) and in the stand of lake club rush south of Site 4 (young *Schoenoplectus* peat), air dried, then analysed for total P. The ability of these sediments to take up phosphate (PO_4^{3-}) was then determined by shaking 2.0g of sediment with 50ml of known concentration phosphate solution, and after 3 days measuring the PO_4^{3-} left in solution. A series of phosphate adsorption isotherms were then calculated using the Freundlich isotherm:

$$x = k\,c^{1/n} \qquad \text{E 3.1}$$

where x = quantity of P (mg), adsorbed per gram (dry weight) of sediment

c = equilibrium solution concentration of $P\text{-}PO_4$(ppm)

k is a constant, and indicates adsorbent capacity

and $^{1/}n$ is a constant, related to the intensity of adsorption

The Freundlich isotherm was used, as in preliminary trials on Herdsman Lake peats, this provided a reasonable fit for results (Lantzke, unpublished).

From March to June (1988) all other work was rescheduled, as necessary, to fit in measurements on storm water entering the lake. Estimates of the volume of water entering the lake through storm drains were made, and the quantities of phosphorus and chloride it carried were measured. Entry flow rate was estimated from the time it took to fill a container of known volume, except on 24/6/88 when flow rate was calculated from Manning's formula

(Gerhart and Gross, 1985 and Section 8.2), and the concentrations of P and chloride measured on samples collected at regular intervals. Total quantities were calculated by summing quantities calculated for successive 5 minute intervals.

TABLE 1A

Lake areas and relative depths used in all calculations

Description	Area (m^2)		Depths relative to SE post of jetty (cm)
SE post of jetty	-		17
South arm, deep pool	7,600		50
" " shallower	25,580		25
" " west edge	1,360		17
North east middle including Site 4 (and consists of 60% rushes)	7,860		25
total (south section)		42,400	
West arm, main area	65,650		23
" " , mound	400		18
Road, most	8,520		0
" , deep	2,490		19
total (west section)		76,060	
North east, less Site 3 (Consisting of 100% rushes)	12,010		8
Site 3	2,420		20
total (N E section)		14,430	

Total wet areas 132890 (+ 800) m^2

"Islands"			
West			3,750
South	1,100		
Middle	1,900		
North	17,360		
Total islands		24,110	

Total lake area 157,000 (+ 1500) m^2

TABLE 1B

Rush areas

All bulrush *Typha orientalis* (including on islands)	14,000m^2
All lake club rush (*Schoenoplectus validus*) (including outcrops in *Typha*)	1,820m^2

4.0 RESULTS AND DISCUSSION

The primary data collected during the project is collected in Appendixes 8.3 and 8.4 inclusive. Appendix 8.5 is the work of Mr and Mrs D Clifton, Honorary Lake Wardens, and is included with their permission.

4.1 Lake Morphology and Hydrology (The Water Balance)

4.1.1 Lake Water Volumes

Based on the Perth 2000 BG 34/08/22 map of Lake Claremont, and field measurements of spot depths and vegetation distribution, the lake was divided into 10 "wet" sections each of approximately the same depth. The area of each section determined by the grid method (grouped for reasons described below) is presented in Table 1A. The total rush areas are given in Table 1B.

Because fertilized grass adjacent to lakes is a potential source of nutrients (Section 4.2.4; Dames and Moore, 1987) it is pertinent to note that previous lake filling has reduced the "wet" areas from 20 ha. (Evans and Sherlock, 1950) to 15.7 ha, replacing them with flat, grassed regions around much of the perimeter. The filling has also left the lake with unnaturally steep sides.

Our examination of the chemical parameters of the lake (Sections 4.1.2 and 4.2; Appendix 8.3) suggested that the lake's functioning can be approximated to that of four adjacent wetlands, and the 10 sections could be grouped into the following four segments: Open water on the west of the old Shenton Road; Open water south of the central block of rush and paperbarks; and two smaller and shallower rush filled areas; the NE and the central east. When the water covering the old Shenton Road fell below about 15cm it acted as the dividing line between the two open water areas, but with deeper water, both segments were chemically similar. The chemistry of the NE segment was largely controlled by inflowing ground water, while in the remainder of the rush area, water chemistry was very variable.

4.1.2 Water Balance

In order to calculate the water volume and its associated phosphorus load it was necessary to calculate the volume of water in each of the ten sections using the depths measured on each occasion, and then sum the volumes. The results are collected in Table 2.

The upper portion of this table records for every sampling date a reference water depth and calculated water volume for each of the three distinct areas: - the southern portion (S), including the more southerly rushes; the open western section (W); and the north east rush filled area (NE). The total is also given. This is followed by the chloride ion concentrations and quantities in each section, and its total mass. The lower portion tabulates the water volume changes over the intervals between consecutive sampling days. The volumes calculated correspond to the terms in equation E4.1, with the final value a figure for the net groundwater flow [GW]. N.B. the numbers recorded in Table 2 are those used in subsequent calculations and are not rounded to the level of their accuracy.

We have used the bottom of the NE jetty post as a practical reference level, to enable subsequent monitoring of lake levels (and hence volumes) by any interested townsperson.

The calculated water volumes show a regular sequence, dropping from a maximum of approximately 110,000m^3 in July and August (1987), to a mere 1,400m^3 in March, at the time of the bird deaths, then rising again to about 120,000m^3 in August (1988).

The mass of chloride ion was calculated to check on the accuracy of the calculated water volumes. Chloride was chosen as it is a conservative ion - that is it remains in free solution until salts begin to crystalize. For this reason it is both a useful natural tracer, and indicator of calculated water volume anomalies, since the total amount of chloride ion in the lake should be reasonably constant until the water level falls far enough for crystalization of salts to occur (such as on beach and mud flats, and in pools).

An examination of the calculated quantities of chloride ion, in Table 2, shows that in July and August 1987, and again in August 1988 there were just over 70 tonnes of chloride in the water column. By 9 November 1987 when a beach started to appear at Site 2 the lake water level was about 33 cm lower than on 9 August 1988; the calculated total water volume was down 34% on that of the earlier date but the chloride ion quantity was down only 12%, strongly suggesting the estimated water volumes are not too far from the mark. Similar calculations using total dissolved salts (from conductivity measurements), give a closely similar figure (13%) over the same period.

As discussed below, the near constancy of the total chloride load is in part fortuitous, as more chloride flows out in groundwater than in from that source but at times the storm water run off is comparatively high in chloride (and other mineral salts, Section 4.4)

As a further check on the validity and reliability of the water volume calculations, and hence on the phosphorus budget, it is desirable to attempt to balance the quantities of water in the inflow and outflow of the lake. In Table 2 are the necessary figures, except for ground water. The table contains the calculated volumes of water added by direct rainfall on the lake [Pp]; the estimates of drain water inflow ([S_i] See Section 4.3); and an estimate of the volumes of water lost by evaporation [E]. These latter were calculated from the Perth Regional Meteorological Office monthly evaporation figures, corrected with the pan factors of R. Black, quoted and used by Congdon (1979) for Lake Joondalup. The same pan factor was used for all wet areas, regardless of any rush cover, since comparisons of open water evaporation with emergent macrophyte evapotranspiration do not show a consistent difference between the two situations, e.g. Linacre et al (1970); Snyder and Boyd (1987). By comparison the Perth Urban Water Balance Study (Cargeeg et al, 1987:1) used a fixed pan factor of 0.9 for open water, and for grass evapotranspiration a factor of 0.7, decreased by appropriate proportions for reduced plant cover or soil wetness.

TABLE 2

LAKE CLAREMONT WATER BUDGET 18.8.87 to 27/10/87 (SEE TEXT)

	18/8/87	24/8/87	3/9/87	15/9/87	29/9/87	13/10/87	27/10/87
Depth-post (cm)	76	78	78	75	74	65	61
Vol. (m^3) S	37,407	38,256	38,256	36,983	36,559	32,743	31,047
W	68,337	70,098	70,098	67,456	66,575	58,610	55,126
NE	1,912	1,960	1,960	1,888	1,863	1,646	1,549
Total (m^3)	107,656	110,314	110,314	106,327	104,997	92,999	87,722
Chloride S (mg/L)	600	700	–	–	650	650	–
(t)	22.4	26.78			23.76	21.28	
W (mg/L)	560	610	–	–	700	730	–
(t)	38.3	42.76			46.60	42.79	
NE(mg/L)	–	300	–	–	380	455	–
(t)	–	0.59			0.71	0.75	
Total (t)		70.13			71.07	64.82	
Rain (mm)		20	14	0	43	7.2	3
Rain vol (m^3) [P]*		3,140	2,198	0	6,751	1,130	471
Drain Vol (m^3) [S_i]*		1,780	1,250	0	3,837	642	268
Tot. added H_2O (m^3)		4,920	3,450	0	10,590	1,770	739
Wet area (m^2)		132,900	132,900	132,900	132,900	132,900	132,900
Evap. pan factor		0.9	0.9	0.9	0.9	0.8	0.8
Evap. pan (mm)		15.8	25.6	46.2	55.2	66.6	70.2
Evap Total (m^3) [E]*		1,890	3,062	5,526	6,602	7,081	7,464
Surface diff. (m^3)		+ 3,030	+ 390	– 5,530	+ 3,990	– 5,310	– 6,730
Lake vol. change (m^3) [S]*		+ 2,660	0	– 3,990	– 1,330	–12,000	– 5,280
Net Groundwater contrib (m^3) [GW]*		– 370	– 390	+ 1,540	– 5,320	– 6,690	+ 1,450

* Terms in Eqn E4.1

TABLE 2 (CONTINUED)

LAKE CLAREMONT WATER BUDGET 9/11/87 to 20/1/88 (SEE TEXT)

	9/11/87	24/11/87	8/12/87	21/12/87	4/1/88	20/1/88
Depth-post (cm)	54.5	43	34	24	21	6
Vol. (m^3) S	28,240	23,719	19,599	15,359	14,086	7,827
W	49,803	39,274	31,347	22,540	19,898	7,985
NE	1,406	1,113	895	ea. 650	2.4	0.9
Total (m^3)	79,447	64,106	51,841	38,550	33,989	15,813
Chloride S (mg/L)	800	-	1,875	-	1,600	-
(t)	22.59		36.75		22.54	
W (mg/L)	790	-	1,900	-	2,900	
(t)	39.34		59.56		57.70	
NE(mg/L)	285	-	625	-	240	
(t)	0.40		0.56		0.58	
Total (t)	62.33		96.87		80.82	
Rain (mm)	18.8	8.4	18	0	8.6	2.4
Rain vol (m^3) [P]*	2,952	1,319	2,826	0	1,350	377
Drain Vol (m^3) [S_i]*	1,677	749	1,606	0	767	214
Tot. added H_2O (m^3)	4,629	2,068	4,432	0	2,117	591
Wet area (m^2)	132,900	132,900	132,900	132,000	130,00	110,00
Evap. pan factor	0.8	0.8	0.8	0.7	0.7	0.6
Evap. pan (mm)	73.8	85.6	97.2	94.4	94.2	109.2
Evap Total (m^3) [E]*	7,846	9,101	10,334	8,782	8,572	7,207
Surface diff. (m^3)	- 3,220	- 7,030	- 5,900	- 8,780	- 6,460	- 6,620
Lake vol. change (m^3) [S]*	- 8,280	-15,340	-13,290	-13,290	- 4,560	-18,180
Net Groundwater contrib (m^3) [GW]*	- 5,060	- 8,310	- 7,390	- 4,510	+ 1,890	-11,560

* Terms in Eqn E4.1

TABLE 2 (CONTINUED)

LAKE CLAREMONT WATER BUDGET 8.2.88 to 26.4.88 (SEE TEXT)

			8/2/88	22/2/88	9/3/88	23/3/88	12/4/88	26/4/88
Depth-post	(cm)		-8	-11	-14.5	-14	-14	-13
Vol (m^3)	S		1,900	1,672	1,368	1,444	1,444	1,520
(m^3)	W		0	0	0	0	0	0
	NE		0.8	0.8	0.8	0.75	0.7	0.4
Total	(m^3)		1,901	1,673	1,369	1,445	1,445	1,520
Chloride:	S (mg/L)		4,600	-	10,000	-	5,750	-
	(t)		8.74		13.7		8.3	
	W (mg/L)		0					
	(t)							
	NE(mg/L)		825	-	10,000?	-	620	
	(t)		0		?		0	
Total	(t)		8.7	-		-	8.3	-
Rain	(mm)		0	0	0	2	16	6.4
Rain vol	(m^3)	[P]*	0	0	0	314	2,512	1,005
Drain Vol	(m^3)	[S_i]*	0	0	0	178	1,427	571
Total added H_2O(m^3)			0	0	0	492	3,939	1,576
Wet area	(m^2)		7,610	7,610	7,610	7,610	7,610	7,610
Evap. pan factor			0.6	0.6	0.6	0.7	0.9	0.9
Evap. pan	(mm)		161.4	133.2	104.6	110.2	156.8	54.0
Evap Total	(m^3)		737	608	478	587	1,074	370
Surface diff.	(m^3)		-740	-610	-480	-100	+2,870	+1,210
Lake vol. change	(m^3)	[S]*	-13,910	-230	-300	+80	0	+80
Net Groundwater contrib	(m^3)	[GW]*	-13,180	+380	+180	+180	-2,870	-1,130

* Terms in Eqn E4.1

TABLE 2 (CONTINUED)

LAKE CLAREMONT WATER BUDGET 10.5.88 to 9.9.88 (SEE TEXT)

	10/5/88	23/5/88	8/6/88	21/6/88	18/8/88	9/9/88
Depth-post (cm)	-5.5	16	31	40	83.8	87.4
Vol: (m^3) S	2,052	11,967	14,471	22,142	40,799	41,033
(m^3) W	512	15,605	17,917	36,341	75,382	78,024
NE	157	460	486	1041	2,105	2,178
Total (m^3)	2,721	28,032	32,874	59,524	118,286	121,235
Chloride S (mg/L)	5,400	-	1,400	-	604	590
(t)	11.1		20.30		24.64	24.21
W (mg/L)			1,600	-	604	590
(t)			28.67		45.53	46.03
NE(mg/L)	280	-	100	-		300
(t)	0.04		0.05		0.5	0.65
Total (t)	11.1	-	49.02		70.67	70.89
Rain (mm)	47	129.8	89.8	84.2	290.6	25
Rain vol (m^3) [P]*	7,379	20,379	14,099	13,219	45,624	3,925
Drain Vol (m^3) [S_i]*	4,192	11,507	8,010	7,511	25,922	2,230
Total added H_2O(m^3)	11,571	31,886	22,109	20,730	71,546	6,155
Wet area (m^2)	40,000	113,000	132,900	132,900	132,000	132,900
Evap. pan factor	1.0	1.0	1.0	1.0	1.0	0.9
Evap. pan (mm)	31.2	32.6	20.4	31.2	102	60.1
Evap Total (m^3)	237	1,304	2,711	4,146	13,556	7,189
Surface diff. (m^3)	+11,330	+30,580	+19,400	+16,580	+57,990	- 1,030
Lake vol. change (m^3) [S]*	+ 1,200	+25,310	+ 4,840	+26,650	+58,762	+ 2,950
Net Groundwater contrib (m^3) [GW]	-10,130	- 5,270	-14,560	+10,070	+ 770	+ 3,980

* Terms in Eqn E4.1

The direct rainfall and the run-off (Section 4.3) were calculated using the Floreat station rainfall data.

We did not attempt to measure directly the inflow and outflow of ground water, because of its experimental difficulty.

However in theory the net effect of groundwater flow can be obtained from a hydrologic budget equation such as E4.1

$$S = S_i + Pp - E \pm GW \quad \text{.............. E 4.1}$$

where S = change in volume of surface water storage

S_i = volume of water from surface inflow,

Pp = volume of water from direct precipitation

E = volume of water evaporated,

GW = net volume of ground water $\pm$ indicating net inflow or net outflow.

all for the period under consideration.

An examination of the results in Table 2 shows that there is a general trend in the net groundwater figures, but there are several quite large fluctuations.

The trend is that in autumn and again in late winter (when the regional water table is rising) there is a net ground water contribution to the lake. The rest of the time the lake provides recharge to the groundwater, except for the intermittent fluctuations. Over the year the net balance shows 76,000m^3 water flowing out of the lake into ground water. This is equal to about 60% of the lake's maximum observed volume.

So large a volume, taken in conjunction with the irregular reversals in the direction of groundwater flow, lead us to suspect that the errors inherent in all the data, are quite significant, and to some extent obscure the true picture. There are a number of sources of uncertainty, discussed below, but how they concatenate is not clear to us.

The uncertainties were ± 1% overall in area (but slightly larger for some individual sections) and up to ± 20% in water volume at low water levels, decreasing to about ± 10% when the lake was full. Most of this uncertainty arose from assuming vertical edges at each contour line, rather than sloping surfaces.

Precipitation uncertainties are hard to estimate because of the distance between rain gauging stations and the patchy way Perth's rain can be distributed. A comparison of the Floreat and Perth station results, over the twelve months in question, shows Perth (878.6mm) receiving 4.6% more precipitation than Floreat (840.0mm) but this difference arises largely from their different distances from the coast, so we guess that Lake Claremont rainfall was within 1% of Floreat station rainfall over the year.

Run-off figures are much more uncertain (Section 4.3), as there is at least 10-20% uncertainty in the proportion of any rain fall that actually flowed to the lake. Because of the relatively small volume of water involved the error in its determination is a much smaller percentage error in determining the water budget. It is a more significant uncertainty in determining the phosphorus budget.

Overestimation of the quantity of water lost by evaporation and evapotranspiration will depend to some extent on the season, since the rushes usually go through a full growth cycle in twelve months. Also they are not inundated at lower water levels, while in winter evaporation is less. If in late November, when the open water pan factor is 0.8, the rushes have the same evapotranspiration as grass (0.7, Cargeeg et al, 1987:) then the percentage overestimation is given by the value of:-

$$\frac{(\text{Open pan fact.} - \text{rush pan fact.}) \times \text{rush area} \times \text{evaporation} \times 100}{\text{total evaporative area}}$$

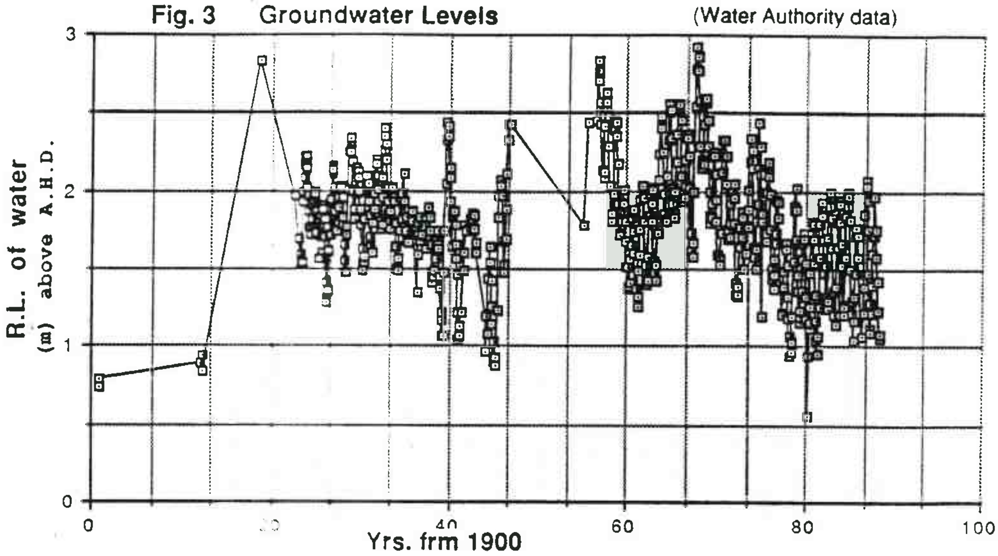
which has the value of about 1%.

4.1.3 Ground Water Contributions

Although the quantities of groundwater entering and leaving could not be determined, the importance of this water in maintaining the lake's water level is clear. For although the lake may act overall as a recharge site for the groundwater, if the level of the latter fell, so too would the lake level.

The most significant evidence for this lies in the correlation of lake levels with ground water levels. These latter, using Water Authority records for this century are, shown in Fig 3.

Fig. 3 Groundwater Levels (Water Authority data)



It is clear that before the lake flooded in 1918-1920 (Evans and Sherlock, 1950) the ground water levels were lower; that during the period when the lake held water all year, the ground water level did not fall below 1.5m (A.H.D); and that in recent years there has been a decline in the average ground water level, with summer levels below 1.0m (A.H.D) corresponding with (late summer) drying out of the lake.

Other evidence for groundwater in-flow in the NE region of the lake lies in the predominantly lower mineral concentrations measured at Site 3, shown in Fig 4 (where Site 3 and Site 1 salinity and chlorinities are compared) and the similarity of Site 3 and the nearby Bore 3 mineral concentrations, shown in Fig 5.

(The single large SO_4^{2-} concentration at Site 3, on 9/3/88, is interesting as we cannot explain it. On that day the lake contained the smallest water volume measure during the year, and a large number of minerals were at much greater concentrations than two weeks earlier. It was also the time of the water bird deaths. However Site 3 was separated from the main lake and although P, Cl^-, HCO_3^-, Mg^{2+}, and pH were all high, so too was DO, so that anaerobic bacterial formation of SO_4^{2-} seems unlikely. Consistent with the high sulphate concentrations the Ca^{2+} concentration had fallen 300%).

Fig. 4 Chlorinity and TDS at Sites 1 and 3

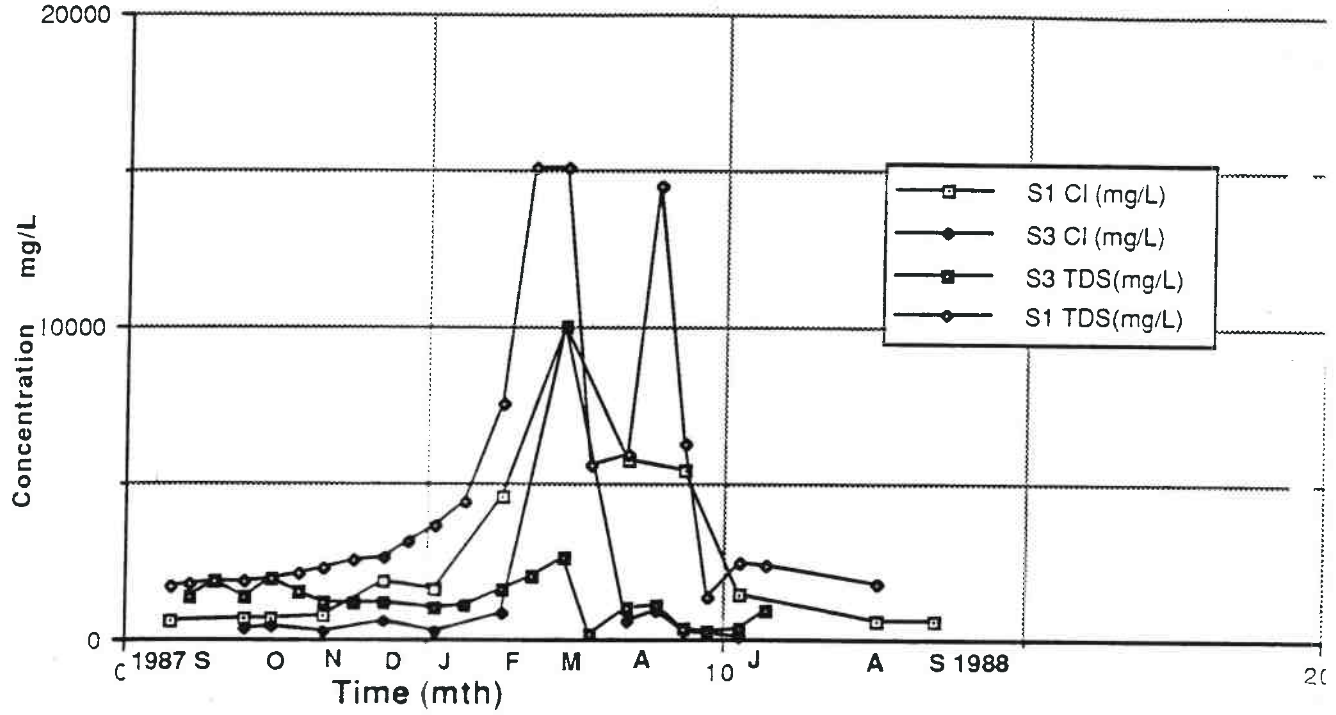
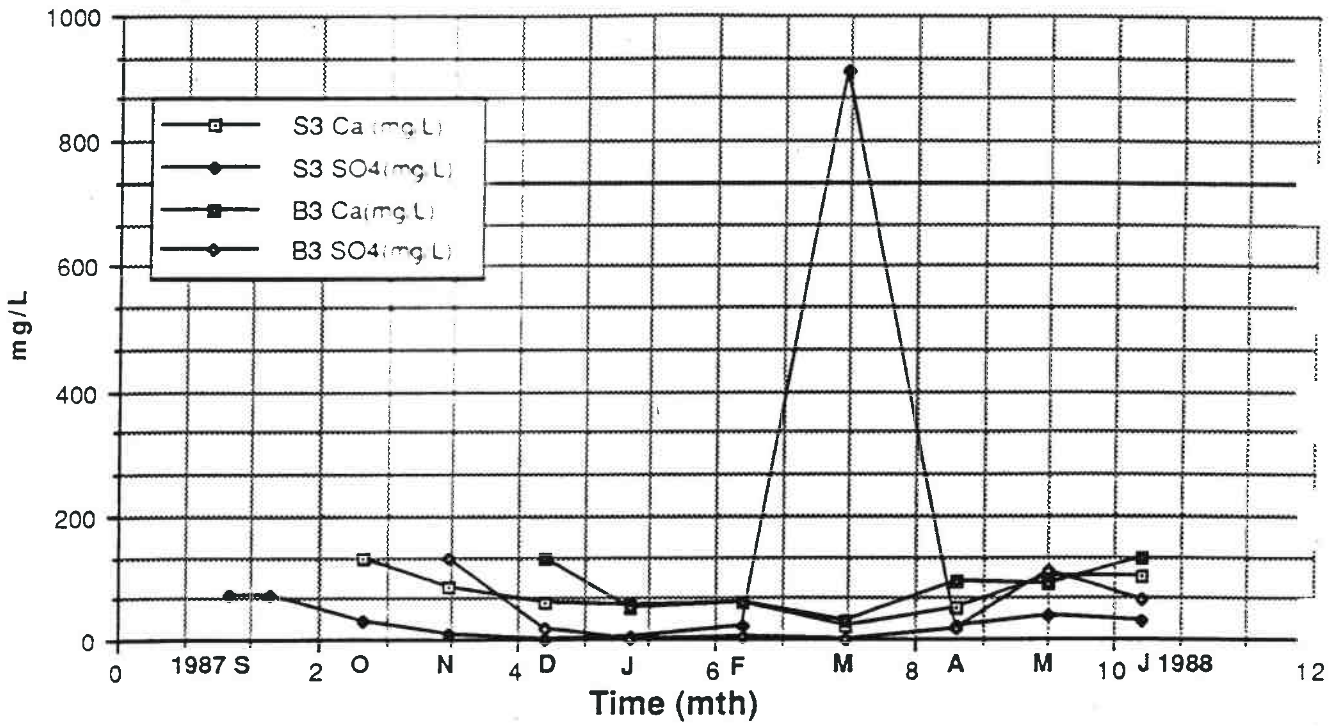
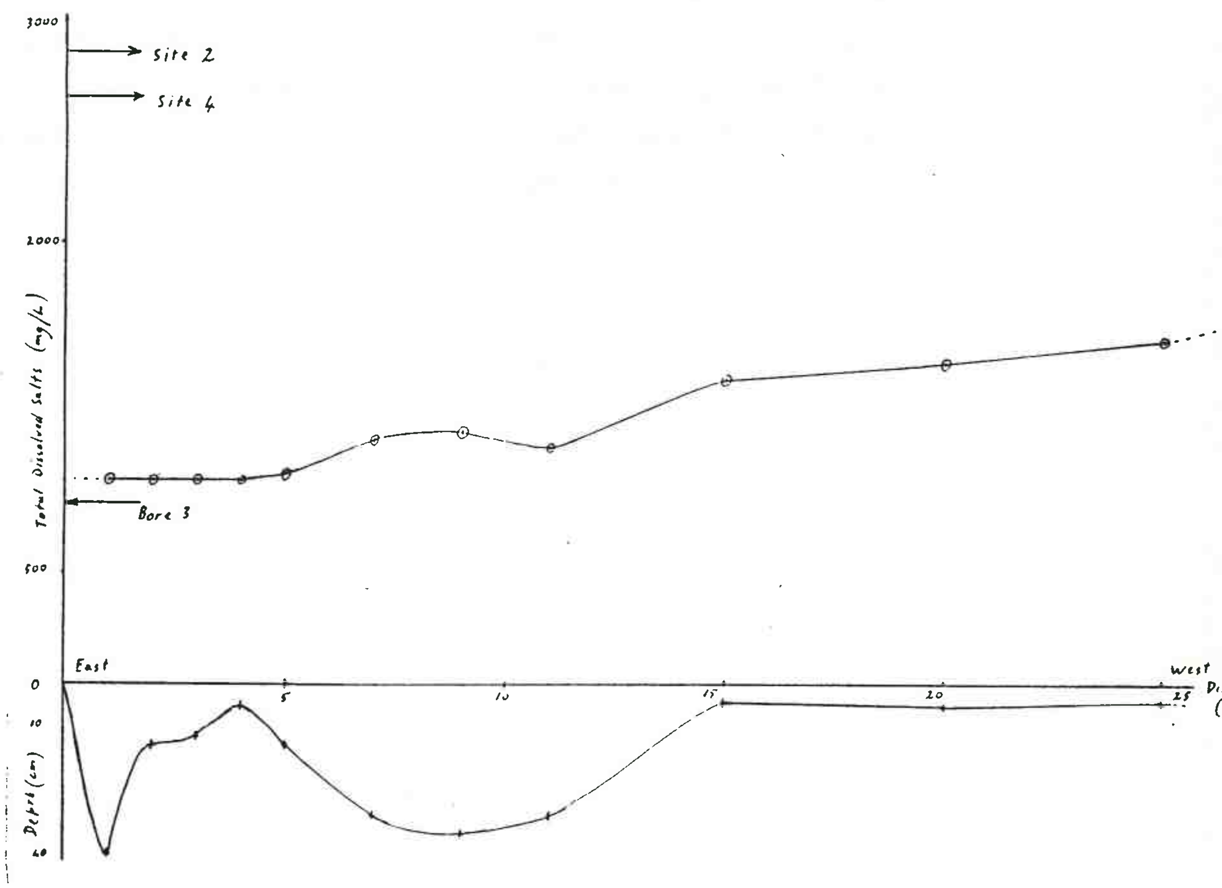


Fig. 5 Ca and SO4 Concentrations at Site 3, Bore 3



There were also long lasting salinity gradients in the NE section of the lake which we attribute to inflowing ground water. The salinity measured along a transect perpendicular to the bank at Site 3, on 21/6/88, is shown in Fig 6. This shows a pool of low salinity water (TDS = 920mg/L) adjacent to the NE bank, mixing only slowly in the shallow rush area with the more saline bulk lake water. On that date the salinity (TDS) of Bore 3 was 820mg/L, while the values at Sites 2 and 3 were 2,860mg/L and 2,655mg/L respectively.

Figure 6 Salinity gradient (top), and Lake profile (bottom), at Site 3 on 21.6.88.

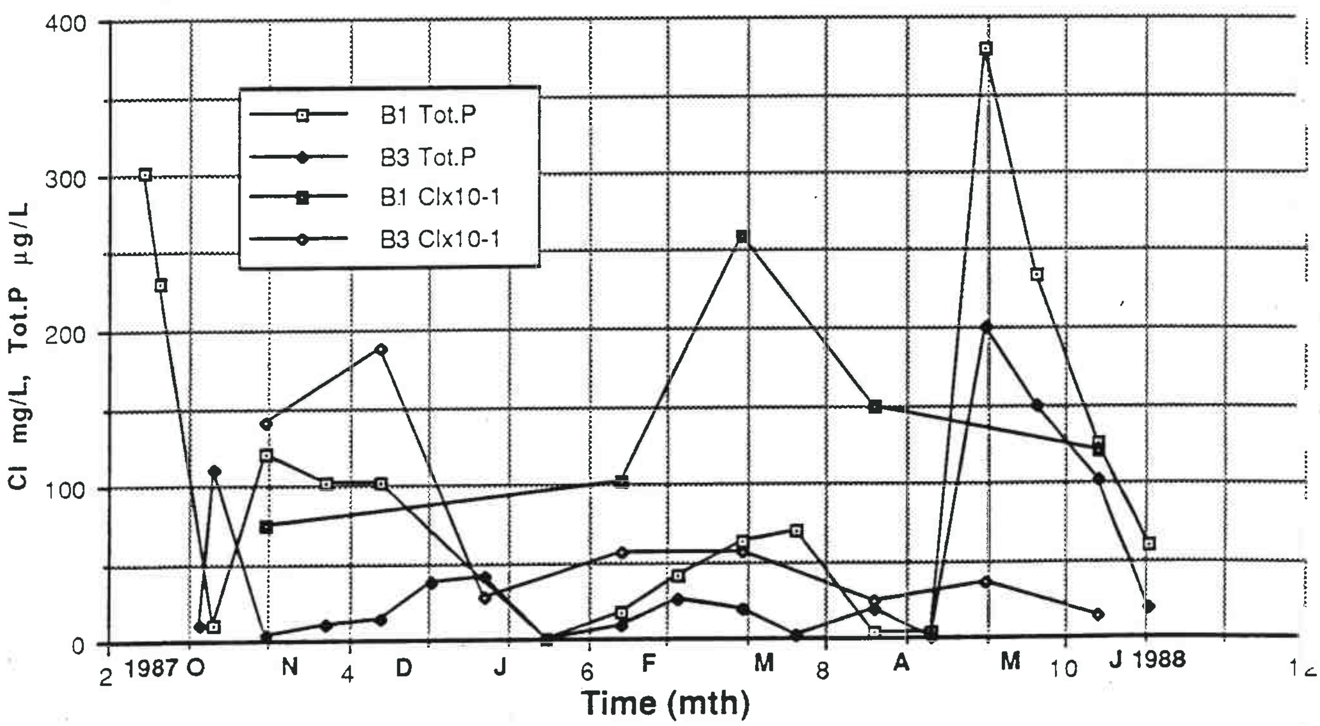


The stability of such a chemocline around a spring in a densely reeded area is not surprising, as wind and thermal mixing are greatly inhibited by reeds. One of us, (IRL) measured a similar situation at Lake Jandabup before ground water extraction lowered the water level beyond the "reeds".

The persisting low salinity water along the NE of Lake Claremont is better explained as inflowing ground water than as rain water run off, because the latter only arrived spasmodically; the chemocline lasted for weeks; and the storm water, although relatively low in dissolved salts (Section 4.3) was frequently high in $P-PO_4$ whereas Site 3 was relatively low in $P-PO_4$ except after the storm of 23/3/88. (The high value on 9/3/88 is discussed in Section 4.2.1).

Groundwater outflow is also occurring since the chlorinity (and some other mineral concentrations) in Bore 1 are clearly greater than those in Bore 3 (Fig 7, Fig 13 and Appendix 8.3). The initial high chloride concentration in Bore 3 is considered to be an artifact from its construction). This direction of flow is to be expected from the published groundwater contours of the Gnangara Mound (Allen, 1976, 1981; Water Authority of Western Australia, 1986).

Fig. 7 Chloride and Tot.P concentrations , Bores 1 & 3



Order of magnitude calculations of groundwater inflow and outflow, based on the Darcy equation are possible, using as values of aquifer hydraulic conductivity those given by Cargeeg et al (1987:2); estimates of the area of the lake sides and bottom through which inflow and out-flow occur; and an aquifer base of ca. 12m. (At the time when the NE side of the lake was being filled with rubbish, solid limestone was reached at 10-12m W. Koreman pers. comm.)

However as the tot. P concentrations in Bores 1 and 3 (outflow and inflow respectively), are not known for the months when water levels were highest (and ground water flow-through greatest) and the difference between them at other times averages to a comparatively small value, the difference between the quantity of P imported and exported in groundwater, although important, will be less than the combined uncertainties in all the estimates used.

In view of the salt added to the lake by run-off and rainfall, the flushing away of salt in groundwater is also important, since without it, or additional human intervention, the lake would slowly become more saline. (Even at its freshest (approximately 1,500 ppm in salt) the lake water is too saline for most exotic fruit, vegetable or ornamental plants. By the beginning of January, Site 1 water (TDS 3,500 ppm) was too saline for most grasses, with only seashore paspalum (Paspalum vaginatum) and salt water couch (Sporobolus virginicus) likely to tolerate sprinkler irrigation by it (Malcolm and Smith, 1971)).

This has implications for lake rehabilitation as it restricts phosphorus removal, by irrigating the golf course grasses with lake water, to spring and early summer. It also imposes more corrosive conditions on metal pumps, etc used with the lake water.

4.2 Mass of Phosphorus in the Water Column

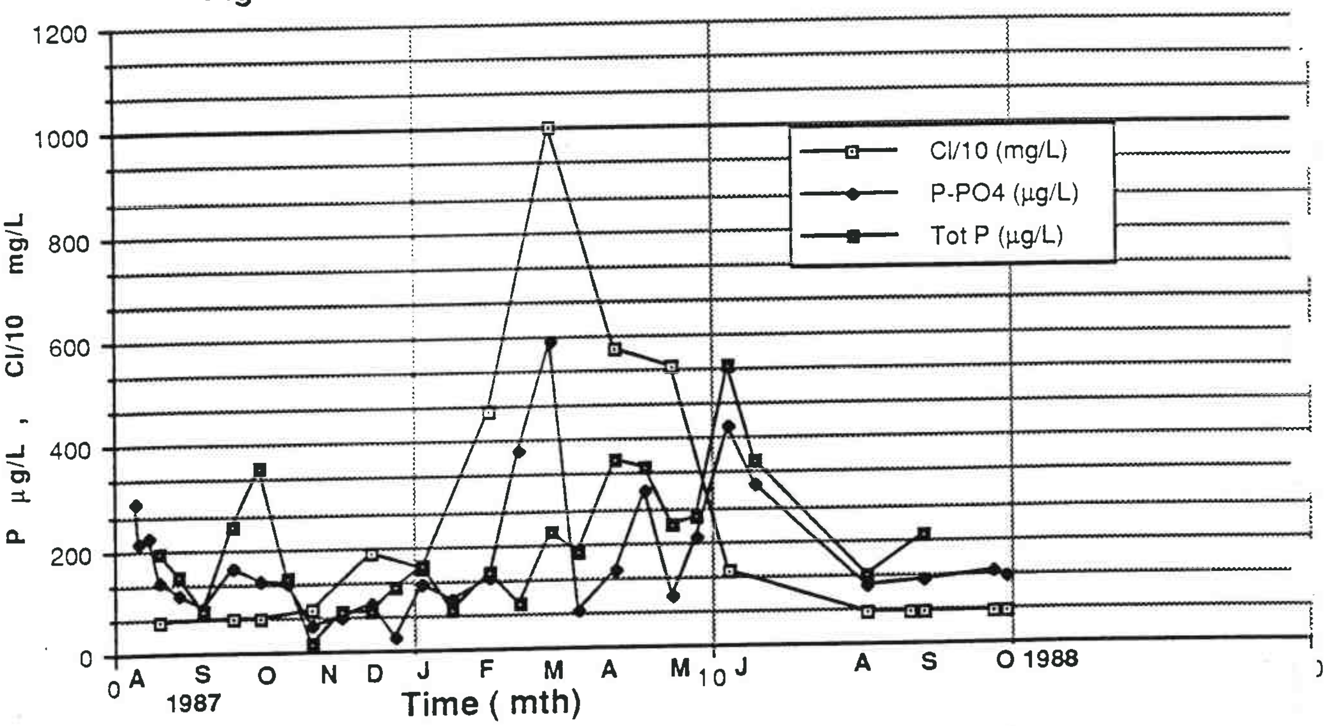
In considering the quantity of phosphorus in the lake, it is important to distinguish between concentration (quantity per unit volume), and total amount in the lake, or standing stock. Concentration is what we measured. Concentrations will determine if chemical reactions will or will not occur, and concentrations are what matter for plants, which all have a lower limit on their ability to abstract phosphorus from solution.

But as will be seen in Section 4.2.4 it is the calculated total mass of phosphorus in the lake which gives more information on what is actually happening, since the dynamic changes that tend to maintain concentrations constant are exposed. It is also the total mass which shows how much P must be "inactivated" to reduce concentrations to a desired level.

4.2.1 Seasonal Variations in Phosphorus Concentrations

Figures 8, 10, 11 and 12 show the measured concentrations of reactive phosphorous ($P-PO_4$); total phosphorus (tot. P) and chloride (Cl^-), at Sites 1, 2, 3 and 4 respectively, during the period 1 August 1987 to August 1988.

Fig. 8 P and Cl concentrations, Site 1

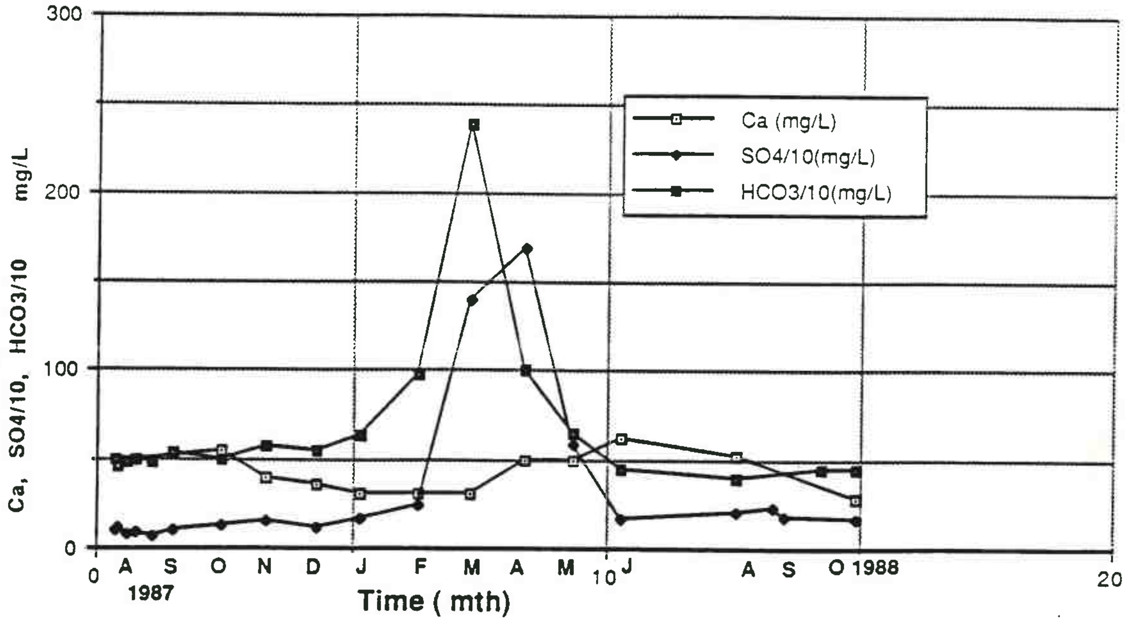


At Site 1 (the jetty) the chloride ion concentration (also termed chlorinity) increased after October to a maximum of 10,000 mg/L (ie 10g/L) in March, and then with the onset of winter rain decreased again to about 600 mg/L in August; in all a 17 fold difference between the extremes. The measured $P-PO_4$ also peaked in March, but was also high in April and June, whereas tot. P was high in October, April and June. The March $P-PO_4$ figures are though to be spurious because they greatly exceed the tot. P present.

(Total P analysis has greater potential for low results because it includes a high temperature digestion, but $P-PO_4$ determinations are elevated by humic acids in the water. In the straightforward analytic methods used in this project, no precaution was taken to eliminate humic acids, although with hindsight interfering quantities should have been anticipated in late summer, if only because of the colour of the water at that time. We therefore think humic acids the most likely cause of the discrepent results.)

Excluding the spurious $P-PO_4$ results there was an 8 fold range in $P-PO_4$ concentrations, and nr P varied between less than detectable (ca 4µg/L) and 250µg/L, a 60+ fold concentration change. These changes could be rapid, especially for the more labile $P-PO_4$, with fluctuations by as much as 100% in two weeks. By contrast, chlorinity, and most other mineral concentrations (such as calcium; sulphate; or bicarbonate; Fig 9) changed much more slowly. This dynamic flux of phosphorus is discussed in Section 4.2.4.

Fig. 9 Ca, SO4, & HCO3 concentrations at Site 1



At Site 2 (Fig 10) in October and June there were concentration peaks in $P-PO_4$ and tot. P of similar magnitude as at Site 1, and an additional peak in January, when that section of the lake was drying up. There were also anomolously high "$P-PO_4$" analyses in November and December, again attributed to high humic acid concentrations.

Site 4 (Fig 12) phosphorus concentrations peaked in October, but when allowance is made for spurious $P-PO_4$ analyses, the concentrations in November, just before it dried up, were similar to the contemporaneous values at Sites 1 and 2; not elevated as at the drying Site 2.

Fig. 10 P-PO4, Tot.P, Cl concentrations at Site 2

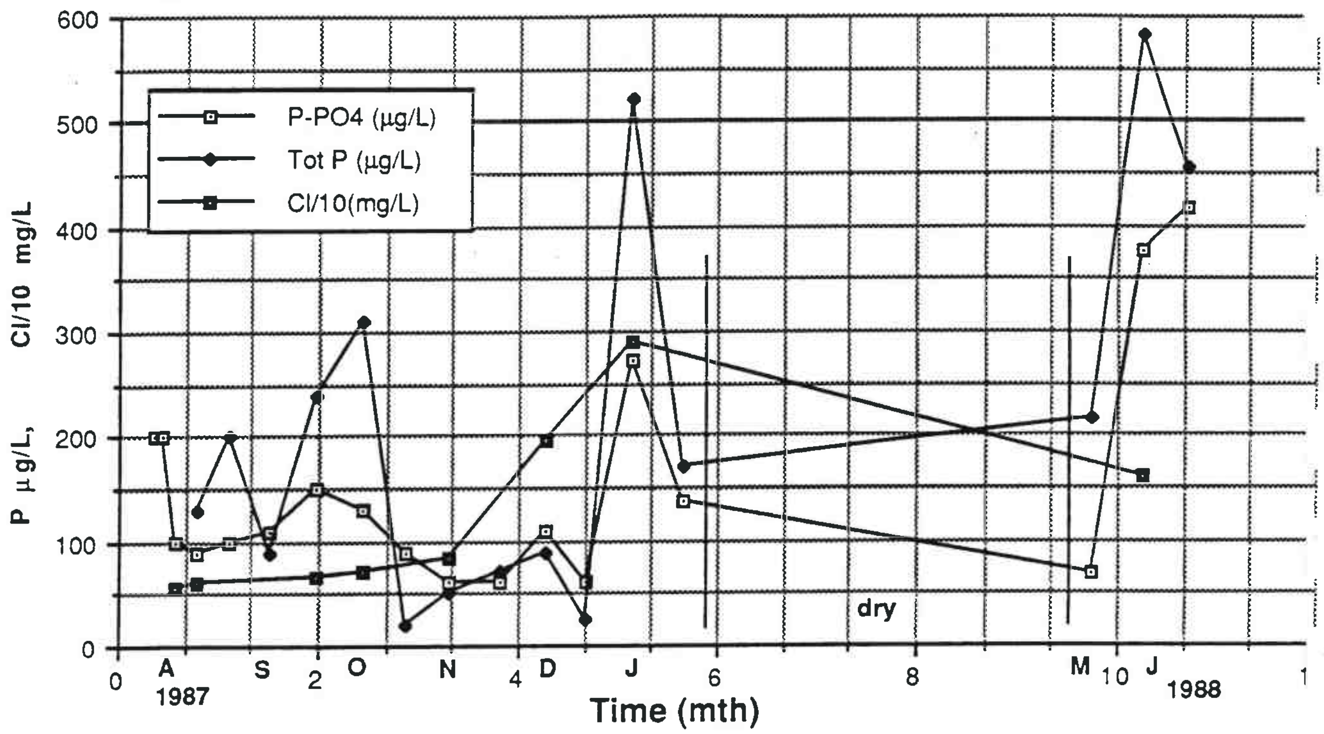


Fig. 11 P-PO4, Tot.P, Cl concentrations at Site 3

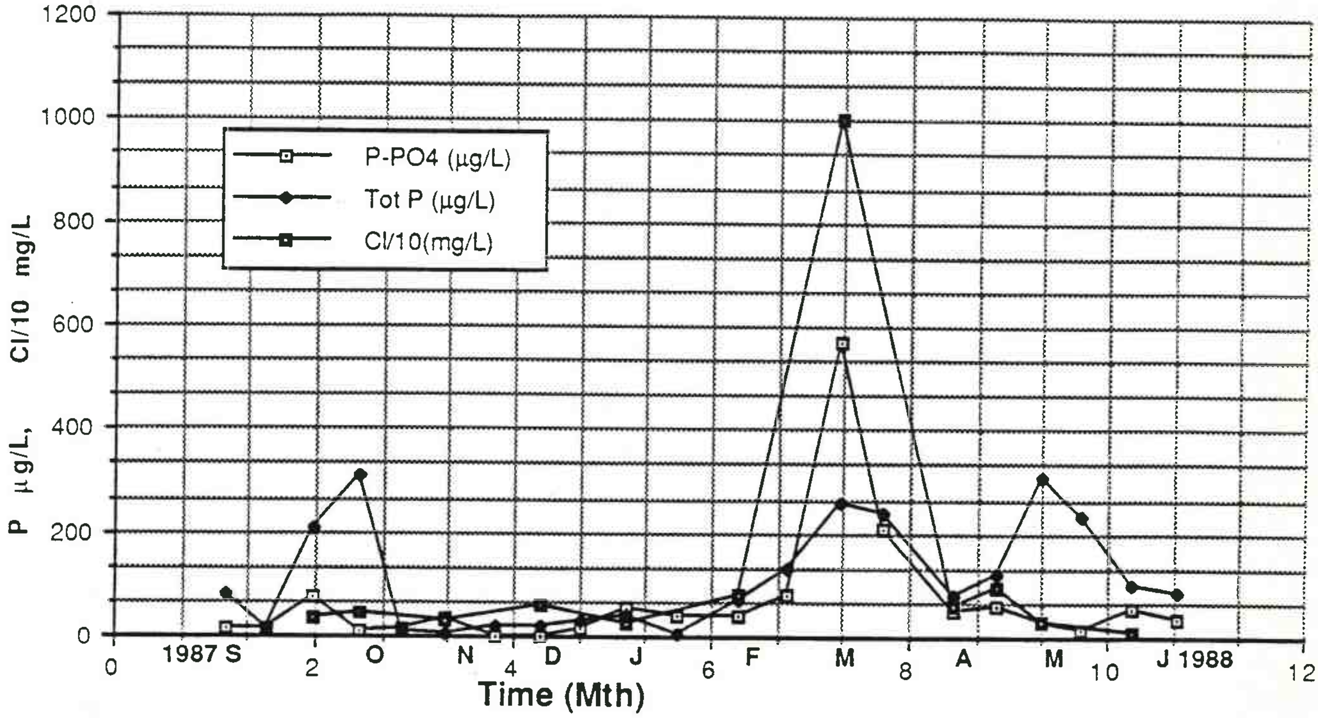
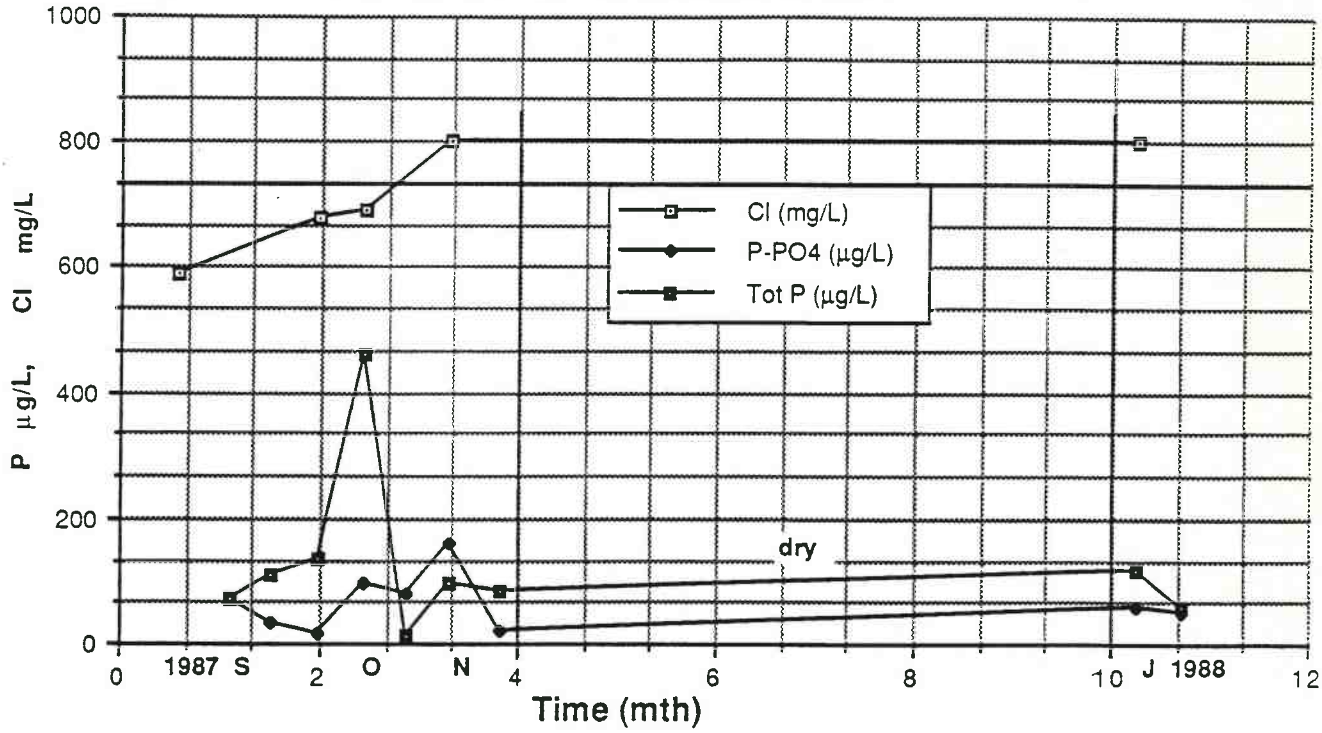


Fig. 12 P-PO4, Tot.P, Cl concentrations at Site4



At Site 3 (Fig 11) there were October, March and May peaks in tot. P concentration to about the same value as at the other sites, but at other times both tot.P and $P-PO_4$ concentrations were significantly lower than the contemporary values at Sites 1 and 2. Since chlorinity at Site 3 was also lower, and Bore 3 recorded even lower P and Cl^- figures we interpret the low P concentrations as a result of groundwater inflow (see also Section 4.1.3). The cause of the spasmodic high concentrations is discussed in Section 4.2.4.

In Table 3 the autumn and spring $P-PO_4$ and total P concentrations in Lake Claremont are compared with those at some other metropolitan lakes. With the exception of Lake Jandabup, their major catchment areas are over or through Karrakatta soil (Churchward, H.M. and McArthur, W.M., 1980). Lake Jandabup lies on Bassendean sands and Lake Joondalup lies against Cottesloe soils on its west.

TABLE 3

Approximately maximum and minimum phosphorus concentrations in six metropolitan wetlands.

Lake	Year	$P-PO_4$ (µg/L)		Tot.P (µg/L)		Reference*
		Autumn	Spring	Autumn	Spring	
Claremont (Site 1)	87-88	150	110	360	150	This work
	76	210	70	500	120	IRL
Perry (East)	76	30	7	40	70	IRL
Carine	86	90	13	-	-	IRL
Joondalup	85-86	11	ca 1	10	10	D & R
Jandabup	85-86	ca 80	10	200	10	D & R
Monger	85	650	10	10	900	D & R

* IRL - Lantzke I.R. unpublished
D & R Davis, J.A. and Rolls, S.W. (1987: 2)

When the phosphorus concentrations measured in Lake Claremont are compared with those in the other lakes, and with the classification of lake trophic status used in Environmental Protection Authority Bulletin 265 (Davis, and Rolls, 1987: 1) reproduced in Table 4, it can be seen that although Lake Monger experienced larger peak autumn phosphorus concentrations, the spring levels in Claremont were still hyper-eutrophic and that in terms of $P\text{-}PO_4$, the form assimilated by plants, Lake Claremont is "loaded", and has been for some years.

A comparison of the 1987-1988 values with the 1976 figures suggests that over the last 10 years either change in phosphorus standing stock has been less than the experimental error, or the sediments have "removed" added P.

(We suggest the highly desirable, increased perception by Claremont citizens of the problem of the Lake's health is a combination of greater public awareness of the value of wetlands and the falling groundwater level resulting in regular, lower, summer water levels)

TABLE 4

Classification of lake trophic status based on nutrient concentration.
(After Wetzel 1975, modified from Vollenweider, 1968)

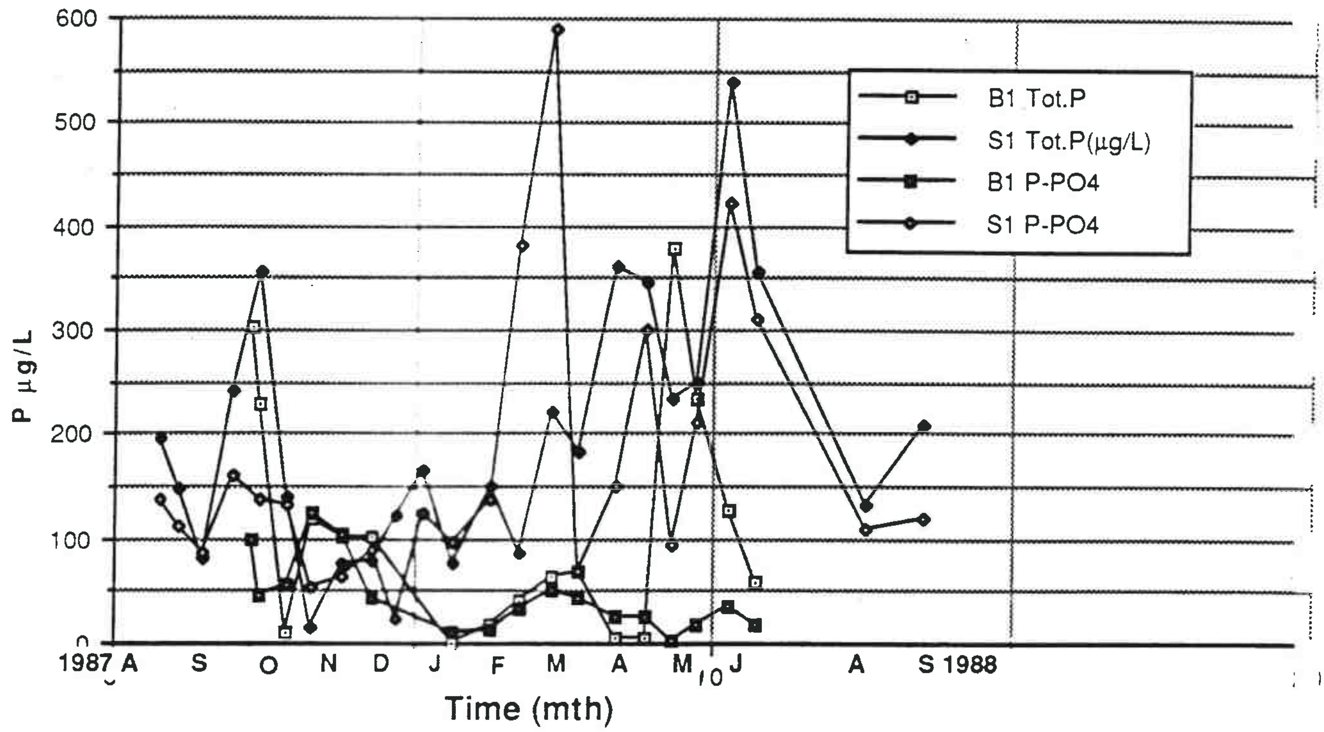
	(µg/L)	
Category	Total P and Ortho P	Total N
Ultra-oligotrophic	0-5	0-250
Oligo-mesotrophic	5-10	250-600
Meso-eutrophic	10-30	300-1100
Eutrophic	30-100	500-15 000
Hyper-Eutrophic	> 100	> 15 000

from EPA Bulletin 265, p 42

4.2.2 Groundwater

The general relationships between inflowing ground water (monitored at Bore 3; NE corner) and low mineral concentrations in the N.E., and outflowing groundwater (monitored at Bores 1 and 2; South and West sides) and higher mineral concentrations, has been described above in Section 4.1.3. The situation with regard to phosphorus is similar, but as the data in Fig 13 shows, the concentration of P measured in Bore 1 was less than that at Site 1, except in November and early December, and again on 10/5/88. As well there was no obvious relationship between lake water, and outflowing ground water phosphorus concentrations. Since from mid January to late May the lake at Site 1 had fallen so much that the water's edge was well distant from Bore 1 (and also Bore 2) it is not surprising that the relationship was not obvious.

Fig. 13 P-PO4 & Tot.P concentrations, Site 1,Bore 1



The peak in tot. P in both bores on 10/5/88 could be a result of fertilizer leaching. The records show the golf course greens fertilized (DAP: 20%P) on 27/4/88, and the Floreat rain records show 41 mm for the 24 hours to 9.00am on 28/4/88. The available records do not show if the south end and Cresswell Park (or Scotch College playing fields) were also fertilized at the same time.

The average difference between tot. P inflow and outflow concentrations, over the measured period (November to June), is about 40 µg/L. For reasons given in Section 4.1.3 the uncertainty in a calculated total phosphorus flow would be too great to be used with any confidence. However it seems clear that there is a net outflow of phosphorus in the ground water.

4.2.3 Seasonal Changes in Mass of Dissolved Phosphorus

Table 5 contains values of the calculated total of the mass of phosphorus in the water column, expressed as tot. P; $P\text{-}PO_4$ and nr P (tot. P less $P\text{-}PO_4$), together with the water volumes and concentrations used in the calculations.

TABLE 5

MASS OF PHOSPHORUS IN LAKE CLAREMONT WATER COLUMN 18.8.87 to 27.10.87

	18/8/87	24/8/87	03/9/87	15/9/87	29/9/87	13/10/87	27/10/87
Depth-post (cm)	76	78	78	75	74	65	61
Vol: S (m^3)	37,407	38,256	38,256	36,983	36,559	32,743	31,047
W (m^3)	68,337	70,098	70,098	67,456	66,575	58,610	55,126
NE (m^3)	1,912	1,960	1,960	1,888	1,863	1,646	1,549
Total (m^3)	108,000	110,000	110,000	106,000	105,000	93,000	88,000
Tot.P: S (µg/L)	-	195	147	82	242	357	140
(kg)	-	7.459	5.624	3.033	8.847	11.689	4.347
W (µg/L)	-	130	200	115	242	310	17
(kg)	-	9.113	14.020	7.757	16.111	18.169	0.937
NE (µg/L)	-	100	80	14	212	310	10
(kg)	-	0.196	0.157	0.026	0.395	0.510	0.015
Total (kg)	-	16.77	19.80	10.82	25.35	30.37	5.3
$P-PO_4$ S (µg/L)	223	137	112	87	161	137	132
(kg)	8.342	5,241	4,284	3.218	5.886	4.486	4.098
W (µg/L)	106	90	101	109	149	125	86?
(kg)	7.244	6.309	7.080	7.353	9.920	7.326	
NE (µg/L)	ca 20	15	14	16	76	11	14
(kg)	0.038	0.03	0.027	0.030	0.142	0.018	0.02
Total (kg)	15.62	11.58	11.39	10.60	15.95	11.83	
nrP S (kg)		2.22	1.34	0	2.96	7.20	0.25
W (kg)		2.80	6.94	0.40	6.19	10.84	?
NE (kg)		0.17	0.13	0	0.25	0.49	0
Total (kg)		5.2	8.4	0.4	9.4	18.5	?
"Apatite" solubility		Supersat.		Unsat.	Unsat.	Supersat.	Unsat.

TABLE 5 (CONTINUED)

MASS OF PHOSPHOROUS IN LAKE CLAREMONT WATER COLUMN 9/11/87 to 20/1/87

			9/11/87	24/11/87	8/12/87	21/12/87	4/1/88	20/1/88
Depth-post		(cm)	54.5	43	34	24	21	6
Vol:	S	(m^3)	28,240	23,719	19,599	15,359	14,086	7,827
	W	(m^3)	49,803	39,274	31,347	22,540	19,898	7,985
	NE	(m^3)	1,404	1,113	895	ea. 650	2.4	0.9
	Total	(m^3)	79,000	64,000	52,000	39,000	34,000	16,000
Tot.P:	S	(µg/L)	16	75	78	121	164	75
		(kg)	0.452	1.779	1.529	1.858	2.310	0.587
	W	(µg/L)	46	69	86	26	523	170
		(kg)	2.092	2.710	2.696	0.586	10.407	1.357
	NE	(µg/L)	3	17	17	29	43	3
		(kg)	0.004	0.019	0.015	0.019	ea 0	0
	Total	(kg)	6.76	4.51	4.24	2.46	12.72	1.94
$P-PO_4$	S	(µg/L)	53?	64	90?	23	125	97?
		(kg)		1.518		0.353	1.761	
	W	(µg/L)	57?	62	107	26	273	138
		(kg)		2.434		0.586	5.432	
	NE	(µg/L)	7?	0	1	15	55	36?
		(kg)		0	ca 0	0.010	ca 0	
	Total	(kg)		3.95		0.95	7.19	
nrP	S	(kg)		0.26		1.51	0.55	
	W	(kg)		0.28		0	4.98	
	NE	(kg)		0.02		0.01	0	
	Total	(kg)	?	0.6	?	1.5	5.5	?
"Apatite" solubility								

TABLE 5 (CONTINUED)

LAKE CLAREMONT PHOSPHORUS BUDGET 8/2/88 to 26/4/88

	8/2/88	22/2/88	9/3/88	23/3/88	12/4/88	26/4/88
Depth-post (cm)	-8	-11	-14.5	-14	-14	-13
Vol. S (m^3)	1,900	1,672	1,368	1,444	1,444	1,520
W (m^3)	0	0	0	0	0	0
NE (m^3)	0.8	0.8	0.8	0.75	0.7	0.4
Total (m^3)	1,900	1,700	1,400	1,450	1,450	1,500
Tot.P S (µg/L)	149	86	222	184	361	345
(kg)	0.283	0.143	0.303	0.266	0.521	0.524
W (µg/L)	dry	dry	dry	dry	dry	dry
(kg)						
NE (µg/L)	72	126	261	235	83	118
(kg)	ca 0	ca 0	ca 0	ca 0	ca 0	ca 0
Total (kg)	0.28	0.18	0.30	0.27	0.52	0.63
$P-PO_4$ S (ug/L)	137	381?	590?	69	149	301
(kg)	0.260			0.100	0.215	0.457
W (µg/L)	dry	dry	dry	dry	dry	dry
(kg)						
NE (mg/L)	37	81	570?	206	47	63
(kg)	0	ca 0			ca 0	ca 0
Total (kg)	0.26					
nrP S (kg)	0.02	?	?	0.17	0.31	0.07
W (kg)	-	-	-	-	-	-
NE (kg)	ca 0			0	0	0
Total (kg)	0.02	?	?	0.2	0.3	0.1
"Apatite" solubility		equilib		equilib		

TABLE 5 (CONTINUED)

LAKE CLAREMONT PHOSPHORUS BUDGET 10/5/88 to 9.9.88

	10/5/88	23/5/88	8/6/88	21/6/88	18/8/88	9/9/88
Depth-post (cm)	-5.5	16	31	40	83.8	87.4
Vol. S (m^3)	2,052	11,967	14,471	22,142	40,799	41,033
W (m^3)	512	15,605	17,917	36,341	75,382	78,024
NE (m^3)	ca 157	460	486	1,041	2,105	2,178
Total (m^3)	2,700	28,000	33,000	60,000	118,000	121,000
Tot.P S (µg/L)	233	250	539	356	132	-
(kg)	0.634	2.992	7.880	7.882	5.385	
W (µg/L)	dry	217	582	455	189	-
(kg)		3.401	10.428	16.535	14.247	
NE (µg/L)	305	233	102	86	ca 25	-
(kg)	ca 0	0.107	0.050	0.090	ca 0.05	
Total (kg)	0.63	6.50	18.28	24.51	19.7	
$P-PO_4$ S (µg/L)	95	211	422	309	110	-
(kg)	0.259	2.525	6.107	6.841	4.488	
W (µg/L)	dry	68	375	416	186	-
(kg)		1.061	6.719	15.118	14.021	
NE (mg/L)	30	17	57	34	ca 20	-
(kg)	ca 0	0.008	0.028	0.035	ca 0.04	
Total (kg)	0.26	3.59	12.85	21.994	18.5	
nrP S (kg)	0.38	0.47	1.69	1.04	0.9	
W (kg)	-	2.34	3.71	1.42	0.23	
NE (kg)	ca 0	0.10	0.02	0.06	ca0.01	
Total (kg)	0.4	2.9	5.4	2.5	1.1	
"Apatite" solubility		equilib.	equilib.	supersat.	supersat.	

The data shows two things of immediate interest. The first is the confirmation it provides of the highly dynamic condition of the water column phosphorus. The most spectacular examples of this were the drop in tot. P of 25kg between 13/10/87 and 27/10/87; and the increases in tot. P of 15kg between 15/9/87 and 29/9/87, and 12kg between 23/5/88 and 8/6/88. For reasons discussed in Section 4.2.4 these latter two are not thought to be spontaneous; but increase of 6kg tot. P (3kg $P\text{-}PO_4$) between 10/5/88 and 23/5/88 probably is "spontaneous".

The second is the actual mass of phosphorus, which when in solution produces the observed hyper-eutrophic conditions. In the late summer period of bird deaths (late March 1988) only 300g (expressed as weight of P) of phosphorus in all forms made the concentration 222 ug/L at Site 1. This quantity of P would be supplied by only 10kg of a fertilizer containing 3% total P (such as Turf Special or 3-6-3), although this latter is not in the same form as in the lake.

This means that if the lake's phosphorus removal system "broke down" it would leave the lake vulnerable to rapid overloading by even small amounts of phosphorus.

It also means that a management plan based on removal of phosphorus from the water column would take some time to have an effect, since there is so relatively little P in solution. (An approximate figure for the time required can be derived by assuming the sediments can release 6 kg per fortnight. If P were removed from the water column at this rate it would take 1000 weeks, that is over 19 years, to remove all the estimated 3 tonne of P (see Section 4.4) in the top 1 cm of the sediments)

Table 5 also includes a summary of the extent of saturation of the water with respect to solubility of hydroxyapatite at Site 2, and at Site 1 (February - March 1988), as discussed in Section 4.2.4.

4.2.4 Discussion (Possible mechanisms of phosphorus mobility)

The chemistry of dissolved phosphorus compounds in natural waters is quite complex, for a number of reasons.

For a start there are 3 quite different types of phosphorus compounds involved:- orthophosphate (PO_4^{3-}); various condensed inorganic phosphorus compounds; and the organically bound phosphorus. The basic chemistry of the different groups is quite different, and, as well there are also differences between the substances in each group.

Then there is the inter-related nature of the chemical reactions possible between the minerals in solution. Thus depending on acidity (pH), calcium ion (Ca^{2+}) has the potential to form two very slightly soluble phosphorus compounds with PO_4^{3-}; dicalcium phosphate ($Ca\ HPO_4.2H_2O$; brushite) and hydroxyapatite ($Ca_{10}(PO_4)_6(OH_2)$. But Ca^{2+} also forms slightly soluble chalk ($CaCO_3$) when there is enough CO_2 dissolved in the water and the pH is appropriate. In every case the concentrations of the reacting species must exceed a certain minimum, which is different for each reaction, in order to form the insoluble material. Additionally the necessary concentrations are modified by the concentrations of all the other ions in solution (ionic strength effects).

Likewise iron ions in water containing oxygen (Fe^{3+}) can form insoluble ferric phosphate. If there is no dissolved oxygen this can be reduced to the more soluble ferrous (Fe^{2+}) phosphate.

Next there is the possibility of reversible adsorption of P compounds onto the sediments, either on the bottom, or suspended in the water (see Section 4.4).

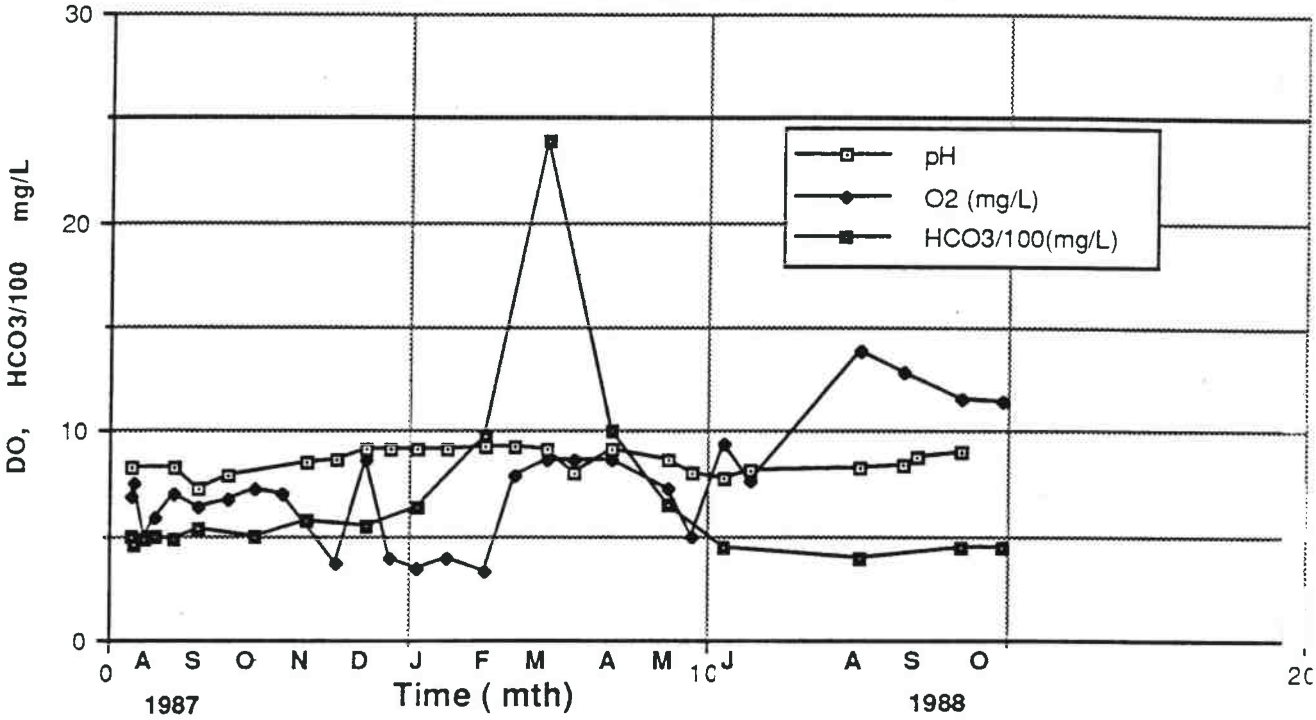
Also there is the possibility that although concentrations are adequate for a reaction, it just does not happen. It may just need a "chemical push" (eg. heating), or it may be that all the reagent molecules do not come together at the same time, (kinetic effects).

The uptake of $P\text{-}PO_4$ by plants is an important path for the removal of this form of phosphorus from the water, but this too is dependent on pH.

Finally, the bacteria living on submerged plants and on the bottom also play a part, although this is much less well characterized. These are probably the major consumers and changers of the dissolved organic phosphorus compounds.

The most probable phosphorus removal mechanism was thought to be adsorption on to the sediments (Section 4.4), with uptake by floating plants (Section 4.5) also important in summer. But there was also the possibility of the removal of P-PO_4 by its precipitation in a calcium-phosphate compound or its co-precipitation in $CaCO_3$, especially given the significant concentrations of calcium ion measured in the water (see Fig 14). As oxygen concentrations in open water were always greater than 2ppm, and mostly greater than 5ppm (Fig 14), iron concentrations in the water were expected to be very low, and iron phosphate was unlikely to be a primary product. Because of the significance of pH and bicarbonate in the calcium-phosphate equilibria the values at Site 1 are also given (Fig 14) as these were representative of the seasonal water column conditions.

Fig. 14 DO, pH, & HCO3 concentrations at Site1



The thermodynamic (ie chemically possible) relationships between Ca^{2+} and PO_4^{3-} in soils have been worked out by Clark and Peech (1955), and expressed graphically in a solubility diagram. By making similar calculations using the measured Ca and P-PO_4 concentrations it was possible to determine from Clark and Peech's diagram if the water were supersaturated with regard to either dicalcium phosphate or hydroxyapatite (ie, had the potential to precipitate either of these compounds).

However, kinetic factors often result in a water column being supersaturated with regard to hydroxyapatite (Stumm and Morgan, 1970: 1; Martens and Harris, 1970) and co-precipitation of PO_4^{3-} in $CaCO_3$ (calcite) was a distinct alternative (Stumm and Morgan, 1970: 1; Otsuki and Wetsel, 1972; Somlyody and van Straten, 1986: 1). Freshly precipitating $CaCO_3$, formed when the pH rises during photosynthesis, adsorbs PO_4^{3-} very effectively. In either case there is a possibility of subsequent slow formation of one of the apatites in the solid phase.

To check on $CaCO_3$ (calcite) formation we calculated the value of $[Ca^{2+}]\gamma_{Ca} \cdot [CO_3^{2-}]\gamma_{CO_3}$ for the water column on three occasions. The constants used were K_2 for H_2CO_3 dissociation 4.84×10^{-11} (25^o) (Cotton and Wilkinson, 1962) and Ksp $CaCO_3$ of 0.99×10^{-8} (15^o) and 0.87×10^{-8} (25^o) (Hodgman et al 1958).

(In all the thermodynamic calculations we based ionic strength on the experimental TDS, using the Debye-Hückel limiting law to calculate the single ion activity coefficients, for ionic strengths less than 0.04, and the full Debye-Huckel law for higher ionic strengths. (Robinson and Stokes, 1959). For the latter calculations a value of 0.4nm was used for the value of the "a" parameter, as a reasonable estimate of the separation of Ca^{2+} (aq) and HPO_4^{2-} or CO_3^{2-} ions)

Because the total $P\text{-}PO_4$ flux was largest in the Western section we used Site 2 concentrations to calculate calcium and phosphate activities to evaluate the extent of saturation in that water column with respect to calcite and calcium-phosphate compounds.

The values of $[Ca^{2+}]\gamma_{Ca} \cdot [CO_3^{2+}]\gamma_{CO_3}$ obtained for 13 October and 9 November (1987) were slightly less than Ksp (by factors of about 3 and 6 respectively), but an increase (or mis-measurement) in pH from 7.5 (assumed) on 13 October, to greater than 7.6, would have given a product in excess of K_{sp} - ie. supersaturation. It would seem then, given the uncertainties in the calculations, that during spring at Site 2, thermodynamics (rather than kinetics) determined the concentrations of Ca^{2+} and HCO_3^- (CO_3^{2-}) remaining in the decreasing water volume.

The results, of the "Ca-PO_4" calculations together with appropriate portions of the total phosphate standing stock data, and other relevant data are collected in Table 6. The estimated "interval P-PO_4 additions" tabulated are for weights of P-PO_4 added to the whole lake and calculated on the values of averaged P-PO_4 run off (in Table 9 Section 4.3) over the interval between measurements. The exception is for 23/5/88 when the western portion of the lake was separate, and only drain D5 run-off P-PO_4 is tabulated.

Also in Table 6 are similar calculations for Site 1 at the time of the bird deaths. (A summary of these calculations at both sites is also included in Table 5.)

What Table 6 shows for the western arm of the lake (Site 2) is as follows:-

During the spring (from 24/8/87) there was a constant decrease in the volume of water, accompanied for the first six weeks by large increases in P-PO_4 standing stock, and then large decreases. It also shows that during this period the total phosphorus in the aquatic animal compartment was relatively constant, and P-PO_4 additions in drain water to the whole lake (Section 4.3) were relatively small, compared with the P-PO_4 fluxes. Finally it shows that the approximately 2kg of P-PO_4 added to the water column between the 15th and 29th September made it supersaturated with respect to solid hydroxyapatite formation, but in a further 14 days about 2.5kg of P-PO_4 had been lost from the water column and conditions no longer favoured hydroxyapatite precipitation, a state which then persisted to the 9 November, by which time a further 4.5kg (approx) of P-PO_4 had gone from the water column.

During the early winter (from 23/5/88) there was a constant increase in water volume, and large increases in the mass of dissolved P-PO_4, with the actual quantities of P-PO_4 much greater than during spring, even though the water volumes were less. It also shows that the total phosphorus in the animal compartment also increased over the period, and that, although this was the time when phosphorus in run-off was greatest (Section 4.3) the actual quantities contributed (to the whole lake) over the intervals was only large, relative to the water column flux, for the 8.5 weeks between 21 June and 18 August.

Finally it shows that during the early winter period the Ca^{2+} and PO_4^{3-} concentrations were in equilibrium with solid hydroxyapatite, then between the 8 and 21 June about 8.4 kg of $P\text{-}PO_4$ was added to the water column to make it supersaturated with respect to solid hydroxyapatite formation.

TABLE 6

Extent of "Ca - PO_4" saturation in the water column, and factors influencing it (See text)

	Measured			Calculated		Interval rainfall			Aquatic invertebrate animal densities		
	pH	Ca^{2+} mg/L	P-PO_4 (mg/L)	Water Volume (m^3)	P-PO_4 Standing Stock (kg)	Direct (mm)	Estimated P-PO_4 Additions (kg)	Calculated saturation	planktonic herbivores	planktonic carnivores	benthic
Site 2											
24/8/87	ca 7.5	50	90	70 100	6.31	-	-	Super.(apatite)			
3/9/87	7.1	45	100	70 100	7.08	14	0.13	Unsaturated	high	high	high
15/9/87	7.4	45	109	67 460	7.35	0	0	Unsaturated	maximum	increasing	increasing
29/9/87	7.6	est 45	149	66 580	9.92	43	0.58	Super.(apatite)	decreasing	high	"
13/10/87	8.0	43	125	58 610	7.33	7.2	0.10	Unsaturated	"	"	maximum
27/10/87	-	-	86	55 130	4.74	3	0.04	-	-	-	-
9/11/87	6.9	41	57	49 800	2.84	18.8	0.25	Unsaturated	high	high	high
10/5/88	Site dry							dry			
23/5/88	7.4	est 95	68	15 610	1.06	129.8	0.04	Sat.(apatite)	nil	few	many
8/6/88	7.0	93	375	17 917	6.72	89.8	0.80	Sat.(apatite)	many	few	high
21/6/88	7.6	85	416	36 341	15.12	84.2	0.75	Super.(apatite)	decreasing	-	few
18/8/88	8.7	44	186	75 382	14.02	290.6	2.59	Super. ($CaHPO_4.2HO$)	moderate	few	few
Site 1											
22/2/88	9.2	28	est 80	2 050	0.18	0		Super.(apatite)			
9/3/88	9.2	28	?	1 370	-	0			Bird deaths		
23/3/88	8.0	est 28	69	1 440	0.10	0		Sat.(apatite)			

When expressed in a more comparative form (Table 7) the magnitude of the changes in P-PO_4 load, compared with the water volume changes are quite informative.

There are three important aspects of the behaviour of the lake's P budget which the data in Tables 6 and 7 strongly suggest. Firstly that the large increases in P-PO_4 standing stock in both spring and autumn, to make the water supersaturated with respect to solid hydroxyapatite formation, is due to the addition of unaccounted for phosphorus - it cannot be attributed to decomposition of nr P; expected run off additions; or re-solution from sediments. The most likely source is fertilization of the adjacent grasslands.

The golf course records show that it was fertilized (6 bags; Horticultural Special: 3.5%P) on 2/9/87. They do not show any major fertilization in early June 1988. However we did not have access to information on the fertilization of Cresswell Park or the Scotch College playing fields.

TABLE 7

Changes* in Water Volume and $P-PO_4$ Mass
in the West Arm of Lake Claremont

	Water		$P-PO_4$	
Date	Volume (m^3)	Interval % volume change	Standing Stock (kg)	Interval % change
24/08/87	70 100		6.31	
03/09/87	70 100	0	7.08	+ 12
15/09/87	67 460	- 4	7.35	+ 4
29/09/87	66 580	- 1	9.92	+ 35
13/10/87	58 610	-12	7.33	- 26
27/10/87	55 130	- 6	4.74	- 35
09/11/87	49 800	-10	2.84	- 40
23/05/88	15 610		1.06	
08/06/88	17 920	+ 15	6.72	+534
21/06/88	36 340	+103	15.12	+125
18/08/88	75 380	+107	14.02	- 7

* % based on value at start of each interval

The second observation of significance is that when again submerged after drying out, the lake sediments did not immediately adsorb $P-PO_4$, and the concentration in the water column appeared to be controlled only by the solubility and dissociation of hydroxyapatite.

That this was only temporary, is shown by the subsequent return of $P-PO_4$ concentrations to levels similar to those of the previous late winter (113µg/L on 16/9/88; 109µg/L on 15/9/87).

The last important observation relates to mechanisms of $P-PO_4$ removal. At high concentrations of $P-PO_4$ there is the possibility of the formation of solid hydroxyapatite. But observed $P-PO_4$ concentrations in winter and spring fall below the equilibrium hydroxyapatite values, so at least one (other) mechanism is also operating. Two other mechanisms relate to calcite formation.

Since the calculations of calcite formation, described earlier, point to its concentration being thermodynamically controlled (in spring and early summer at least) we examined the Site 1 and 2 data (Figures 9 and 14 and Appendix 8.3). These show that during spring and early summer there were steady decreases in water volume and Ca^{2+} concentration; essentially steady HCO_3^- concentrations; and fluctuating increases in pH. This points strongly to calcite ($CaCO_3$) precipitation throughout the drying period.

Such a situation would be capable of either co-precipitating, and/or adsorbing significant amounts of $P-PO_4$, reducing its concentration to the levels observed.

In late summer, autumn, and early winter the $P-PO_4$ concentrations stabilized around the (higher) equilibrium hydroxyapatite values. In late summer when the water volume was constant, Ca^{2+} and pH were also constant (Site 1; Appendix 8.3) but HCO_3^- (and hence CO_3^{2-}) steadily increased until 9/3/88. On that date the calculated value of $[Ca^{2+}]\gamma_{Ca} \cdot [CO_3^{2-}]\gamma_{CO_3}$ was about twice Ksp. The accuracy of this calculation is not high as the approximate calculated γ values were only approximate in the water column conditions: a soup of algae (Section 4.5) and resuspended sediments with an ionic strength greater than

0.26. So while there is some possibility of calcite removing of phosphate, it seems more likely that another mechanism was involved in reducing the P-PO_4 concentration from supersatured, with respect to hydroxyapatite, on 22/2/88 to equilibrium by 23/3/88. Either precipitation or algal uptake are possibilities. (We were unable to find a source for the PO_4^{3-} which made the lake supersaturated, but it would not have needed much - the loss of 80g from the water column, coupled with a drop of pH to 8.0 by 23/3/88 had reduced the concentrations to an equilibrium between free ions and solid hydroxyapatite.)

In early winter, with inflowing water, the Ca^{2+} concentration doubled, but HCO_3^- and pH decreased. The P-PO_4 concentration was the equilibrium value for re-solution of hydroxyapatite. With the volume of fresh water increasing; little or no phytoplankton (for photosynthesis); and a consistently lower pH, there will not be precipitating $CaCO_3$.

The evidence available does not indicate what part, if any, bottom sediment adsorption plays in controlling the concentrations of P compounds (See also Section 4.4).

The nr P transformations in the lake are much less clear than the PO_4^{3-} reactions, although it can be seen from Table 5 that rapid changes in nr P occur. There is no obvious relationship between decreases in nr P, and increases in P-PO_4, as might be expected if direct conversion were the major pathway for its removal from the water column.

Polyphosphates hydrolyse to PO_4^{3-} at rather slow rates, with half lives probably of the order of 4 to 50 days, but perhaps much greater (Stumm and Morgan, 1970:2), dependent upon the species; pH; complexed metal ions; presence of bacteria and algae; and temperature. With so much P-PO_4 flux from other causes, so slow a release is obscured.

Not enough is known about the specifics of the dissolved organic phosphorus compounds. Direct use as nutrient is one possibility; hydrolysis is another; and some at least should be adsorbed by sediments, since they still carry a significant charge at the PO_4 group. At Lake Balaton, sediments were found to contain significant amounts of inositol phosphate (from animal or plant membranes) (Somlyody and van Straten, 1986:2).

More research is needed to clarify the fate of the nr P in Lake Claremont.

4.3 Inflowing Storm Water

Limited overseas and Eastern States studies of drainage water found it contained significant concentrations of phosphorus compounds (Cullen, et al, 1978), but we did not know if the same happened in Perth's climate and on Claremont's sandy soils, so the seven pipes identified on Figure 2, and observed discharging water into Lake Claremont were investigated.

The studies reviewed by Cullen et al (1978) showed:

(i) P (and sediment) concentration were usually greatest early in a run-off event.

(ii) Concentrations changed over short (5-20 minute) time internals.

(iii) Maximum total P concentrations as high as 2,400mg/m^3 (Florida, USA); 1,690mg/m^3 (Canberra) and 4,900mg/m^3 (Sydney) were possible.

(iv) The factors affecting P concentrations included those affecting run-off (Pilgrim, 1988) viz:

a Surface type, nature and slope.
b Time since previous rain.
c Rate of rainfall.
and also d Elapsed time since run-off started.
e Time (or season) of year.

4.3.1 Storm Events

Table 8 summarizes the results of monitoring storm water discharge to the lake. It records the date and time for each drain monitored; the rainfall (Floreat station) for that period; for the previous day; and the number of rain free days between. It also tabulates the total water reactive phosphorus ($P\text{-}PO_4$) and total phosphorus (reactive plus non-reactive (nr P) phosphorus) entering the lake; and the average concentrations of $P\text{-}PO_4$ and nr P per cubic metre (1000 L) of water. These averages were calculated from the total quantities of P, and total volumes, not from the initially measured concentrations, in an attempt to reduce the significance of extreme values.

The results clearly show that, at Lake Claremont, run-off is significant, with large amounts of phosphorus brought in during every storm.

Particularly obvious are events such as that at drain D2 (from the Swanbourne catchment) on 18/9/87 where 65 minutes of the tail of a rain event discharged 2.2g of $P\text{-}PO_4$ and a further 0.1g of nr P, and at D4 (draining the Shenton Close development) on 12/5/87 where two consecutive rain events over 165 minutes contributed 5.19g total P (4.58g $P\text{-}PO_4$).

As a check that drain phosphorus was not rain provided, samples of rain water were collected on 24/6/88 (1200 to 2300 hours) in the open, around the south end of the lake. Approximately 13mm of rain was collected and this averaged 11µg/L (11g/m^3) PO_4 concentration (range 5µg/L - 17µg/L). We suspect the true figure is below 7µg/L, the higher values resulting either from splashing of soil water into the containers which sat directly on the ground, or, more likely, desorption of phosphorus (originally in detergent used to wash the ice cream containers employed) since they were not acid rinsed prior to used. A figure of 7µg/L for rain phosphorus in Canberra is quoted by Cullen et al (1978).

Using a figure of 7µg/L for rain borne $P\text{-}PO_4$ means that the 770.4mm rain during the study deposited a maximum of 0.7kg P onto the 132,900m^2 of the lake's wet areas. It would also provide 0.5kg of P for the 75,000m^3 of (estimated) run off (see Table 10) entering the lake.

TABLE 8

Rain Events Monitored at Lake Claremont Between 1.8.87 and 31.7.88

Date	Rainfall			Drain Data							Average P Concentrations	
	That Day (mm)	Previous Wet Day (mm)	Days Since Rain	Site	Start Time (hrs)	Finish Time (hrs)	Calcul Time Base (min)	Water Volume (L)	Calcul $P\text{-}PO_4$ (mg)	Totals tot.P (mg)	$P\text{-}PO_4$ (mg/m^3)	nrP (mg/m^3)
1987												
18.9	2	7	nil	D1	0820	0920	65	5183	974	1167	190	40
				D2	0830	0930	65	7603	2295	2465	300	20
				D3	0815	0815	0				16	0
23.9	2	20	nil	D5	0945	0945	0				30	20
25.9	5	2	1	D1	1308	1308	"5"	34	3.4	7.4	100	120
					1930	1930	"5"	292	40	-	140	-
				D2	2000	2000	"5"	86	3.9	-	40	-
				D4	0950	0950	"5"	2.7	0.3	0.4	110	40
				D5	2032	2032	"5"	116	12	-	110	-
31.10	7	0.8	nil	D1	1549	1552	3	2.5	1.2	1.2	50	0
				D2	1620	1620	"5"	290	47	49	160	6
				D4	1158	1615	20	159	14	15	90	4
1988												
23.3	2	2	70	D5*	0720	0830	65	327	42	139	130	300
	13	2	nil	D1	0950	1020	35	804	60	199	70	175
				D2	1010	1025	20	80	40	63	500	290
				D4	1000	1030	35	245	11	43	40	130
21.4	4	1	5	D5	0704	0745	42	2408	400	380	160	0
27.4	41	2	nil	D1	1040	1150	75	1153	72	189	60	100
					1440	1520	45	97	5.8	18	60	130
				D2	1055	1145	55	411	47	104	110	140
					1455	1515	25	50	4.6	11	90	130
12.5	51	8	nil	D1	0841	1119	160	15003	1037	2439	70	90
				D2	0851	1100	130	10593	1024	2627	100	150
				D4	0900	1103	125	13770	4583	5190	330	40
				D5	1241	1350	70	$>$ 3990	933	925	230	0
				D7	1405	1430	30	1671	93	217	60	70
26.5	3	7	nil	D1	0930	1006	40	702	76	324	110	350
				D2	0934	1010	40	320	25	65	80	120
				D4	0938	1015	40	299	30	73	100	140
31.5	21	11	nil	D7	1534	1602	30	734	29	46	40	20
1.6	21	21	nil	D6	1120	1140	25	365	21	26	60	10
				D5*	1155	1216	25	44	1.8	2.8	40	20
				D1	1305	1405	65	9127	580	1015	60	50
7.6	5	5	nil	D1	0945	1145	125	3124	320	400	100	30
				D2	0952	1136	105	2331	183	215	80	10
				D4	0957	1140	105	2484	70	70	280	0
24.6	34	4	4	D1	2030	2215	125	37292	2173	-	58	-

* D5* sampled at drain opening; D5 sampled at lake edge after crossing the golf course.

Over the drain monitoring period, the maximum measure total P concentrations were at D4 - 1.033mg/L (PO_4 = 0.961mg/L) 12/5/85; D5 - 0.989 mg/L (PO_4 = 0.208mg/L) 23/3/88; and D2 - 0.811mg/L (PO_4 = 0.519mg/L) 23/3/88. Even minimum measured total P concentrations were very high, the lowest being at drain D5 - 0.043mg/L (PO_4 - 0.032mg/L) 1/6/88; with D2 - 0.074mg/L (PO_4 = 0.067mg/L) 7/6/88 and D4 - 0.15mg/L (PO_4 = 0.15 mg/L) 7/6/88.

It is important to repeat that the figures in Table 8 only show minimum phosphorus loads:-

(i) Because of experimental limitations (Appendix 8.2) the water flows recorded in Table 8 were underestimates, sometimes being as little as 10-20% of the total discharge, so true water volumes, and their associated phosphorus loads could be up to 5 times greater than the values in Table 8.

The exception is drain D1 on 24/6/88 when the flow rate was estimated using Manning's formula (eg. Gerhart and Gross, 1985, and see Sect. 8.2) On that occasion the peak flow calculated over 3 successive rain events was 8.7 L/sec. The peak flow obtained by collecting as much of the water as possible on 1/6/88 was 4.4 L/sec over 2 storm events and on 12/5/88, 3.8 L/sec on 1 storm event. Because rain events differ in intensity, and the ease of collection at different drains varied, we do not place enough reliance on the drain D1 differences to use this as a correction factor, (although in the absence of accurate flow monitoring equipment we suggest Manning's formula is a better measuring technique than water collection).

(ii) The coarser sediments in the discharges settled out from the samples, but were not analysed. However because of its humus like properties we think it also contained significant amounts of phosphorus.

There can be little doubt that such quantitites of phosphorus entering the lake year after year have contributed to its present entrophication and will, if continued, exacerbate the present problems with algal growth.

Because this study was designed to find if phosphorus was entering in drain water, and if so, how much (not the sources and forms of such P) there is little direct evidence on its sources. However there are some clues, discussed later, which provide guidance for planning a project to pin point their sources and forms.

Other observations from Table 8, concerning phosphorus transport to Lake Claremont are consistent with the Eastern States findings (Cullen et at, 1978). Thus the average P-PO_4 and nr P concentrations varied:-

(i) In different drains during the same rain event;
(ii) at the same drain during any one rain event;
(iii) at the same drain during different rain events;
(iv) in the proportions of P-PO_4 and nr P at different times, events and drains.

Some of the reasons for this variability can be discerned from the plot in Figure 15 of water flow rate, and of concentrations of P-PO_4, tot. P and total soluble salts, obtained at drain D5 (draining the NE corner of the catchment) on the morning of 23/3/88. The sampled storm event precipitated the first rain after 70 days of summer, depositing 2mm at the Floreat station.

Fig. 15 Flow & P-PO4, Tot.P, TDS in drain D5, 23/3/88

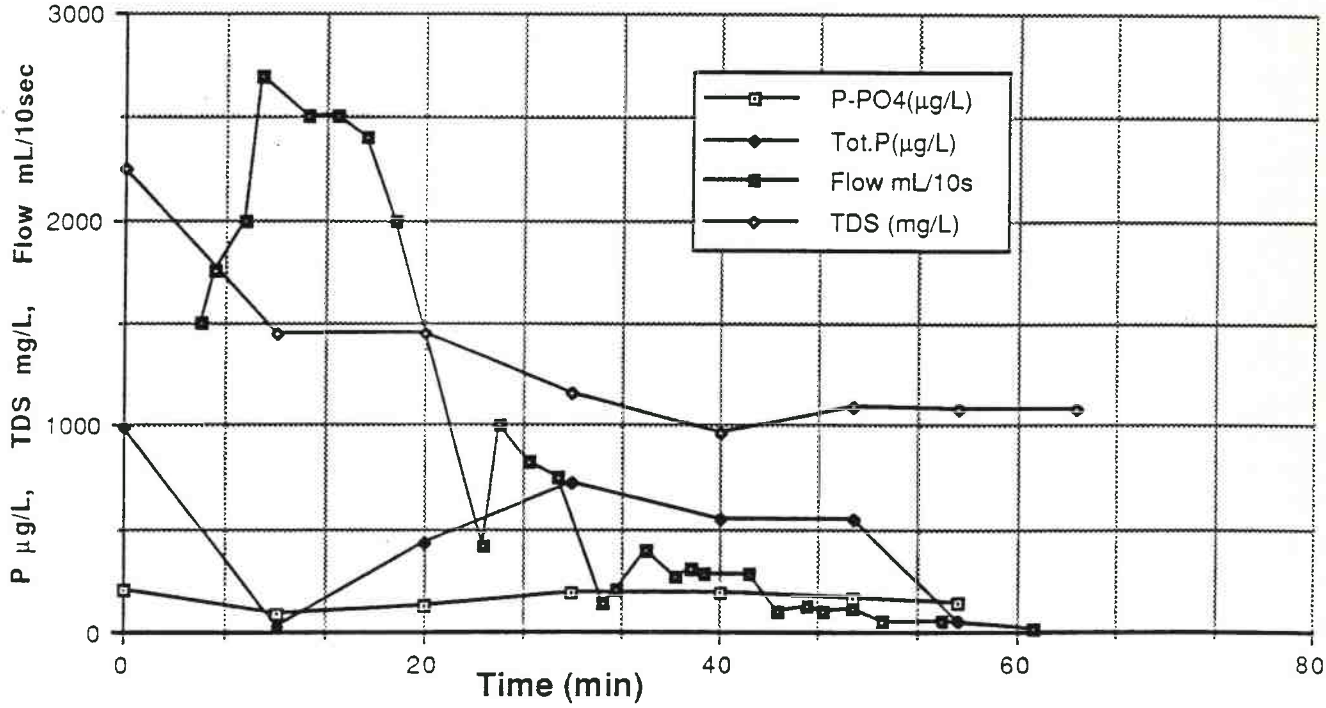
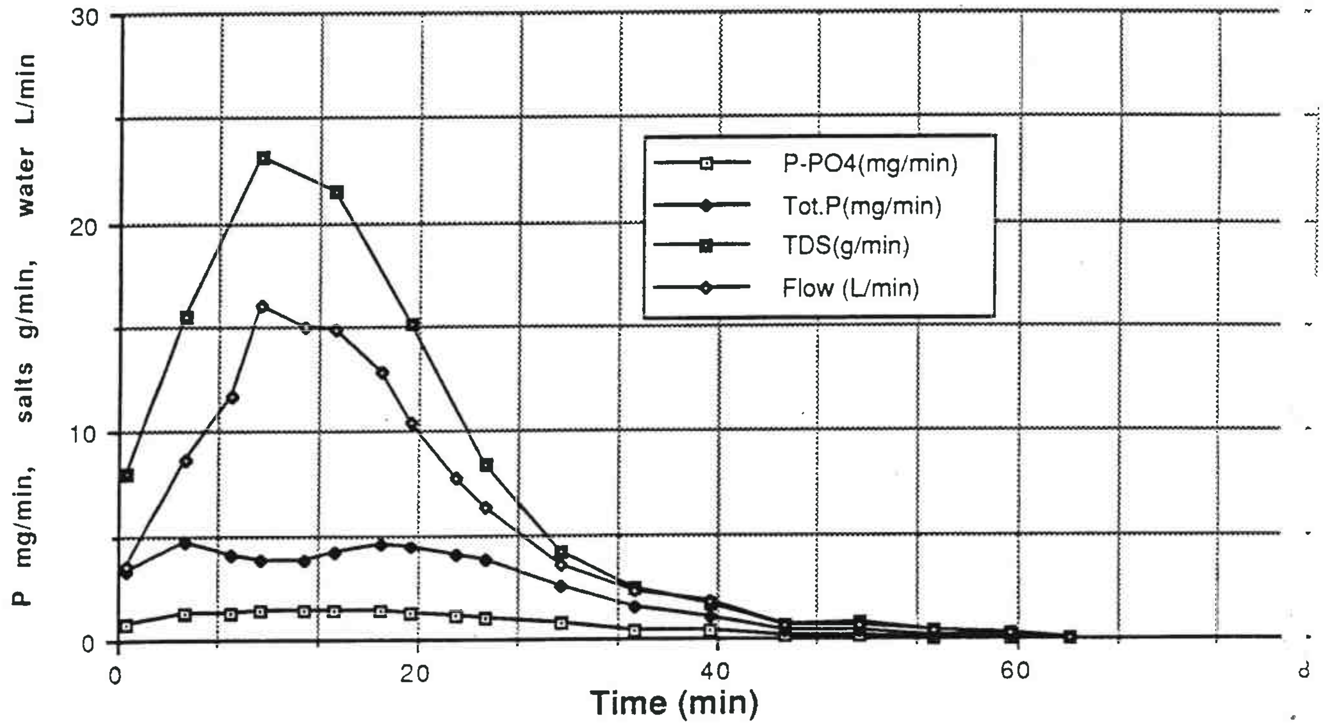


Figure 15 shows that the initial sample contained a high concentration of P-PO_4 (208µg/L) and even more nr P (780µg/L) but as more water flowed down the drain, the concentrations fell, rising again, especially that of nr P, after the rate of water flow eased. Soluble salts concentrations (probably mostly NaCl) also started high (2.25g/L) fell rapidly at first, then more slowly to become more or less constant during the tail of the flow. However Figure 16, which shows at each 5 minute interval the calculated water volume and quantitites of P-PO_4, nr P and soluble salts discharging in 1 minute, indicates that the actual amounts of P-PO_4 and nr P started low, but were then comparatively constant over the next 22 minutes of the flow, with a small increase in nr P towards the end of the main water peak, and then P quantities steadily decreased along with the water flow. (This was the general pattern of phosphorus discharge). The total soluble salts took about 10 minutes to reach maximum quantities and then decreased, in line with the volume of water issuing.

Fig. 16 Discharge of water, P & salts at D5 on23/3/88



These results suggest that the mechanism of phosphorus collection is different from that of the soluble salts. The water carrying these materials flows different distances to the outlet, so outlet flows may fluctuate, but it is not generally possible to correlate the condition of emerging water with a particular portion of the catchment, because of hold-ups and temporary impounding of water along the drainage path, together with the slower release of (possible nutrient rich) water from saturated surface soils.

However the high phosphorus concentrations in the small early water flow strongly suggests that phosphorus sources had accumulated in all parts of the catchment, including close to the discharge point.

The near constant quantities of phosphorus compounds, even when the volume of water was decreasing, could result from a slow solubilizing of the P compounds adding to the water flowing past from more remote parts of the catchment (possible even in the drains), whereas salt dissolves relatively rapidly and gets carried away.

The removal of salt is supported by the occurence of much lower total soluble salt concentrations in samples collected after rain, eg. at D5 on 12/5/88 where total salts concentrations averaged about 0.04g/L (Total P ranged between 120µg/L and 380µg/L).

Some indication of the source of the drain P was obtained from a brief examination of the samples taken for analysis. All samples were strongly brown coloured, and contained dark particulate matter (about 20mg/L). When shaken they frothed considerably. (This test was not tried on the first sample collected). It is relevant to note here that the discharge from drain D2 on 27/4/88 and again on 12/5/88 frothed considerably. Examination of the particulate matter under a microscope suggested that the major component was humus, but some leaf particles were distinguished, and in the first sample there were some pieces of insect cuticle (? cricket and ? ant).

This suggests that a project to identify phosphorus sources should consider loose plant matter in the catchment, and since both plant saponins and synthetic detergents produce froth, these possibilities would need testing.

4.3.2 Total Phosphorus Additions to the Lake

A precise figure for the phosphorus added to the lake from drain water would have required continuous gauging and analysis of all drains over the entire 12 months, but an adequate estimate can be obtained by calculation from the average phosphorus concentrations, and the water volume discharged from each catchment.

The average seasonal PO_4 and nr P concentrations in Table 9 were obtained from the separate rain event average PO_4 and average nr P concentrations, after allowing for single sample values. In cases where insufficient discharges had been sampled during summer or spring, the winter values have been used. As these were smaller drains (D6 and D7), any error introduced will not be larger than the other uncertainties in the calculation. Since, "time since last rain" is a variable in run-off, the natural breaks in rainfall over the year were chosen to give seasonal groupings; Spring - September and early October; Summer - late October to April inclusive; and Winter - the rest. Between 1/8/87 and 31/7/88 Floreat station rainfall was 770.4mm, made up of:

Winter	589.0mm
Spring	54.2mm
Summer	127.2mm

Run-off from an area can be calculated in a number of ways (Pilgrim, 1988) but most need some data for the location. Graphs of run-off against rainfall intensity, with curves for different conditions of soil and building such as those in the 1977 edition of Australian Rainfall and Run-off, are not very successful. For sandy soil this predicts no run-off for rainfall at less intensity than about 7mm per hour. During the period of this study the Perth station recorded only 7 events, or about 10% of the 12 months rain, at an intensity of 7 or more mm per hour, but Lake Claremont drains flowed much more often.

TABLE 9

Average Seasonal Phosphorus Concentrations in Lake Claremont Drains 1987-88

(All concentrations in mg/m^3)

	Drain No.											
	1		2		4		5		6		7	
Season	PO_4	nr P	PO_4	nr P	PO_4	nr P	PO_4	nr P	PO_4	nr P	PO_4	nr P
Winter	90	130	80	100	240	60	140	10	60	10	50	40
Spring	140	80	150	100	110	50	110	10	60	10	50	40
Summer	70	130	220	140	70	60	140	150	60	10	50	40

Pilgrim (1982) suggests that for the lower rainfall areas (such as Melbourne, as distinct from Sydney and Brisbane) a reasonable estimate of run-off is the fraction of impervious surface in the catchment. For the Perth Urban Water Balance computer model (Cargeeg et al, 1987:3) the water flowing to drains was taken as a fixed fraction of rain falling on paved areas only (13% for high density residential) and all other rain, including that on building roofs was treated as entering the soil.

The Lake Claremont catchment has about 20% imperious surface. Many down pipes in the area do not discharge to on-site sumps, and in view of the hydrophobic nature of Perth soils, and the presence of organic material in early season samples, we think there is also some run-off from, or over, vegetated and/or bare soil areas as well. Therefore although 20% run-off seems high for a sandy soil we have used it as a best estimate in calculating the annual phosphorus discharges in Table 9.

The quantities of phosphorus annually added by the drains (Calculated P mass in Table 9), are large, being about half the quantity found in the water column when the lake was full of water. They do not take account of any unusual additions, or of P washing in from the grassed area. Clearly some consideration must be given to this phosphorous source in planning for Lake Claremont.

TABLE 10

Total Drain Water and Phosphorus Discharges to Lake Claremont

1.8.87 to 31.7.88

Drain	Catchment Area (m)	Season	Rain Water Volume (m)	Estimated Run-off Volume (m)	Calculated (rounded) $P-PO_4$ (g)	P Mass nr P (g)
D1	50 000	Winter	29 450	5 900	530	770
		Spring	2 700	500	70	40
		Summer	6 360	1 300	90	170
D2	170 00	Winter	100 130	20 000	1 600	2 000
		Spring	9 180	2 800	270	180
		Summer	21 620	4 300	950	600
D4	20 000	Winter	11 780	2 400	580	140
		Spring	1 080	200	20	10
		Summer	2 540	500	30	30
D5	100 000	Winter	58 900	11 800	1 650	120
		Spring	5 400	1 100	120	10
		Summer	12 720	2 500	350	370
D6	6 000	Winter	3 530	7 100	430	70
		Spring	320	60	4	1
		Summer	760	100	6	1
D7	100 000	Winter	58 900	11 800	590	470
		Spring	5 400	1 100	50	40
		Summer	12 720	2 500	130	100
ARITHMETIC TOTALS			(343 490m)	(74 960m)	(7 470g)	(5 121g)
TOTALS				75 000m	7.5kg	5kg

4.4 Lake Sediments

In recent years the great importance of lake sediments in influencing water chemistry has been widely recognized (Golterman, 1977; Cullen et al, 1978; Congdon, 1979; Somlyody and van Straten, 1986:4; Sly and Hart, 1989) and at the commencement of this project we hypothesized that the usual PO_4^{3-} adsorption-desorption by the sediments would control Lake Claremont's water phosphorus concentrations.

As the results in Section 4.2.4 (Discussion of possible mechanisms of phosphorus mobility) show it seems likely that at higher phosphate concentrations there is an additional mechanism influencing dissolved $P-PO_4$ concentrations. Although the chemistry is complicated by the linked nature of the potential reactions, calculations based on the concentrations measured in the lake show that depending upon pH, the formation of hydroxyapatite is thermodynamically favoured at high $P-PO_4$ concentrations, and in the lake there was a loss of $P-PO_4$ under such conditions.

However even when apatite formation was not thermodynamically feasible there were changes in the quantities of $P-PO_4$ in the water column, so other $P-PO_4$ removal and release mechanisms must be operating, and the calculations suggest that some aspects of these are associated with the precipitation of calcium carbonate.

What happens to the non-reactive phosphorus (condensed phosphates and organic phosphorus) is even less clear, but one possibility is adsorption occurred when the water column concentrations were high, and desorption when water column concentrations were low. Another is microbially mediated conversion, either to PO_4^{3-} or to biomass.

The re-release of adsorbed or precipitated phosphorus is of major significance to the lake, since sedimentation is the only natural mechanism for the removal of P from a closed lake, and with a steady inflow from the surrounding catchment, the phosphorus concentration has the potential to remain at excessive levels all year round.

It is therefore essential to examine the role of the sediments, in Lake Claremont's functioning. In the time available in this study, a large part of this has been done, but we suggest that more studies are desirable.

In 1950 Evans and Sherlock (1950) referred to a thin deposit of marl in the vicinity of the swamp "at a higher level than the present (1949) high water mark of Butler's Swamp", and then quoted records of 1844 describing the area as consisting of rich black soil (10-25cm deep) overlying shell marl (25cm thick) then rich black loam, varying in places to light peaty soil overlying coarse sand.

Our examination showed that, when the lake was dry, the western arm had a grey marly surface deposit of about 15cm thickness, with a sharp boundary to the underlying lighter coloured siltier soil. Both contained mollusc shells; a small turban shell tentatively identified as Gyraulus sp. (Family Planorbidae), and a smaller planar shell, possibly Physa sp. (Family Physidae). The surface soil also contained large (up to 2.5mm long) ostracod exoskeletons (probably Mytilocypris sp. (Family Cyprididae)).

The only sandy areas we noticed were around the edges of the present lake (now only 15 ha in area), extending 1 to 5m from the edge and averaging 2m.

When the soil was wet the surface sediments were soft, and we sank into them, often to depths of 50cm. Examined in this state all the sediments appeared to be homogeneous, calcareous, and dark grey. Sediments in the rush areas seemed a little softer than elsewhere; they contained living and dead roots and rhizomes, and carried a thin (1 - 5cm) layer of plant detritus on their surface.

Only surface sediments were examined for this project since they were anticipated as carrying the highest concentrations of phosphorus, and as phosphorus exchange from, or to, the overlying water was most probably from, or through, them. The large amount of water in the upper layers of the sediments added considerable uncertainty to a number of aspects:- what depth of dry soil was involved in this soft soil; what was the rate of movement of the pore water; in what ways did the entry and exit of this water influence phosphorus transfer into or out of the surface layers; and how fast did phosphorus move through this zone.

Most sediment samples were collected when there was no free water on the surface of that locality, both for practical reasons, and to minimize loss of fine particles in free water. For this reason the south arm sediments were not sampled, but we have no reason to expect them to differ greatly from those of the western arm. Soil sampling sites are marked on Figure 2.

Analytic figures for the sampled sediments are given in Table 11. Except for the W1 and W2 soils, the analysed samples were composites of the top 5cm of soil. Sample W1B was from the top of the underlying layer in the western arm (ie. from 15 to 20cm); samples $W2A_1$ and $W2A_2$ were respectively the top 1cm (ie. 0 to 1cm) and 1 to 5cm layers in one of the depressions in the western arm, and were collected under a thick layer of dried algae.

All the analysed sediments show very large concentrations of phosphorus. There is a distinct possibility that the samples contained crystals of phosphorus compounds deposited on drying out. Few published local lake sediment analyses are available to compare the Lake Claremont results with, but Teakle and Southern (1937) give values for phosphorus in various Herdsman Lake peats, extractable in boiling hydrochloric acid (probably equivalent to our total, less some organic, phosphorus), which after recalculation to P (from P_2O_5) range from 0.25mg/g - 0.08mg/g (Njookenboroo peat) to 0.61mg/g - 0.08mg/g (Njookenboroo loamy peat).

Congdon (1979) analysed samples from Lake Joondalup and obtained total phosphorus values in surface sediments ranging from 0.15mg/g to 0.97mg/g and Lukatelich (1985) quoted total phosphorus in Harvey Estuary sediments at 0.433mg/g. This was made up of 0.123mg/g organic phosphorus, 0.093mg/g "apatite" phosphorus, and 0.224mg/g of non-apatite inorganic phosphorus.

TABLE 11

Total phosphorus, organic content, carbonate and calcium content of air dried sediment.

Sample	Source		Total P (mg/g)	Organic (%)	CO_3^{2-} (%)	Ca^{2+} (%)
W1A	0-5cm, west arm	(30/3/88)	1.662	22	40	22.1
W1B	15-20cm west arm	(30/3/88)	0.470	15	51	37.1
$W2A_1$	0-1cm depression, west arm	(30/3/88)	2.841	33	30	-
$W2A_2$	2-5cm depression, west arm	(30/3/88)	2.610	26	36	35.3
W3	0-5cm, 5m out, site 2	(11/4/88)	1.186	26	30	21.3
E1	0-5cm, 4m out, site 4 in T. orientalis	(19/11/87)	0.940	-	-	21.3
E3	0-5cm, 4m out, site 4 in S. validus	(24/12/87)	0.475	7	12	7.9
E4	0-5cm, 10m out, site 4 in S validus	(24/12/87)	0.282	10	9	5.4
E5	0-5cm, site 4 in S validus	(24/12/87)	0.386	-	-	17.3
E6	0-5+cm, 12m out, site 4 in T. orientalis	(08/01/88)	0.519	17	37	25.6
E7	0-5+cm, 16m out, site 4 in T orientalis	(08/01/88)	0.896	27	33	20.4
E8	0-5+cm, 5m out, site [illegible] in T orientalis	(11/04/88)	0.826	25	25	15.1
E9	0-5+cm, 10m out, site [illegible] in T orientalis	(11/04/88)	0.894	29	32	20.0
E10	0-5+cm, 12m out, site 4 in T orientalis	(11/04/88)	0.966	30	29	17.9
E11	0-5+cm, 16m out, site 4 in T orientalis	(11/04/88)	1.044	30	32	19.6

While some of the Claremont figures are greater than these, in Lake Balaton (Hungary) which has sediments composed mainly of calcium carbonate, the total phosphorus concentration is about 200-600mg/g. (Somlyody and van Straten 1986:3).

The Lake Claremont results give average total phosphorus values of 0.87mg/g in the bulrush areas; 0.38mg/g in the lake club rush; and 1.42mg/g for the open surface (based on the W1A and W3 samples). In our opinion the W2 samples represent the P concentration in the depressions where the last water collected, together with all its nutrients and the algae, as the area dried up. These represent about 10% of the western arm (see Section 4.5).

4.4.1 Mass of Phosphorus Present

The value and use of the data in Table 11 depends upon a number of factors, most of them uncertain. One is the proportion of the different phosphorus compounds making up these total P quantities. Others relate to the quantities and speed of uptake of P compounds by the surface sediments as they now exist; how fast any of this P becomes bio-unavailable; and the extent and speed of P return to the water column, when water concentrations fall. Finally there are problems in generalizing from point source data to the distribution of surface and subsurface soil P content of the whole lake.

Using the total P values in Table 11, and the data in Table 1, the mass of P in the top 1cm of sediment is given in Table 12. The top 1cm of sediment was chosen as this will be the most important in any restoration program. An average sediment particle density of 1.76g/ml (soil W1A) was used.

TABLE 12

Estimated Total Phosphorus in the top 1cm of Lake Claremont Sediments in Autumn 1988 (All figures rounded)

Portion of Lake Bed	Area ($10^3 m^2$)	Tot. P concentration mg/g	Total P (kg)
90% of open area	105	1.4	2 600
enriched depressions (10%)	11.7	2.6	540
bulrush areas	14	0.9	220
lake club rush areas	1.8	0.4	10
		TOTAL	3 370 kg

As a check on the validity of this large figure (3.37 tonnes) we divided it by the weight of soluble phosphorus compounds estimated as carried into the lake in drain water in the 12 months (12.5kg), to get 270 years as the time for the build up. If allowance is made for the large, but unquantified amounts of insoluble material - including phosphorus containing humus - also washed in, and a natural level of phosphorus presumably there before settlement, the figure is more like 100 years, which is within sufficient range to be acceptable for basic management planning.

Not all the 3 tonnes is presently either bio-available, or available for exchange to the water column, and in the course of time the available P should decrease, through both diffusion away and chemical fixation, but in the meantime one question is how much more phosphorus can the sediments mop up until a management strategy is in action.

4.4.2 Phosphorus adsorption

To answer this we obtained some PO_4^{3-} adsorption isotherms with sediment samples. In general terms these showed that while the sediments are still capable of adsorbing large quantities of PO_4^{3-}, adding PO_4^{3-} also gave higher equilibrium water column phosphate concentrations.

For example, after shaking 2g of soil W1A, with 50ml of $P\text{-}PO_4$ solution three times a day, for three days, the solution $P\text{-}PO_4$ concentration fell, but the greater the starting phosphate concentration, the greater was the $P\text{-}PO_4$ concentration in the final solution. Thus for an initial solution of 8mg/L $P\text{-}PO_4$ the final solution was 1.0mg/L. For an initial solution of 56mg/L the 3 day resultant was 28mg/L. While these initial $P\text{-}PO_4$ concentrations are greater than any measured at Lake Claremont (maximum drain; D4, 0.961mg/L on 12/5/88; maximum water column; Site A, 0.422mg/L on 8/6/88) they show the sediments as establishing an equilibrium, not acting as a sink.

The results of the quantitative treatment of the adsorption results, using the Freundlich isotherm (Equation E3.1, Section 3) are shown in Table 13.

TABLE 13

Values of log k and $\frac{1}{n}$* obtained with Lake Claremont sediments, using the Freundlich isotherm

Sediment	Initial sediment total P mg/g (dry weight)	log K (± 10%)	$\frac{1}{n}$* (± 20%)
W1A	1.662	-0.88	$\frac{1}{1.94}$
W1B	0.470	-1.1	$\frac{1}{2.1}$
$W2A_1$	2.841	-0.9	$\frac{1}{2.0}$
$W2A_2$	2.610	-0.9	$\frac{1}{2.0}$
W3	1.186	-0.58	$\frac{1}{1.6}$
E1	0.94	-0.54	$\frac{1}{2.6}$
E8	0.826	-0.1	$\frac{1}{1.7}$
E10	0.966	-0.9	$\frac{1}{2.5}$
E11	1.044	-0.9	$\frac{1}{2.5}$

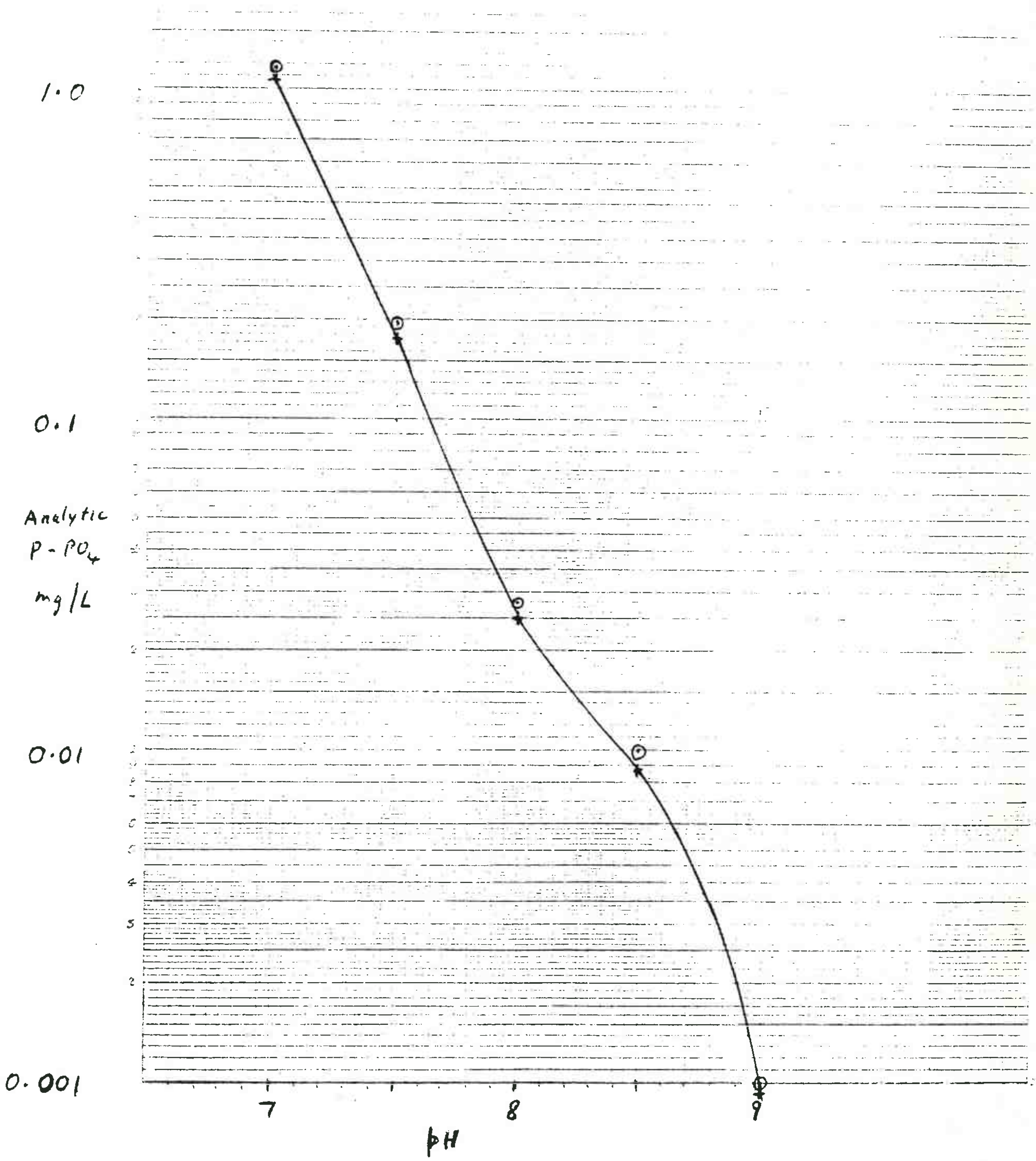
* Note units used in E3.1; mg/g (^{o}/oo) for x. but mg/L (ppm) for c

While the results in Table 13 suggest that all the peats were adsorbing PO_4^{3-} by a similar mechanism (values of $\frac{1}{n}$ similar) their magnitude suggests that in each case the process was precipitation of a calcium - phosphorus complex. Calculation of thermodynamic values for hydroxyapapite formation (by the method of Clark and Peech 1955) as was done for the water column - Section 4.2.4 for sediment W1, in aerated water at 22^{o} and with dissolved

Figure 17 Water column concentration of P-PO_4 in thermodynamic equilibrium with solid hydroxyapatite in the presence of 40 mg/L calcium ion, in the pH range 7 to 9 (T= 25°).

Ionic strength 0.03 +

0.25 ⊙



CO_2 in equilibrium with the air, showed that within the concentration range used (maximum initial P-PO_4 of 56 mg/L) the process was not apatite formation.

We interpret this as confirming that if P continues to flow into the lake, the water P concentration will slowly rise as the sediments adsorb more and more until it reaches a concentration controlled by the solubility of hydroxyapatite. To what extent, in the lake, the co-precipitation of phosphate with calcite would modify much higher PO_4^{3-} concentration is not readily apparent, as the isotherm experiments used potassium chloride to minimize calcium ion effects.

Should P-PO_4 concentration be controlled by hydroxyapatite solubility the concentration will be pH dependent. The relationship between pH and equilibrium P-PO_4, for 1mM calcium ion (40 mg/L) is given in Figure 17 to illustrate how much phosphate will be available in the water column. It is worth noting that as the concentration of other dissolved salts increases, so too does the concentration of phosphate.

4.4.3 Phosphorus release

The important question of the return of sedimented P to the water column at Lake Claremont is not answered. It is a complex problem since many factors contribute to both the speed and magnitude of release. These include the sediments and the water chemistry; the depth and wind mixing of the water, especially of oxygen; temperature; presence of plants; and sediment surface, including presence and type of burrowing animals. (Golterman, 1977). The water chemistry data (Appendix 8.3) shows that some of these factors are fairly constant (when water was present); deoxygenation was not observed in bottom water, even at the time of bird deaths, and salt (NaCl), calcium, and bicarbonate ion concentrations were always high, but others are variable or even unknown for Lake Claremont.

Return of PO_4^{3-} to the water column is also a central issue because unless there is either a rate, or concentration, limit to release that is significantly less than that required by nuisance plants - in this case *Anabaena* and *Anacystis* (*Microcystis*) species, P-PO_4 deposited on the surface sediment can be pulled back into use as it is needed. Since in laboratory growth trials on *Microcystis aeruginosa* cultures Okada, et al (1982) observed some growth even in nominally phosphorus free media (see also Section 4.5) it could be that a slow rate of release of sedimented P will be more important than a low equilibrium concentration.

Desorption cannot in general be predicted from adsorption experiments since different mechanisms are usually involved, but those adsorption isotherms which included shaking sediment in phosphate free water do show release of significant amounts of P-PO_4, as shown in Table 14.

TABLE 14

Concentration of P-PO_4 released from 2g of Lake Claremont sediment, shaken in 50ml of phosphate free water.

Sediment	Sediment Total P analysis mg/kg (ppm)	3 day equilibrium P-PO_4 concentration in distilled water mg/L (ppm)	in 0.05M KCl solution mg/L (ppm)
W1A	1660	1.1	0.6
W1B	470	0.4	0.85
W2A_1	2840	0.7	0.5
W2A_2	2610	1.0	0.7
W3	1186		0.1
E1	940		0.1
E8	830		0.2
E10	970		0.1
E11	1040		0.1

The large scatter in the values in Table 14 may arise in part from sediment properties, but probably also results from laboratory problems with ensuring all solutions were shaken adequately.

Sediment sample W1A was well shaken, and we consider it "typical" of the open water samples, so the thermodynamic (hydroxyapatite) values of Clark and Peech were calculated for the "three day equilibrium concentration" of the sediment in 0.05 M KCl. The ionic strength of 0.05 M potassium chloride was chosen as being more like that which exists in the lake when pools of water form on the sediment when the autumn rains come, than the nominally zero ionic strength of distilled water.

As expected the water was not saturated with respect to hydroxyapatite formation. One reason for this could be the slow rate of solution of hydroxyapatite (Hull and Hull, 1987). We however favour the alternatives, at least in the earlier stages of re-solution, that, either PO_4^{3-} is being released as calcite in which it was co-precipitated dissolves, or adsorbed PO_4^{3-} desorbs into solution. This is more consistent with the observations of the drying lake, but not with conditions observed in late summer (Site 1) or late May - early June (Site 2) where solid hydroxyapatite was in equilibrium with its dissolved ions.

While specific desorption experiments may give more information on the mechanisms, we think a more important task is to investigate methods of reducing water column phosphorus in late summer, in an attempt to reduce algal blooms.

Another area of useful investigation would be the rates of movement (diffusion) of phosphorus compounds through the sediments. This information could be used to calculate time requirements for establishing stable lower phosphorus concentrations in the upper sediment layer.

4.5 Lake Plants

The most conspicuous plants of Lake Claremont are the trees, the "reed" beds, and the alga. The trees, whether dead or alive hold their phosphorus for years, but the aquatic plants have annual or shorter life cycles, and this complicates determination of the phosphorus budget.

The aquatic plants observed during this study were the following:-

Three species of rush:- Bulrush (Typha orientalis); lake club rush (Schoenoplectus validus until recently classified as Scirpus lacustris); and one clump of jointed twig rush (Baumea articulata).

Three species of submerged, "rooted" plants:- Potamogeton pectinatus; and two species of stone wort (tentatively identified as Chara australis and a Nitella sp).

Epiphytic green algae on anything standing in the water during spring.

At least five species of floating algae (phytoplankton), of which the three most important were the noxious blue-green alga Anabaena spiroides and Anacystis sp. and an unidentified plant which grew in the shallows of the western arm during summer and left a phosphorus rich dried plant mat when the area dried out. The other two floating plants were a bloom of a **Chlorophyte sp.** at Site 3 in late summer, and lumps of grey green algal material (possibly Oscillatoria sp.).

While total quantity of plant matter (standing crop) is a factor in determining a species' phosphorus holding capacity, it is not the only one, and certainly it does not always reflect its importance to the lake's functioning.

4.5.1 Trees

Surrounding trees and associated understory would stop detritus from washing into the lake, as well as extracting water and phosphorus, with the latter then held in the tree (principally leaves and shoots) for an extended period.

The present marginal trees are mostly exotics, but they will hold phosphorus, although we did not evaluate its quantity.

The principal marginal trees in 1902 (Evans and Sherlock, 1950) were paper barks (*Melaleuca rhaphiophylla*), blackboys (*Xanthorrhoea preissii*) and eucalypts, presumably tuart (*Eucalyptus gomphocephala*) but possibly swamp gum (*E. rudis*).

The paperbarks (the tea trees in early references) appear to be particularly important, as they are credited with inhibiting bulrush and *Anabaena*/*Anacystis* growth. (There are several theories about this:- Their shade enables plants needing less sunlight than bulrush/*Anabaena* to outgrow them. Alternatively chemicals leached from the paper bark needles, or possibly bark, inhibit the growth of the blue green algae and the bulrush. It is even possible that nitrogen from the needles falling into the water, enables non-nitrogen fixing competitors of the blue green algae to remain competitive).

At present there are few paper barks at the lake, and most are small so we did not evaluate their phosphorus content.

4.5.2 The Rushes

Because of their density; ecological importance; and ability to assimilate phosphorus from both the sediments and the water column, we determined the mass of phosphorus in the two major rush species in the lake. Both species normally have an approximately annual cycle and during the latter part of it drop (phosphorus containing) dead plant matter into the water.

However bulrush and lake club rush are very different plants. Bulrush is a colonizing plant, pushing out rhizomes up to a metre a year, usually at a depth of 15-30cm below the litter layer. New shoots appear about March, and flower spikes appear from about December, while the wind borne seeds disperse in late March-April. Their maximum standing crop occurs about December.

Lake club rush is much shallower rooted (5-20cm) and the rhizomes much shorter, so that the vertical shoots give the impression of rising from a clump. New shoots appear after May; flowers and fruit develop after January; and seeds are shed about April-May. In pure stands the individual shoots, and their flower tassels, are smaller in all dimensions than the equivalent bulrush structures, but in mixed stands they appear to grow as tall as bulrush, and at Lake Carine they out grow bulrush in shady locations.

Both species have water depth limits, which have not been determined precisely, but are of the order of 80cm of overlying water for extended immersion. Also both species have been the subjects of considerable research into their ability to clean up highly enriched water, such as sewerage effluent. Both provide habitats for micro organisms and oxygenate the soil around their roots, thereby accelerating de-nitrification, and increasing P removal. (Chambers, 1984:2).

Macan (1974) notes that in the natural succession of lakes the nature of the substratum influences the species growing in each zone, with Typha the emergent macrophyte favouring where silt is particularly fine and plentiful. If this also applies in Western Australian conditions then it is possible that bulrush will spread only slowly west across the old Shenton Road.

TABLE 15

Aerial standing crop and phosphorus content of Lake Claremont rushes

Collection		Average Aerial Standing Crop		Weighted Average* P Content	
State	Date	No. stems per m^2	Dry weight (g/m^2)	by weight (mg/g)#	by area (g/m^2)
Typha orientalis					
Live	15/9/87	-	992 (±490)	2.318	2.3 (±1.1)
Dead	(4 sites)	-	previous season		
Live	9/11/88	28	2780 (±900)	1.439	4.0 (±0.3)
Dead	(3 sites)		480 (±170)	0.604	0.29(±0.09)
Live	8/12/88	28	1590 (±360)	1.465	2.3 (±0.4)
Dead	(3 sites)		306 (±40)	0.654	0.20(±0.04)
Live	8/12/88	16	1190	1.723	2.05
Dead	(mixed stand with *S. validus*)		240	0.625	0.15
Schoenoplectus Validus					
Live	8/12/88	436	1730 (±330)	1.624	2.81
Dead	(1 site)	30	590 (±90)	0.445	0.26
Live	8/12/88 (mixed stand with *T. orientalis*)	36	220	1.722	0.38

* Results weighted by the proportions of leaf and stem collected.

\# P determinations on samples of similar material from the same quadrant agreed within 3%.

Total areas of the two species in Lake Claremont, (given in Table 1B) are, bulrush 14,000m^2 and lake club rush 1820m^2.

Because of the organization of data collection, only the September Typha standing crop was obtained in 1987. So the 1988 standing crop was collected around the time of its maximum. Since in undisturbed stands, bulrush growth in Perth's bright light is more likely to be water limited, than restricted by any other seasonal factor, and since at Lake Claremont the rushes are in wet ground virtually all year, every year, we consider the year of collection of standing crop data provides less uncertainty than does stand variability. Stand variability, due to variation in size and rate of growth, is natural, (and also occurs in the lake club rush) but it makes estimates of the 1987-88 average maximum standing crop uncertain by about 25%.

Table 15 contains information on the standing crop of the rushes, and their phosphorus content, around the time of their expected maxima, during late 1988. While there is acceptable agreement between the P concentrations in each species in November and December, there are large differences in the Typha standing crop, both between consecutive months in 1988 and with the September 1987 sample.

4.5.2.1 Bulrush

From a comparison of the data in Table 15, with the figures for Herdsman Lake in Table 16 (Lantzke, unpublished) we consider a maximum standing crop of bulrush in Lake Claremont of 2kg/m^2 a reasonable approximation.

TABLE 16

Standing crop of above ground portions of _Typha orientalis_ at 2 sites in Herdsman Lake (Lantzke, unpublished)

	SITE 1				SITE 2			
Date	Standing crop dry weight (g/m^2)	No. of stems/m^2	P (mg/g)	(g/m^2)	Standing crop dry weight (g/m^2)	No. of stems/m^2	P (mg/g)	(g/m^2)
12/11/81	3275*	36	-	-	4424*	48	-	-
14/12/81	3212*	28	-	-	2566*	20	-	-
17/11/83	1512	-	1.40	2.117	1346	-	1.06	1.427
20/12/83	2572	-	-	-	453	-	-	-

* includes about 15% dead material

Roberts and Ganf (1986) in determining above ground mean maximum live standing crop of bulrush in a Murrumbidgee irrigation channel (where the same large stand variability was observed), found that 13% of the primary production of a season was lost from the plants prior to the time they reached maximum dry live weight standing crop, and a further 20% was produced after the maximum.

The Lake Claremont, December bulrush samples included about 19% dead material, consistent with Roberts and Ganf, and so the plants presumably produced about another 0.4kg/m^2 of green tissue before completely dying. In this case our best estimate of dead bulrush tissue falling into the water is 300g/m^2 of tissue dead by December, and 2.4kg/m^2 dying subsequently, again consistent with the annual above ground production of bulrush of 2334g/m^2 obtained by Roberts and Ganf in similar growing conditions (near Griffith).

The total P mobilized in above ground bulrush structures is therefore 3.516g/m^2 (live tissue) plus 0.200g/m^2 held in dead tissue or 52kg over all the bulrushes.

Because death of bulrush involves withdrawal of large amounts of minerals, we determined the density of dry green (live) and dry dead bulrush leaves, obtaining 0.24g/ml and 0.17g/ml respectively. Using these figures we calculate that the 2.4kg/m^2 of live leaves (dry weight) subsequently falling into the water, would have weighed only 1.7kg/m^2, and contained 0.654mg/g of P. Adding the 300g/m^2 of already dead material leads to a figure for the phosphorus return to the lake of 18kg (approximately 35%) of the mobilized P.

4.5.2.2 Lake Club Rush

Undoubtedly the variability in lake club rush stands is similar to that of the bulrush (ie at least 25%) but in the absence of more information we have used the December 1988 standing crop rounded to 1700g/m^2 dry live weight to calculate an estimate of the P mobilized by the specie. We have also used the bulrush density figures to calculate the weight of dead leaves eventually returning P to the water column.

The values are 5.5kg of P mobilized and 3.2kg (60% of the total mobilized) returned to the water. The much smaller area of lake club rush makes its contribution much smaller than that of the bulrush, but intrinsically it has similar mobilizing power as it produces a similar standing crop, containing a similar quantity of phosphorus. It also releases more of the mobilized P, although because of the way many dead stems lie in a mat above the autumn water level, this release probably does not occur until the water level rises again; a very important contribution to minimizing late summer, water phosphorus concentrations.

4.5.3 Other Aquatic Plants

The plants living totally in the water do not change the total P, but knowing how much is in that compartment at different times of the year gives information on how much phosphorus is available for animals to graze on, and how much could become available to the water column when the plants die (usually when the seasons change).

The general cycle in Lake Claremont at present is slow regrowth of the rooted submerged plants and small amounts of phytoplankton during late winter and on into early summer. In 1988 Chlorophyl a concentration in the central section of the lake rose from 20μg/L on 22/9/88 to 160μg/L on 26/10/88 (C. Nicholson, pers. comm.) These help oxygenate the water, and provide food for the herbivores and detritovores (see Section 4.6). As summer progresses with falling water levels, and rising water temperatures and pHs, the lake develops heavy growths of algae (not identified in this study) on open shallow areas, and increasing concentrations of blue-green algae in the southern portion. Drying out removes the algae in the shallow areas, and with the onset of rain the blue green's disappeared. The reason for the latter, very important, occurrence is not know.

The only submerged aquatic plants in sufficient quantity to justify phosphorus measurements were the late summer algae.

Table 17 records the weights of suspended solids (per litre) obtained in sampling the water column, between mid February and the first rains of April. Because blue-green algae have variable buoyancy it was necessary to sample the full depth of the water column, and this introduced unknown amounts of silt into every sample. This was particularly so on 9/3/88, when the total solids of 5.5g/L were obtained.

Because of the contaminating silt load, only the sample collected at the time of bird deaths (9/3/88) was analysed for phosphorus, since it was not practicable to separate PO_4^{3-} adsorbed on silt from P obtained from algae. Using this figure (1.256 mg/g) and the calculated water volume ($1368m^3$) we calculated that the water column contained about 9.5kg of P floating around, in, or on, suspended material. It was unfortunate that we could not distinguish between how much P was in the algae, and how much on sediments, as P on sediments would be more readily bio available. The water column at that time held about 0.3kg of total P in solution, at a concentration of 0.22mg/L.

TABLE 17

Algal concentrations at Lake Claremont, February - April, 1988.

	Site 1			Site 3		
Date (1988)	Concentration of suspended matter (g/L)	Major species	P (mg/g)	Concentration of suspended matter (g/L)	Major species	P (mg/g)
18 Feb	0.1852	Anabaena spiroides		0.2510	Chlorophyte sp	
9 Mar	5.5289	*Anabaena spiroides	1.25_6	1.5796	Chlorophyte sp	1.45_3
23 Mar	0.7569	A. spiroides & Anacystis sp		0.0904	Chlorophyte sp Chlorophyte sp	
12 Apr#	0.5813	none identified		0.7541	Chlorophyte sp	

* Bird deaths occurring

\# 18mm of rain during previous 19 days

As Site 3 was only a pool of less than $1m^3$ of water, the main interest of this is that it shows the possibility of other alga than blue-greens blooming if the water column phosphorus concentrations are consistently lower. (From December to mid February, Site 3 tot. P concentration was half (or less) of the value at Site 1).

The vital questions on the conditions that will not favour blue-green algae, such as Anabaena spiroides, and Anacystis (Microcystis) in our coastal lakes have not yet been answered. (Gerloff et al, 1952; Aplin, 1977; Congdon 1979; Gordon et al, 1981; Okada et al, 1982; Colman and Santha, 1988). Just lowering the water column $P\text{-}PO_4$ concentration does not appear to be the complete solution, but as the observations at Site 3 show, in a competitive, field situation it is possible for less harmful green algae to be the dominant species, at Lake Claremont.

We consider that practical field measures to reduce phosphorus levels in the water column, combined with long term monitoring and feed back into the lake's management, does provide a good option for the lake.

On 30/3/88 the surface soils of the dry western area of the lake were examined. In all the depressions there was a thin (0.4cm) crust of dried algae. A $2250cm^2$ ($\pm$11%) section of this, (air dried) weighed 366.7g and analysed at 2.84_1mg/g (air dried) total P. Twenty one $1m^2$ quadrats along a random 100m transect showed 11% coverage of the area ($65,650m^2$) with this algal mat.

On this basis there were about 33kg of P present in this crust.

In comparison with only ca 57kg held in rushes over ca $16,000m^2$ this is a surprisingly large quantity. It may contain a significant amount of P precipitated or crystalized from the drying water, and held in, or on, this crust, but the water of the western arm only held ca 5kg of total P on 4/1/88, at about which time interchange with the rest of the water ceased.

We therefore think that most of the algal P has been desorbed from the sediments (Section 4.4.3) and shows the store of bio-available P in the sediments to be so large that neither the equilibrium water column concentration, nor the rate of release is limiting for algal growth, at least in the warm, shallow, well illuminated waters in summer. It is well recognized that many algae are capable of luxury uptake of phosphorus, that is assimilating more than is immediately required for growth, and storing it as polyphosphate for later use. This seems the most likely reason for the large phosphorus load in these dried algae.

The high total P observed in the water column when the western section of the lake was drying up would appear also to have been released from these algae, which had been encouraged by the warm shallow water, then killed as the lake approached dryness.

4.5.4 <u>Summary of Mass of Phosphorus in Plants</u>

Table 18 summarizes the quantities of phosphorus calculated as involved with various plants over the period of the study.

The most unexpected of these is the large amount (33kg) left by the algae in the western arm of the lake, almost double that released from dead bulrush.

It does show that harvesting bulrush would remove some phosphorus, although the amount removed, if say one tenth the total area were cut (ca 5kg of P) would not even equal the amounts of phosphorus entering in storm water (ca 12.5kg).

TABLE 18

Summary of major plant phosphorus masses in Lake Claremont in 1988.

Plant	Time of maximum Standing Crop	P (mg/g) (dry weight)	Area Covered (in 1988) (m^2)	Average Plant Density g/m^2	Estimated Total P in Lake	
					held at maximum (kg)	available to water column (kg)
Bulrush	Dec	1.465	14,000	2,400	52	18
Lake Club Rush	Dec-Jan	1.624	1,820	1,700	5.5	3.2
West Arm Algae	Jan	2.841	7,200	1,600	?	33
Blue Green Algae (south arm)	March	$\gg$1.25 [6]	7,600	$\ll$ 99	9.5	?
Chlorophyte sp (site 3)	March	1.45 [3]	5	250	0.001	?

4.6 Lake Animals

While the animals constitute a significant phosphorus compartment of the lake, they are also frequently used to judge the state of a wetland. This ranges from subjective feelings about the health of popular animals, to detailed quantitative studies of the composition; nutrition and interactions of all the biotic members of the community.

It is therefore necessary in this section of the report to include information additional to the phosphorus budget. For this purpose we have dealt with Lake Claremont's animals in three groups, based on their habitats and their importance. These groups are; the aquatic macro-invertebrates; the birds; and the rest. And we will deal with "The Rest" first.

The "Rest" of the animals consist of the micro-invertebrates, about which we can say no more because of a regrettable lack of information, and the vertebrate creatures that people traditionally think of as animals. We saw dogs, and a few cats on the lake's surrounds; they looked to be domestic animals and none were seen entering or leaving the wetlands area. Rats and mice were also seen; the rats near Site 4 in a lake club rush stand during December, and in the bulrushes in January; the mice in long grass on the golf course in late summer. All four of these species could have contributed to the very poor breeding success of those ducks that produced hatchlings, but then, too, so could the tortoise and other birds.

No snakes were seen, and with so little vegetation left we doubt any remain in the region. On occasions lizards of several sorts were seen in sunny places around the lake.

In the water there were an estimated twenty plus long necked tortoise, and mosquito fish (Gambusia affinis) and carp were sighted between November and January. While these latter probably survived autumn, they were not seen again, as observation conditions were very poor then. Several species of frog were heard calling in November, and again in April as water returned.

While this is not the place to examine the methods whereby truly aquatic creatures colonize new waters, it is relevant to record that in the nineteen fifties (at least), Lake Claremont contained a native Goby (fish) specie, and carp (Dr G. Knight pers. comm.), and Mr A. Doepel, (see "Land Use Report") recalls transferring some "carp" from Mongers Lake to Lake Claremont in 1918.

There is insufficient data to permit any calculation of the quantity of phosphorus in the aquatic vertebrates. The fish (omnivores or carnivores) will only cycle the phosphorus within the aquatic pool, but the tortoise (omnivores) will add formerly terrestrial phosphorus to the aquatic pool whenever they eat land fed/grown material, such as dead birds and picknickers' scraps.

4.6.1 Aquatic Invertebrates

Table 19 summarizes the animal observations in both open water and rushes, in September, December, March and June. Presence of a specie during those months is marked with a letter recording the maximum observed animal density per litre.

In all, 31 distinguishably different types of animals were collected in the lake over the study. Only two species (6%) were found in March, and the greatest number of species in one habitat occurred in June (15 species (48%) in rushes; 11 (35%) in open water) and September (15 species in open water; 6 (19%) in rushes), while in December species numbers were still high (19 (32%) open; 13 (42%) rushes).

Only broad generalizations can be made from the results in Table 19 because of significant sampling variations in the data's acquisition. As described in Section 8.2 the sampling method was changed in mid 1988 from container capture to netting. Differences in sampling effort also arose from the number of samples at each site on any occasion. When animal numbers were large, samples were taken at three depths (top; middle; bottom) and all three analysed and recorded, whereas when animals were few and field time limited only single samples were taken, or if multiple depth samples were

TABLE 19

Seasonal variations in the aquatic invertebrate animal numbers in open (O) and rush (R) habitats in Lake Claremont 1987-88.

F(ew) 15; L(ow) 15-30; M(edium) 30-50; G(reat) 50 animals per litre.

TAXON	COMMON NAME	SEASON							
		SEPTEMBER		DECEMBER		MARCH		JUNE	
		O	R	O	R	O	R	O	R
PLATYHELMINTHES									
Turbellaria									
?*Tricladida sp.*	Flat worm								
ANNELIDA									
Oligochaeta	Aquatic worm								G
? Tubificid sp.									
Hirudinea sp.	Leech								
MOLLUSCA									
Gastropoda			F					F	F
?Gabbia sp.	Water snail								
ARTHROPOD									
Crustacea									
Daphnia carinata	Water flea	M						G	G
Simocephalus sp.	" "	F							
Ceriodaphnia quadrangula	" "	F			G				
Chydoridae		L		L					
Copepoda									
Calanoid sp.		F	G	G	G			F	F
Cyclopoid sp.				F				F	F
Ostracoda	Seed shrimp								
Mytilocypris ambiguosa		F						F	
Sarscypridopsis aculeata		F	G	F	F			G	G
Candonocypris novaczelandiae			F	F	F			G	G
Bennelongia Australis			F						
Kennethia cristata		F	G	F					G
Isopoda									
Paramphisopus palustris	Scud	L		M	L				F
Arachnida									
Hydracarina	Water mite							F	G
Diplodontus		F							
Hydracarina sp.									

TABLE 19

Seasonal variations in the aquatic invertebrate animal numbers in open (O) and rush (R) habitats in Lake Claremont 1987-88.
F(ew) 15; L(ow) 15-30; M(edium) 30-50; G(reat) 50 animals per litre.

TAXON	COMMON NAME	SEASON							
		SEPTEMBER		DECEMBER		MARCH		JUNE	
		O	R	O	R	O	R	O	R
Insecta									
Odonata									
<u>Zygoptera sps</u>.	Damsel fly								
Hemiptera									
<u>Micronecta robusta</u>	Water boatman	F		F	F		F	F	L
<u>Agraptocorixa hirtifrons</u>	" "	F					F		
<u>Anisops sp</u>.	Backswimmer				F				
<u>Merragata sp</u>.	Pond skater				F				
Coleoptera									
? Dytiscidae	Diving beetle								
Orange spotted sp.									
Black sp.									
Larval forms					F				F
Diptera									
Chironamidae sp.	Midges	F		F	F			F	G
Culicidae sp.	Mosquito			F	F			F	F
Stratiomyidae sp.	Soldier fly larva				F			F	
Trichoptera sp.	Caddis fly larva								

taken, only those showing animals were recorded. Finally sampling was carried out more frequently in September (3 times, at 2 sites of each type), than June (2 x 2, each site type), and December (1 x 2 for open; 1 x 1 for rushes) and March (1 x 1 both types).

Within these sampling constraints it is possible to make several comments. The first is that some species were so short lived (or poorly collected?) that they do not appear in Table 19. The second is that while some specie show definite habitat preferences (eg. Tubificid; Merragata) others appear to survive equally in both, and a few "migrate" from one habitat to the other as the seasons changed (eg. the Hemiptera).

This is significant since the aquatic fauna help to modify their environment, including the chemical environment. Bottom fauna are important in bio-transport, both of nutrient sediment particles to the surface, and of water and gases, especially oxygen, down into the sediment. Animals such as chironamids and tubificids are the most obvious examples, but the corixids (Hemiptera) contribute to water mixing and gas exchange at the top of the sediment layer.

A final observation from the information in Table 19 is that except for September, the rush habitat had as many (in October), or more, species present than the open water. This is a situation one of us has noted before at Herdsman Lake and Lake Carine (Lantzke, unpublished). It seems to us very likely that this results, at least in part, from the thermal sheltering of the shallow summer water by dense emergents, so that it does not reach the peak high temperature that occurs in equivalent open water. This is consistent with the hemipterans continuing to survive in the rushes, but not the open water (ie. to "migrate" from open water) in March.

Like species distribution (which is a guide to the lake's health), numbers (or weights) of animals were also greatest in June. On 21/6/88, by which time ostracod numbers were decreasing in the open water, the figures at Site 2 (representative of open water) were total animals (4 species) 130 per litre (59% water fleas) with a dry weight of 0.0257g, while at Site 4 (typical of rush habitat), total animals (10 species) of 130 per litre (53% water fleas) and a dry weight of 0.0568g were obtained.

Jorgensen (1979) gives the phosphorus: biomass ratio for copepods as ranging between 0.4% and 0.8% P on a dry weight basis, and in the absence of better information the median value of 0.6% P can be used to estimate the phosphorus mass held in the collected invertebrates. With the Site 2 collection this gives 0.15g of P in the animals in each cubic metre of water, while for the Site 4 samples it gives 0.34g of P/m^3.

Extrapolating these figures to the whole lake is tricky since the animals are not homogeneously distributed. The ostracods are bottom dwellers, while the water fleas move up and down the water column on a 24 hour cycle. They also drift with the wind to give patchy horizontal distributions. (On 21/6/88 the water flea counts were 794 animals/litre at Site 1, but 130 at Site 2). However, assuming the Site 2 data approximates to homogeneity both horizontally and vertically, gives an open area invertebrate phosphorus mass of about 8.5kg of P.

It is possible to compare the general biological health of Lake Claremont with the best, the worst, and the nearest of the five metropolitan lakes examined by Davis and Rolls (1987) (Lakes Jandabup, Joondalup, and Mongers respectively) by comparing invertebrate populations. Because their study used different levels of classification for some animal groups, it is necessary to collapse a number of categories, with some loss of information. It is also necessary, in order to draw meaningful comparisons, to assume that so far as invertebrates were concerned both seasons were equivalent.

Table 20 summarizes the species numbers, percentages and changes between autumn and winter in the four lakes. The table shows that Lake Jandabup, with an annual species total of 92% of the 39 common to the four lakes, and a summer minimum of 23% maintains greatest species diversity (generally a sign of ecological health). Lake Claremont with annual species number of:- 54% (open), 67% (rush), and summer minima of 0% and 5% respectively; Lake Joondalup (51% and 18%); and Mongers Lake (51% and 28%) show less diversity.

However in winter, while Lake Jandabup carried 56% of the common species, Lake Joondalup contained only 21%, whereas Lake Claremont carried 26% in open water and 36% in rush areas, and Lake Monger 36% also.

The phosphorus concentrations are interesting, as Lake Jandabup's tot. P did not exceed 50µg/L, whereas Lake Joondalup had much higher average tot. P with several peaks of around 200µg/L, while Lake Monger varied between winter-spring tot.P concentrations of around 100µg/L and values around 800µg/L for the rest of the year.

Although Lake Claremont has higher tot. P concentrations it has greater invertebrate diversity, and greater seasonal range in species abundance (as expected for a seasonal wetland), than Lakes Joondalup, and Monger.

We do not consider it valid to make interlake comparisons of particular animal numbers (eg seasonal densities) because of differences in methods in the two studies.

TABLE 20

Comparison of seasonal invertebrate diversity at Claremont, Jandabup, Joondalup and Mongers Lakes

		Lakes					
		Claremont			Jandabup	Joondalup	Mongers
Season		open	rush	total			
Autumn (March/April)	No of species	0	2	2	9	7	11
	% of common sp.	0	7	7	23	18	28
Winter (June/July)	No of species	10	14	15	22	8	14
	% of common sp.	26	36	38	56	21	36
Annual	No of species	21	26	27	36	20	20
	% of common sp.	54	67	69	92	51	51

No of common categories = 39

4.6.2 Birds

The intention of this section is to relate bird observations to the lake's phosphorus budget. A number of other aspects related to bird habitation at the lake are discussed in the section of the project 'Lake Claremont Bird Survey'. We also draw attention to the extensive observations of Clifton and Clifton, included, with permission, as Appendix 8.5.

Like the other animals, the birds are related to the lake's phosphorus budget in three ways:- by being a part of that budget; as being another mover of phosphorus; and as indicators of the health of the lake, assuming that this latter is related to its phosphorus budget, an aspect discussed shortly.

Table 21 is a summary of counts of water associated birds at the lake between 30/9/87 and 15/6/88. It shows only five species of water birds (Black Duck, Hybrid Duck, Seagulls, Dusky Moorhen and Western Swamphen) present on all sampling occasions, and a change from swimming to wading birds in summer, and back the other way in early winter.

TABLE 21

Monthly counts of water birds observed at Lake Claremont between 0630 and 1015 hours, 1987 - 1988

SPECIES	OCT	NOV	DEC	JAN	MAR	APR	MAY	JUN
Black Swan	29	57	89	11	-	-	10	6
Black Duck	27	61	139	123	8	5	90	17
Grey Teal	4	3	27	148	-	-	58	-
Blue Bill Duck	1	5	11	11	-	-	-	-
Pink-eared Duck	5	6	15	16	-	-	-	2
White-eyed Duck	1	-	2	-	-	-	-	-
Mountain Duck	1	-	4	4	-	-	10	4
Blue-winged Shoveller	2	-	2	14	-	-	-	-
Musk Duck	2	-	-	-	-	-	-	-
Hybrid Domestic Duck	10	6	13	14	18	3	2	2
Hoary-headed Grebe	1	-	1	-	-	-	-	4
Little Grebe	-	5	2	-	-	-	-	-
Australian Pelican	1	-	1	-	-	-	-	4
Black Cormorant	1	1	1	-	-	-	-	-
Little Black Cormorant	1	3	3	-	-	-	-	1
Little Pied Cormorant	1	3	2	-	-	-	-	-
White-faced Heron	-	-	1	2	-	-	-	-
White Egret	-	-	-	2	-	-	-	-
Sacred Kingfisher	-	-	-	1	-	-	-	-
Silver Gull	188	451	448	520	160	110	306	202
Caspian Tern	1	-	-	-	-	-	-	-
Black-winged Stilt	-	1	4	70	2	7	16	-
Black-fronted Dotterel	-	-	1	12	12	8	22	-
Greenshank	-	-	-	-	2	-	-	-
Wood Sandpiper	-	-	-	-	2	-	-	-
Coot	86	153	147	145	-	-	2	50
Dusky Moorhen	3	18	10	14	14	2	1	13
Western Swamphen	17	9	16	27	13	7	15	23
Marsh Crake	-	1	-	-	-	-	-	-
Clamorous Reed Warbler	20	32	25	34	4	-	4	7
Little Grassbird	1	5	2	4	-	-	1	5
Tree Martin	21	36	38	136	68	-	56	20
Welcome Swallow	88	89	84	230	140	92	251	68
All "Water Users"								
No. of birds	532	945	988	1538	443	134	844	428
No. of species	24	20	26	21	12	8	15	19
Water Fowl								
No. of birds (N)	402	783	839	1134	231	142	532	328
No. of species (S)	20	16	22	17	9	7	11	12
*H'	1.61	1.39	1.78	1.80	1.18	0.92	1.40	1.37
**J'	1.23	1.16	1.32	1.46	1.24	1.08	1.34	1.27

*H' = Shannon Weiner Diversity Index
**J' = Evenness

We have been unable to calculate the phosphorus content of this bird compartment because, to our surprise, we were unable to find the necessary data, despite the widespread recognition of the aesthetic and ecological importance of water birds.

[In passing we suggest that local secondary school students, after obtaining the appropriate licence from CALM, may be interested in quantitative studies of feeding preferences, nutrition and growth of common wetland birds, together with quantitative data on excretion (even average weight of droppings, let alone mineral composition)].

Fortunately, because of bird longevity and mobility we think the phosphorus in the bird compartment can be treated as a relatively constant quantity, not interacting with the other lake compartments. The amounts of P released from the few birds that die in the catchment, approximately balances that consumed by young birds and the few trans-equatorial migrants building up weight before leaving.

The role of the birds in phosphorus transfer is probably significant, but hard to unravel because of conflicting bird behaviour, and quantitative studies are needed to determine the balance. The formation of guano (rock phosphate) from marine bird droppings is well known, the phosphorus being transported from the birds' prey to the guano site. At Lake Claremont the Cormorants have been importing phosphorus over the years. During 1987-88 cormorants roosted on the dead paper barks, except when the lake was only a small shallow pool, and inter-alia excreted into the lake. This has been going on for some time; Emory et al (1975) recorded up to seven birds roosting in 1974, while during 1987-88 there were 9-20 birds roosting with a maximum of 40 on one occasion in early November. They were not seen to feed in the lake, except in December, confirming their role as phosphorus importers.

It is interesting to speculate if phosphorus contributed by Cormorants is the reason that the calculations (in Section 4.3.2) of the time required for present storm run-off P concentrations to build up 3 tonnes of P in the surface sediments was about 100 years : much longer than the present high flow rate can have existed.

The grass eating birds (eg the grazers such as coot and black swan) will transfer P in the grass, to where ever their droppings end up; most likely into the lake in run-off. But again there is insufficient data to guess at the magnitude of these processes.

The insectivorous birds, especially the terrestrially nesting species (eg welcome swallow), by eating midge and mosquitos provide an avenue for P removal, as well as an important service to neighbouring humans.

The "mud" feeders probably make no noticeable difference to the phosphorus balance, just cycling small amounts from their prey into the water in excreta, but the wader group is of great significance because it includes two trans-equatorial birds (Greenshank and Wood Sandpiper). The feeding habitat of these is mud flats, recently exposed by (slowly) receding water, and they feed from arrival (August) to departure (April), moving from lake to lake. Two Greenshanks and two Wood Sandpipers were sighted at Claremont on March 2nd , having arrived after January 11th, and departing before April 8th.

Both these species are covered by the China Australia Migratory Bird Agreement, and the Japan Australia Migratory Bird Agreement, which oblige all three countries to protect them. Implicitly this means protection of habitat, ie Lake Claremont mud flats (with food in them), even although the lake is not explicitly covered by the International Wetlands Species Agreement, because of its small area.

To reinforce this need to maintain Lake Claremont the RAOU, (pers. comm.) recorded a Black Tailed Godwit, another migrant covered by the Agreements, at Lake Claremont in Autumn 1989.

The use of water birds to assess the water quality and health of the lake needs to be examined carefully because, overall, there is no simple direct relationship between bird numbers (or species) and water quality. The preferences of some species for water of particular salinity does not appear to extend directly to other water quality parameters. This is unfortunate because birds are of such aesthetic interest that (despite this complexity of relationship) comments on wetland health are frequently based on selected birds, but factors within the region as well as in the lake, influence the usage of Lake Claremont; additionally, casual or short term, observations may be misleading.

A major reason for needing a regional view, is the mobility of birds. When conditions are not to their liking (or instincts), they can, and do, move out seeking a better habitat (Serventy and Whittell, 1976). This happened in summer (1987-88) with most of the water using birds, and was reversed for the waders when the rains came. Conversely if no better habitat is within reach, bird numbers on a wetland can build up far beyond optimum numbers.

Another complexity in using bird data comes from birds needing habitats that satisfy four different functions:- feeding; loafing; roosting (shelter); and breeding. Some species need four different habitats, others less, but these need not necessarily be on the same lake, a point made by the cormorants, which mostly fished in the river, but roosted at the lake. This interpretive problem is extended further by the range of habitats and food used by different species (Hnatiuk, 1985). Thus in March when the aquatic plant browsing ducks were being poisoned by the algal toxins, the waders fed, apparently unharmed, on the exposed mud flats only meters away.

It is through food that the influence of water column P is most direct. Too little P will mean limited plant growth and limited feeding for aquatic browsers and "hunters". Too much P (especially, it is thought, if the ratio of P to N increases as well) may produce noxious blue green alga - poisoning the aquatic plant eaters.

Also contributing to the complexity of using bird data, is the opportunistic breeding of many Western Australian water birds, whereas others follow seasonal patterns (Serventy and Whittell, 1976:2), thereby adding a further variable.

Problems of observation and misinterpretation can arise at Lake Claremont because, with its small size, it cannot provide all possible habitats, all year, and with the falling water levels of the district it is too shallow in most summers to adequately support deeper water, water fowl (regardless of algal toxins). Also the small size, and rapid seasonal changes make some habitats so small, or so fleeting, that it is possible to not notice their occupancy, or a change in them, over the years. For example if at Lake Claremont, Western Swamphen; Clamorous Reed Warblers; and Little Grass Birds breed in bulrush at the same density as at Herdsman Lake (Curry 1981) ie 2-3 pairs per hectare, then the 1.4 ha of bulrush will only carry 3 or 4 breeding pairs of each, and all 3 could be overlooked on one visit, while a change from 3 to 2 pairs over several years would also be missed.

In view of the issues discussed above it is our intention to consider the health of the lake in terms of its provision for each of the four bird requirements (food; rest; shelter; breeding) for the birds observed using it in 1987-88.

A comparison with the bird lists of 1972, 1974 (Emory et al, 1975), 1977 (Morris and Knott, 1979) and 1987-88 summarized in Table 22 show that during winter and spring the same species have been present for at least 16 years, although not all were sighted in the September observations, some being seen in October or July.

TABLE 22

Comparisons between bird usage of Lake Claremont in Spring and Autumn in 1972, 74, 77 and 87-8.

	Spring (September)				Late Summer (April)		
Date	5.9.72	24.9.74	14.9.77	30.9.87	7.4.72	3.4.77	8.4.88
Total Birds	81	51	126	367	114	467	136
Total Species	8	9	10	18	8	7	7
*H'	1.64	1.95	1.72	1.56	1.62	1.10	0.795
**J'	1.81	2.04	1.72	1.95	1.79	1.30	0.941

*H' = Shannon Wiener Diversity Index

**J' = Evenness

The values of H' (Shannon Wiener diversity index) and J' (Evenness) show this basic similarity in spring, despite the large number of seagulls present on 30/9/87 (188; half the birds counted).

The Autumn figures, though not so complete, suggest a change in the bird usage of the lake. In 1972 the birds observed were most of the species observed in winter; in 1977 the Little Grebe, an essentially fresh water bird (Serventy and Whittell, 1976:3), and the Blue Bill Duck, a deeper water bird, were "replaced" by Stilts. In 1988, there were only a few ducks present (Black and domestic/hybrid) with Stilts, Black Fronted Dotterel, and many seagulls present (on the exposed flats). This is shown also in the Diversity and Evenness indices, as the limited number of species, and large number of seagulls had a major effect.

We do not think there is a trend, rather a correlation between water depth (and possibly aquatic invertebrate numbers), and the species seen on the lake. By including the observations of Clifton and Clifton in 1978, 1985-87 (Appendix 8.5) with the other bird information, and using the ground water levels (Fig. 3) it can be seen that in an autumn with low water levels there were few ducks; with higher water levels more ducks remained.

In every year under consideration the winter rains proper did not commence until May (June 19th 1972), and waterfowl migration to inland breeding sites would not have commenced in April. The water depth in the southern arm can be estimated since on 31 March 1988 the adjacent WAWA bore level was 1.058m, and the lake water level was about 7cm, (ie the lake bottom is about 0.99m A.H.D.). Using this and the bore water levels, the water depths in Table 23 were estimated.

TABLE 23

Estimated water depth in the south arm of Lake Claremont.

Year	Month of minimum	Bore level (A.H.D.) (m)	Estimated maximum water depth (cm)
1972	April	1.317	33
1977	May	1.206	22
1978	February	0.935	dry
1985	April	1.040	5
1986	April	1.070	7
1987	April	1.090	9

The bird observations show that in 1978 a few coots; black duck; and the domestic ducks were the only "water" birds at the lake. In the Autumns of 1985, '86 and '87 there were falls in the numbers of Black Duck and Grey Teal, although less so in 1985 than in 1986, and congruent with the 1988 observations, no Swans and very few coots were seen. Conversely the observations show the presence of waders at the times of shallow water. We interpret this as indicating the lake to be in reasonable health in Autumn for waders, but only marginally so for ducks and swans, even in the absence of blue-green algae. In the presence of toxic blue green algae (as in March 1988) the lake is distinctly unhealthy for the browsing ducks, as shown by the deaths of 6 Mountain Duck; 8 Black Duck and 16 Hybrid/Domestic Ducks before the rains came.

In winter and spring, when the lake contains more water, it continues to provide food, shelter and loafing space for a number of water fowl. It also provides breeding areas for the birds listed in Table 24.

TABLE 24

Water Birds Observed Breeding at Lake Claremont, and Fledging Success

Species	Months* when hatchlings seen	Total No. of hatchlings seen	% reared (estimated)
Black Swan	O	8	100
Black Duck	O,N,D,J	27	80
Grey Teal	N,D	4	0
Blue Bill Duck	N,D	6	0
Pink Eared Duck	O,N,D,J	22	0
Little Grebe	N	2	0
Coot	O,N,D,J	16	100
Dusky Moorhen	N,D,J	12	75
Swamp Hen	O,N	5	100

* O = October
N = November
D = December
J = January

The high mortality of ducklings leads us to rank the health of the lake for rearing (fledging), as distinct from hatching, as low.

The most common reason for low rearing is predation (J. Lane, pers comm), and any plans to improve rearing should consider the provision of overhead cover to deter swooping birds (eg paper barks; swamp gum; and tuart further back from the water). It should also consider methods for protecting the rush areas and "islands" from rodents and ferrel (pet?) cats and dogs, by either blocking (or capturing?) intruders.

As a means of assessing the value (and health) of Lake Claremont as a waterfowl habitat we compare it in Table 25 with two nearby wetlands, Mongers and Herdsman Lakes. Perry Lakes, which are closer, are rather similar to Lake Claremont in available habitats, water depth and time of drying, although they both contain lesser concentration of dissolved salts and orthophosphate (Table 3; Lantzke, unpublished). Mongers Lake is much larger than Claremont, more open and contains permanent water. Herdsman is larger again and offers a wide range of habitats. To compare open water and a whole range of habitats, we have treated Herdsman as Floreat Waters Lagoon (permanent; open) and as a total lake (many habitats), the latter being a guide to the species diversity possible in the region. As a simple measure of carrying capacity we have used bird density (number of birds per hectare).

At the species level Floreat Waters and Mongers have more permanent (all year) species than Claremont, directly attributable to the permanent water, but also possibly assisted by available food (see Table 20). In spring Claremont has a greater number of species (21) than either the Lagoon or Mongers, but still only 57% of the range of aquatic birds of the total Herdsman Lake. This shows the high value of the diverse environment at Lake Claremont. In autumn the situation is very different with Floreat Waters carrying 86% of the species in Herdsman Lake and Mongers 69%, while Claremont only carried 25%.

At the level of bird density the results are similar. In winter Claremont carries 20 birds/ha, while Floreat Waters 13 birds/ha and Mongers 10 birds/ha are less densely used. In autumn the Lagoon and Mongers both carried 30 birds/ha (showing the great pressure on permanent water) whereas Claremont carried 14/ha.

Our conclusions are that during winter (and spring) Lake Claremont is a very favourable lake for "water living" water fowl, but it is of low value for these species as it dries out. However since it then provides feeding areas for the waders, including Greenshank and Wood Sandpiper this is an extremely valuable event.

TABLE 25

Water Bird Usage of Claremont, Herdsman and Mongers Lakes

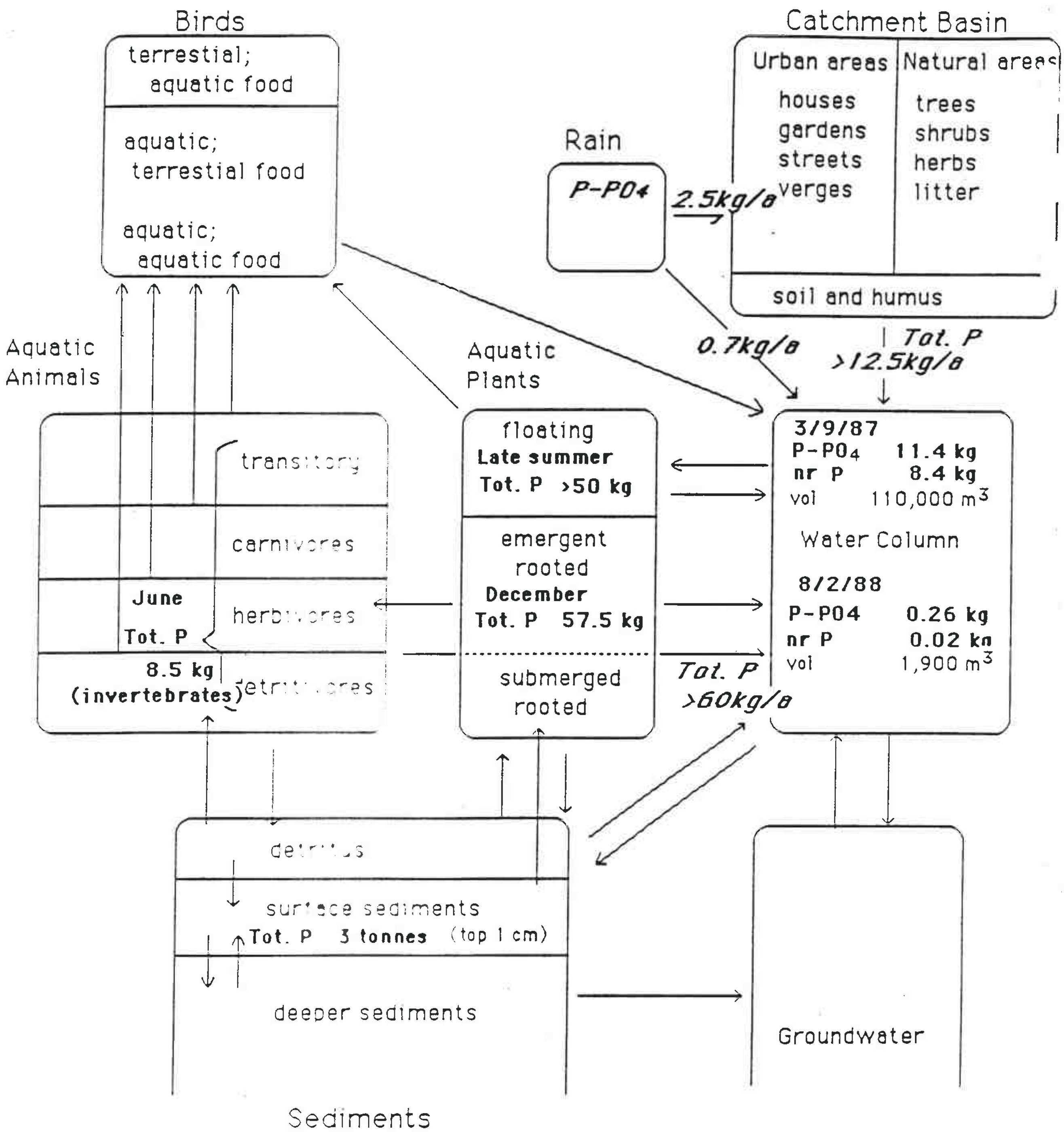
	Lakes			
	Claremont 1987-88	Herdsman (1) 1980-81 Floreat Waters Lagoon	Herdsman (1) 1980-81 Whole Wetland	Mongers (2) 1980-81
Approx max wet area (ha)	16	16 (3)	384 (4)	70 (5)
Number of all year species	5	9	23	9
SPRING (October)				
No. of species	21	17	37	15
Max. No. of birds	324	206	-	671
Bird density(/ha)	20	13		10
AUTUMN (March)				
No. of species	9	31	36	25
Max. No. of birds	223	466	-	2084
Bird density (/ha)	14	30		30

1. Bird data from Curry (1981)
2. Bird data by G. J. Roberts, Appendix 2 of Curry (1981)
3. Obtained by comparison of map areas of Lake Claremont and Floreat Waters Lagoon.
4. From Beckle (1984)
5. From Davis and Rolls (1987 : 3)

5.0 THE PHOSPHORUS BUDGET - 1987-1988 BALANCE SHEET

Figure 18 summarizes the masses of phosphorus found in the lake between August 1987 and August 1988 and also includes those annual fluxes which have been determined.

Fig. 18 Phosphorus Budget, 1987-88



The budget shows the major quantity of phosphorus to be in the lake sediments (3 tonnes in the top 1cm, which is 150 times as much P as was in the August water column in equilibrium with it). The sediment phosphorus appears to exert overall control on the phosphorus concentrations in the water.

Because of its much greater quantity, sediment phosphorus mass was effectively seasonally constant. The phosphorus content of all the other measured compartments was seasonally variable.

In August the equilibrium water column contained 11.4kg of $P\text{-}PO_4$ and 8.4kg of other dissolved phosphorus. On occasions (eg 29/9/87 when $P\text{-}PO_4$ was 16kg) greater masses of phosphorus were in solution, but natural lake processed reduced these to concentrations in equilibrium with solid hydroxyapatite in surprisingly short times (mostly less than 2 weeks).

In late summer the water (volume less than 2,000m^3) held 0.26kg of $P\text{-}PO_4$ and only 0.02kg of other soluble P.

During summer the plants had amassed large quantities of phosphorus (from the sediments), accumulating almost 110kg between them.

The maximum mass of phosphorus in invertebrate animals was 8.5kg in June. We do not know the size of the phosphorus pool in either the vertebrate animal compartment, or the aquatic bird compartment, but think that each is probably fairly balanced, not contributing greatly to the water column quantities.

The quantity of phosphorus in the catchment basin is unknown, and may well be unknowable.

The flows of phosphorus, although not as extensive as the budget figures, provide essential management information. Direct rain, onto the lake, provides up to 0.7kg per annum, and run-off contributes more than 12.5kg each year, to the water column.

The plants could release in excess of 60kg per annum to the water column, but whether this total quantity flows directly into the water, or only potentially enters the water via the detritus is not determined.

Flows between the sediments and the water column have not been quantified, but overall the sediments are net accumulators of phosphorus, receiving tens of kilograms of phosphorus, with only a small fraction of this mass of phosphorus being in the water column.

Of great importance, and not yet determined, is the rate of release of phosphorus from the sediments to plants, via the water column. This aspect, which is probably related only in part to the nature of the sediments, needs further investigation.

The contributions of ground water to the budget can not be calculated without values for its inflow and outflow. At present with low phosphorus concentrations in the entering groundwater, it is favourable for the lake. If (when) groundwater becomes richer (polluted?) with phosphorus this may cease to be the case.

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8.0 APPENDICES

8.1 Symbols and Units

a	Annum (year)
A.H.D	Australian height datum
Ca ; Ca^{2+}	Calcium; calcium ion
$CaCO_3$	calcium carbonate, chalk, limestone
$CaHPO_4 \cdot 2H_2O$	Brushite, dicalcium phosphate
$Ca_{10}(PO_4)_6(OH)_2$	Hydroxyapatite (unit cell formula)

Debye-Hückel Law $\log \gamma_{\pm}(25^{o}) = \dfrac{-0.5115\,|Z_1 Z_2|\sqrt{I}}{1 + 0.3291 \times 10^{8}\, a^{o} \sqrt{I}}$

where Z_1, Z_2 = ionic charges

a^{o} = distance of closest approach of two ions (in Angstroms)

I = ionic strength ($1/2\ C_i Z_i^2$)

Debye-Hückel Limiting Law $\log \gamma_{\pm}(25^{o}) = -\,0.5115|Z_1 Z_2|\sqrt{I}$

DO Dissolved oxygen

Fe; Fe^{2+}; Fe^{3+} Iron; iron ions

Freundlich Isotherm (E 3.1) $x = kc^{\frac{1}{n}}$ (see p. 15)

γ ; $\gamma_{\pm}$ Ionic activity coefficient; mean ionic activity coefficient.

HCO_3; HCO_3^- Bicarbonate; bicarbonate ion

Hydrologic budget equations (E4.1) $S = S_i + P_p - E \pm GW$ (see p. 22)

H' Shannon Wiener Diversity Index = — Pi ln Pi

where Pi = Ni/N

J' Evenness $= \dfrac{H'}{\log S}$ where S = No. of species

K; K^+	Potassium; potassium ion
Ksp	Thermodynamic solubility product
L	Litre
m^3	cubic metre = 1000L
Mg; Mg^{2+}	Magnesium; magnesium ion
mg	milligram (one thousandth of a gram)
μg	microgram (one millionth of a gram)
μm	micrometre (one millionth of a metre)
μs	microsiemens (an electrical conductance of one millionth
of	of a Siemen)
N	Nitrogen
O_2	Oxygen, dissolved oxygen
P	general abbreviation for phosphorus
P-PO_4	phosphorus (mass) present as orthophosphate (soluble reactive phosphorus)
PO_4^{3-}	Phosphate ion, orthophosphate
nr P	non reactive phosphorous; phosphorus not detected by a simple phosphorus test
Tot. P	Total of phosphorus (in all forms)
pH	measure of acidity/alkalinity = $-\log_{10}[H^+]$
ppm	parts per million = ug/g = mg/kg ; mg/L
S	Sulphur
SO_4;SO_4^{2-}	sulphate; sulphate ion
TDS	Total dissolved salts (expressed as sodium chloride)

8.2 Appendix

METHODS AND MATERIALS

1.0 Site Selection

The locations of the sites are shown in Figure 2.

The 4 water sites, and the 4 adjacent ground water sites were chosen in order to monitor the effects of groundwater inflow and outflow, and the effect of the rushes on the water and the invertebrate aquatic animals. When water levels fell, the water depth was calculated using the substratum gradient and the distance paced from the reference position to the actual sampling site.

Bird observation sites were chosen for ease of viewing a large sweep of habitat. Their locations are shown in the figure in the Lake Claremont Bird Survey (Gabriel, 1989).

Sediment sampling sites were chosen with a view to obtaining a reasonably representative coverage of the lake substratum. Any future study of the lake's substratum should consider taking samples from the south arm, and more samples from the western arm. Some sampling in every season of the year would also be informative.

1.1 Sampling Frequency

Sampling frequency was set at the maximum achievable, consistent with meeting all other intentions. Field water parameters and phosphorus concentrations were determined every two weeks, and all other lake variables every four weeks, except for aquatic animals during spring 1987, where collection and identification was also maintained on a two weekly basis.

This frequency was adequate for the determination of static quantities for the budget, but was not high enough to enable the rates of the processes, and some of the overall fluxes, to be evaluated.

3.0 Methods

3.1 Lake and Bore Water

Water sample containers (polyethylene and glass) were initially washed in 1:1 AR nitric acid, and distilled water rinsed. After each use they were scrubbed with phosphate free "Deacon", distilled water rinsed, and air dried.

Water column samples were obtained by pushing the collecting vessel, open end down, into the water to the desired depth then inverting it. Duplicate samples (1 in polythene, 1 in glass) were collected from approximately 10 - 15 cm below the surface (when the water was deep enough). During winter and spring single water samples were also taken (in polythene) from mid depth and from close to the bottom.

Bore water samples were withdrawn with a simple plastic extraction pump. The water in the bore was taken for the sample, because refill was too slow to permit pumping out and collection of fresh inflow. Also, results of analyses showed that significant changes occurred in the water over a two week period.

Samples were returned to the laboratory within four hours of collection.

Lake and bore water were tested in-situ for temperature, dissolved oxygen, pH and clarity. The following instruments were used. An EIL dissolved oxygen meter (Model 1520) fitted with a Mackereth type electrode and thermistor temperature sensor (DO and Temperature). This was recalibrated every 3 months. pH was measured with an EIL field pH meter (Model 3030) and a glass electrode. This was calibrated against commercial buffers before each set of measurements. Clarity was determined by lowering a 1m rule into the water until a 1 cm nail at the bottom end was just not visible. While this method is not directly comparable with Secci Disk readings it is more useful in a shallow lake, and experience has shown it to be about as reproducible as the latter.

Conductivity was determined on site with an Alfloc field conductivity meter, with a cell having a cell constant of 1.0.

Laboratory analysis of water used the methods given in Golterman, Clymo and Ohnstad (1978). Dissolved orthophosphate ($P-PO_4$) was determined on 0.45um membrane filtered samples, either within 6 hours of collection, or on water filtered and frozen within that time. The method of Murphy and Riley was used:- antimony catalysed; ascorbic acid reduced; phospho-molybdate complex; determined spectrophotometrically in 2cm cells at 882nm, on a Unicam SP 600 spectrophotometer.

Total phosphorus (Tot. P) was determined by the method of Murphy and Riley on cooled, neutralized samples, after filtered water had been hydrolysed (2 hours) with 0.15 M sulphuric acid at 120^{o}.

Bicarbonate was determined by titration with 0.025 M hydrochloric acid and methyl orange indicator, on fresh, unfiltered samples (glass container) within 12 hours of collection. Regardless of pH no allowance was made for carbonate, but even in late summer this would have constituted only a few percent of the total alkalinity.

Chloride was determined using an EIL laboratory pIon meter (Model 3050), with chloride and mercurous sulphate electrodes and sodium sulphate salt bridge. Direct concentration readings at constant ionic strength, (obtained with added potassium nitrate) were used after calibration with similar ionic strength 100 and 10,000mg/l chloride reference solutions.

Sulphate was determined turbidimetrically at 420nm in 1cm cells after the formation of barium sulphate in glycerol-ethanol stabilized, filtered samples, within 4 days of collection.

Potassium was determined by flame emission spectrophotometry with an EIL flame photometer.

Calcium was determined by EDTA titration at pH 12.8, using murexide indicator.

Magnesium was obtained by difference between total calcium and magnesium, and calcium alone. Total calcium and magnesium was determined by EDTA titration at pH 10, using eriochrome black indicator.

Nitrate was determined on 0.45µm filtered, freshly collected (<6 hours) samples by complexation of nitrate with chromotropic acid (4, 5-dihydroxy 2, 7-naphthalene disulphuric acid) in concentrated sulphuric acid, and measuring its adsorbence at 410nm.

Suspended solids were determined by filtering a known volume of fresh water through pre-dried, pre-weighed, glass fibre filter papers (Whatman GF/A), and re-weighing after oven drying.

Titrations were duplicated, and the average values used for calculations. Reagents were AR grade, and blanks as well as standards were carried through all chemical processes.

3.2 Rainfall and Drainage

Drainage basins were determined on the basis of personal observation of run-off, and interpretation from contours (Perth 2000 BG 34/08/22 map). The large areas of flat grass of the Scotch College playing fields, and the golf course were not included as catchments for the drains, since the magnitude and direction of their run-off was thought to be unimportant compared with that of the sloping areas.

Areas of the basin were calculated by gridding the map, and are accurate to ± 10%

Rain fall figures at Floreat weather station, approximately 3km north of the lake were used as a better estimate than the more extensive data at the Perth meteorology station, since records at the latter showed most of the sampled rain events occurred when the wind was N and NW. Rainfall frequency was determined using the hourly precipitation figures of the Perth station. Rain water samples for chloride and phosphorus analysis were obtained in 7 open 2L plastic ice cream containers placed on the ground and jetty at the south end of the lake on the evening of 24 June 1988.

Drain flow was determined in all but one case by measuring either the time for a given volume of discharged water to be collected, or the volume collected in a fixed time. In either case the accuracy was most limited by ability to actually collect the discharge. At some drains the drain outlet was only a few centimetres above a concrete spillway apron (eg D5); at others where there was sufficient height, the outflow water ran over the edge in a sheet much broader than any collecting vessel (eg D1). Errors of underestimation of water flow were much greater when the flow was large.

On 24/6/88 at drain D1 the flow was determined using Mannings formula (eg Gerhart and Gross (1985)) to calculate the water velocity.

$$V = \frac{1.0}{n} (Rh)^{\frac{2}{3}} (So)^{\frac{1}{2}}$$

where V = water velocity (m/s)

Rh = hydraulic radius = $\frac{A}{P}$ (m)

A = area of cross section of water (m^2)

P = wetted perimeter of the channel cross section (m)

So= slope of channel section

N = a surface roughness value taken as 0.014 for unfinished cement.

By measuring water depth in the pipe the area of liquid cross section and the wetted perimeter were calculated, and so the flow obtained.

The gradient of drain D1 was determined from the road grill at the north end of Stirling Road to its lake outlet as a fall of 1.246m over 116.44m, using conventional surveying equipment. (We are indebted to the Department of Civil Engineering, University of WA for the loan of this equipment).

A comparison of D1 water volumes obtained using Mannings formula, and by attempting to collect all the outflow over a measured time interval (eg on 12/5/88 and 1/6/88), showed the calculated water velocity to be similar to that estimated by timing floating paper "markers", but the calculated water volumes were considerably (2 to 16 times) larger than the collected ones.

Immediately prior to analysis, drain water samples were shaken, then aliquots were taken for determination of conductivity, chloride ion and phosphorus concentrations, using the same methods as for the lake water, except that the samples were not filtered. Unfiltered, shaken, water was used, as the intention was to determine the total amounts of phosphorus entering the lake, including P adsorbed on suspended matter. Phosphorus in, or on, the coarse particulate matter that settled rapidly was not determined.

The quantity of phosphorus in each monitored "rain event" was calculated by first graphing the observed flow rate, $P-PO_4$ and Tot. P concentrations manually against time (with some smoothing: see Fig 15 for an unsmoothed computer plotted example), then using points interpolated from every 5 minute interval to calculate the water volume, $P-PO_4$ and Tot. P quantities in that 5 minute period. These were then summed to give totals.

It is hard to estimate the accuracy of the results. The major error will be an underestimation of the total phosphorus amounts because of the underestimation of the water flow, especially with large flows. The average $P-PO_4$ and nr P concentrations used in estimating the total annual phosphorus discharge to the lake will not, of course, be influenced by inaccuracies in measurement of individual flow event volumes since these cancel in the calculation of the average concentrations. The accuracy of the total annual phosphorus discharges will depend directly upon the run-off factor selected. This was taken at 20% for reasons described in the main report.

3.3 Sediments

Sediment samples were mostly taken when the lake was dry, for a number of reasons. Firstly sediment sampling only became necessary by summer, and only phosphorus content was needed in this project. It was also much more convenient to reach the sampling sites and to be able to collect all the sample, and not have most of it wash out of the corer or off the shovel.

Samples were placed in freshly made polythene bags and once returned to the lab were either air dried or dried at temperatures below 37^o in stainless steel trays, in a forced air incubator. All samples were then ground to pass a 2mm sieve, and after mechanical mixing were bottled. Samples for analysis and experiments were scooped directly from the storage bottle.

Sediment analyses were carried out as follows:-
For organic content; by loss of weight on ignition at 550^o.
For carbonate; by back titration with freshly standardized (approximately 1M) sodium hydroxide solution, of excess 1.0M hydrochloric acid, after standing for 24 hours, with occasional agitation, with a known weight of sediment. End points were determined potentiometrically.

For elements; by acid digestion at approximately 180^o, of 1.0g of sediment in 10ml of HNO_3 : $HClO_4$ acid (4:1) in teflon beakers, until the acid was a clear yellow to golden colour. The cover glasses were then removed; temperature of the hot plate raised slightly; and the volume allowed to reduce to about 2ml. When cool, this was dissolved in distilled water and transferred quantitatively to a 50ml standard flask, made up to volume, and thoroughly mixed. Blanks and occasional phosphorus standards were carried through with the samples, and showed losses to be less than other experimental errors.

Phosphorous and sulphur were determined on aliquots of the digest, usually 0.4ml of digest for phosphorus, and 10ml for sulphur, using the same methods as for the lake water.

Fe, Mn, Ca and Zn were determined by Atomic Absorption Spectrophotometry on a Perkin Elmer, (Model 560) instrument, using standard conditions.

The phosphorus adsorption isotherms were determined by weighing into each of about 10 labelled flasks 2.0g of the ground sediment. Two burettes were set up, both containing solutions of approximately the same ionic strength. One contained 0.04M KCl solution. The other contained 0.05M KCl and 0.200g/L P-PO_4 (from 0.88g of KH_2PO_4

per litre of solution). To the first flask was added 50 ml of KCl solution. To the second was added 48.0ml of KCl (first) and then 2.0ml of the phosphate containing solution. The third received 46.0ml of KCl and 4.0ml of phosphate, and so on.

Flasks were immediately stoppered and shaken thoroughly. One drop of toluene (to inhibit mould growth) was added to each flask, and they were placed in a dark cupboard. the flasks were usually shaken 4 times each day, for 4 consecutive days. During early runs they were agitated less, and the results were rather erratic.

After 4 days the supernatant liquid was removed, centrifuged (to remove all suspended particles) and the residual $P\text{-}PO_4$ concentration determined using 10ml of it. The phosphate standards were prepared using the phosphate stock solution, diluted 1:5. Phosphorus was determined in the same way as the lake water.

The calculations necessary can be seen from Equation E3.1.

3.4 Plants

To sample the rushes, aerial portions were collected from 0.5m x 0.5m quadrats, usually selected by walking 2 or 3 paces into the stand, harvesting, walking a further 2 (or 3) paces towards (deeper) water, harvesting, and so on. While this method led to greater variation between the samples collected on each occasion, because of the slightly different water regime at different distances from the bank, it provided a more representative total sample for subsequent analysis and estimation of the standing crop of phosphorus.

Plants were cut into "stems", leaves, and flowers, dried in a forced air incubator at approximately 95^{o}, and weighed for standing crop. Ash free biomass was obtained by ignition of weighed samples at 550^{o}.

The amount of dried algae in the western arm of the lake (in late summer) was estimated by counting percentage cover in 1m x 1m quadrats measured on alternative sides of a 100m transect (location marked in Fig 2). The depth of the mat, and its phosphorus content were determined from the material collected from a randomly selected 0.5m x 0.45m plot, just beyond the transect.

Rushes and dried algae were collected and transported in freshly made polythene bags.

Blue-green algae in the southern arm of the lake (February-March) were sampled by vertically inserting a 3.2mm internal diameter plastic pipe into the water to just touch the bottom, placing a hand over the top end (to form a seal), and lifting up the tube, plus the column of trapped water and algae, and then emptying it into a collecting bottle. 1 L of sample was collected at each site. The algae, together with suspended solids and some sediment, were filtered onto pre-weighed Sartorius 0.45um filters, dried and re weighed.

Chemical analysis of plant matter was the same as that used for the sediments. In the case of the rushes a representative sample of plant parts was reduced to fibres and particles in a commercial blender and a sample of this used for analysis.

In order to calculate how much phosphorus was returned to the lake in dead rushes it was necessary to determine the change in density of rush leaves when they senesce. The analysis gave the phosphorus in dead leaves per gram of dead plant, but the only way to determine the total amount of plant matter was to collect and weigh it green. However as both Typha and Schoenoplectus withdraw significant quantities of nutrients and minerals as they senesce the actual leaf density changes.

We assumed that leaf volume did not change as the leaf died, and then determined the average density of dried green, and dried dead leaves. Mature green and full size dead Typha leaves were collected and dried. Their length and their width and thickness at 3 points were measured. The 3 points were 20cm from each end, and 1m up from the base.

Areas of cross section at each measured point was calculated on the assumption that all leaves had a cross section that was a segment of a circle. This was not always valid as some leaves remained slightly curled, but when measuring width these leaves were forced out flat on the underside.

Graphs of area of cross section versus distance from tip (or base) were (providentially) linear from the cut base up to 20cm from the tip. From 20cm to tip the area v length line was taken as linear, although it was bent relative to the main leaf line.

Volumes were calculated for the main part of the leaf by calculating the average area of cross section of the main portion of the leaf and multiplying it by (leaf length-20cm), and adding on the volume of the tip 20cm given by its average cross section times 20cm. We estimate an error of $\pm$ 2% in these volumes:

12 green typha leaves weighed 66.3g. Their total volume was calculated at 284ml (283.79cm^3). Density = 0.23g/ml.

12 dead rushes weighed 80.5g, had a calculated volume of 473ml, and density of 0.17g/ml.

On the basis of these figures we calculated that only 17/23 of the weight of the green Typha leaves would be left in the dry leaves.

3.5 Animals

Bird observations were initially made three times a day (0630 to 1015 hours; 1130 to 1520 and 1530 to 1920 hours) with 30 minutes spent at each site. (sites are shown in Fig 2). This was repeated for one whole week each month. Schedules and frequency were changed when it became clear that the rate of change of bird populations was relatively slow. Observations were than reduced to only one day per month. On a future occasion it might be preferrable to observe every second week, as the trans-equatorial birds were only observed once on the monthly cycle, and they could easily have been missed.

Bird identifications were confirmed using Slater (1970) and Wade (1975).

Aquatic animal collection techniques were also modified during the project. Initially sampling, identification and counting was carried out every two weeks. After November, when the spring flush was over, monthly sampling was used.

In May (1988) the sampling method was changed from taking water samples in wide mouthed jars (300ml or 1 L capacity) to a netting technique. This latter was standardized at using a 10 second sweep, from bottom to top, with a net of 250um pore size and $410 cm^2$ collecting area. Animals had then to be washed from the net into a tray using clean lake water.

Aquatic animal identifications used the following references:- Williams (1980); Smirnov and Timms (1983) and De Deckker (1978a, b), (1981).

Voucher specimens have been lodged with the WA Museum.

8.3 Appendix

Tables of Measurements of the Lake and Bore Water

The following points apply to these tables.

* Depth, is the water depth expressed as the height above, or below, the lake bed at the following measuring points:

Site 1:	the NE corner post of the jetty.
Site 2:	2m into the lake from the foot of the steep portion of the bank.
Site 3:	1m into the lake from the foot of the steep portion of the bank.
Site 4:	2m into the lake from the foot of the steep portion of the bank.

Lake water depths, relative to the Site 1 reference point are given in Table 2.

Bore water depths are the distances below the surface of the water at each bore.

Conductance is expressed as μS (x 10^{-2})/cm at 25^{o}
ie. a table figure of 31 = 31 x 10^{2} uS/cm.

TDS Total dissolved salts are expressed as the sodium chloride concentrations that would give the observed conductance.

HCO_3^- has been calculated from acid titration with no determination of, or allowance for, CO_3^{2-}, regardless of pH.

Site 1 Water Parameters

Wed, 12 Jul 1989 1:13 PM

	Date	Time (mth)	Depth* (cm)	pH	Conduct (25°)	TDS (ppm)	Temp (C)	DO (mg/L)	Clarity† (cm)	No. Spp.
1	11/08/87	0.35484	72	8.2	29	18.2	19.0	6.9	43.0	-
2	13/08/87	0.41935	75	-	-	-	16.0	7.5	46.0	-
3	18/08/87	0.58064	76	-	30	18.9	18.0	5.0	49.0	
4	24/08/87	0.77419	78	-	27.5	17.4	16.5	5.8	33.0	3
5	03/09/87	1.10000	78	8.2	28.5	18.0	17.0	7.0	43.0	5
6	15/09/87	1.50000	75	7.2	29	18.8	20.2	6.3	47.0	9
7	29/09/87	1.96667	74	7.9	29	18.1	18.2	6.8	33.0	7
8	13/10/87	2.41935	65	-	31	19.2	18.5	7.2	34.0	4
9	27/10/87	2.87097	61	-	33	20.8	21.5	7.0	23.0	5
10	09/11/87	3.30000	54	8.5	37	23.2	24.0	-	22.0	8
11	24/11/87	3.80000	42	8.7	40.5	25.9	20.0	3.7	16.0	-
12	08/12/87	4.25806	34	9.2	41.5	26.2	23.0	8.6	15.0	7
13	21/12/87	4.67742	24	9.1	50	31.5	25.0	3.9	6.0	-
14	04/01/88	5.12903	21	9.1	58	35.8	28.5	3.4	8.0	9
15	20/01/88	5.64516	6	9.2	70	44.3	23.5	4.0	2.0	-
16	08/02/88	6.27586	-8	9.3	120	74.6	33.0	3.3	7.0	4
17	22/02/88	6.75862	-11	9.3	240	151.7	27.8	7.9	5.5	-
18	09/03/88	7.29032	-15	9.2	240	151.7	24.0	8.6	5.5	0
19	23/03/88	7.74194	-14	8.0	89	56.7	23.5	8.6	4.0	-
20	12/04/88	8.40000	-14	9.1	94	58.7	22.5	8.7	6.0	1
21	26/04/88	8.86667	-13	-	230	145.0	-	-	7.0	-
22	10/05/88	9.32258	-6	8.6	100	63.1	21.5	7.2	10.0	7
23	23/05/88	9.74194	16	8.0	22	13.9	17.8	5.0	11.0	6
24	08/06/88	10.26667	31	7.8	39	24.9	16.6	9.4	27.0	5
25	21/06/88	10.70000	40	8.1	38	19.2	17.9	7.6	23.0	4
26	18/08/88	12.58064	84	8.3	28.2	17.8	18.0	13.8	-	-
27	09/09/88	13.30000	87	8.4	-	-	19.0	12.8	-	-
28	19/09/88	13.53333	84	8.8		-	-	-	-	-
29	07/10/88	14.22581	89	9.0	26.6	16.8	18	11.6	-	-
30	21/10/88	14.67742	-	-	27	17.0	-	-	-	-
31	28/10/88	14.90323	82	8.6		-	23.5	11.4	-	-

Site 1 Water Chemistry

Wed, 12 Jul 1989 1:10 PM

	Date	P-PO4 (µg/L)	Tot P (µg/L)	nr P (µg/L)	Cl (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	11/08/87	289	-	-	-	100	490	-	-	-
2	13/08/87	215	-	-	-	110	460	-	-	-
3	18/08/87	223	-	-	-	80	480	90	-	-
4	24/08/87	137	195	58	630	85	490	70	50	50
5	03/09/87	112	147	35	-	60	480	60	-	-
6	15/09/87	87	82	0	-	100	530	59	-	-
7	29/09/87	161	242	81	650	-	-	60	-	-
8	13/10/87	137	357	220	650	130	500	55	55	160
9	27/10/87	132	140	8	-	-	-	-	-	-
10	09/11/87	53	16	*	800	150	570	77	40	70
11	24/11/87	64	75	11	-	-	-	-	-	-
12	08/12/87	90	78	0	1880	110	550	85	35	65
13	21/12/87	23	121	98	-	-	-	-	-	-
14	04/01/88	125	164	39	1600	160	630	140	30	60
15	20/01/88	97	75	0	-	-	-	-	-	-
16	08/02/88	137	149	12	4600	240	980	300	30	110
17	22/02/88	381	86	*	-	-	-	-	-	-
18	09/03/88	590	222	*	10000	1400	2390	190	30	250
19	23/03/88	69	184	115	-	-	-	-	-	-
20	12/04/88	149	361	212	5750	1690	1010	560	50	270
21	26/04/88	301	345	44	-	-	-	-	-	-
22	10/05/88	95	233	138	5400	590	650	290	50	190
23	23/05/88	211	250	39	-	-	-	-	-	-
24	08/06/88	422	539	117	1400	160	440	95	62	95
25	21/06/88	309	356	47	-	-	-		-	-
26	18/08/88	110	132	22	600	200	400	-	52	63
27	09/09/88	-	-	-	600	230		-	-	-
28	19/09/88	120	208	88	600	180				
29	07/10/88	-	-	-	-	-	440	-	-	-
30	21/10/88	138	-	-	600	-	-	-	-	-
31	28/10/88	129	-	-	610	160	440	-	28	46

Site 2 Water Parameters

Wed, 12 Jul 1989 1:16 PM

	Date	Time (mth)	Depth (cm)	pH	Cond/100(25)	TDS (ppm)	Temp (C)	DO (mg/L)	Clarity (cm)	No. Spp.
1	11/08/87	0.35484	45	-	-	-	15	7.5	>45	-
2	13/08/87	0.41935	-	-	-	-	-	-	-	-
3	18/08/87	0.58064	56	-	30	1900	18.0	9.4	>56	5
4	24/08/87	0.77419	56	-	29	1800	16.5	5.0	>56	8
5	03/09/87	1.10000	48	7.1	29	1830	16.0	7.3	>48	8
6	15/09/87	1.50000	46	7.4	30	1850	21.0	9.0	>46	5
7	29/09/87	1.96667	52	7.6	30	1850	17.5	10.8	>52	4
8	13/10/87	2.41935	54	-	31	1960	20.5	8.6	>54	14
9	27/10/87	2.87097	40	-	34	2160	20.0	18.0	>40	-
10	09/11/87	3.30000	25	6.9	36	2200	24.5	-	>25	10
11	24/11/87	3.80000	18	8.6	38	2400	20.5	2.1	14	-
12	08/12/87	4.25806	16	8.9	42	2760	25.2	8.4	8	7
13	21/12/87	4.67742	1	8.9	55	3470	27.0	7.8	9	-
14	04/01/88	5.12903	-1	8.8	70	4410	27.4	7.0	7	6
15	20/01/88	5.64516	-9	9.0	100	6140	27.0	13.2	5	-
16	08/02/88	6.27586		dry						
17	22/02/88	6.75862								
18	09/03/88	7.29032								
19	23/03/88	7.74194								
20	12/04/88	8.40000								
21	26/04/88	8.86667								
22	10/05/88	9.33258		dry						
23	23/05/88	9.74194	-2	7.4	0.3	19	17.5	4.9	17	6
24	07/06/88	10.23333	20	7.0	53	3340	16.5	2.2	20	9
25	21/06/88	10.70000	27	7.6	45	2860	23	5.5	27	4
26	18/08/88	12.58064	66	8.7	28	1770	18	14.0	-	-
27	16/09/88	13.53333	-	8.8	26.5	1680	-	-	-	-

Site 2 Water Chemistry

Wed, 12 Jul 1989 1:14 PM

	Date	P-PO4(µg/L)	Tot.P(µg/L)	Nonrct P(µg/L)	Cl (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	11/08/87	200	-	-	-	100	500	-	-	-
2	13/08/87	200	-	-	-	90	480	-	-	-
3	18/08/87	100	-	-	560	50	500	60	-	-
4	24/08/87	90	130	40	610	80	500	60	50	65
5	03/09/87	100	200	100	-	50	500	60	-	-
6	15/09/87	110	90	*	-	100	540	50	-	-
7	29/09/87	150	240	90	650	-	-	60	-	-
8	13/10/87	130	310	180	700	110	510	60	40	285
9	27/10/87	90	20	*	-	-	-	-	-	-
10	09/11/87	60	50	*	830	140	560	80	40	70
11	24/11/87	60	70	10	-	-	-	-	-	-
12	08/12/87	110	90	*	1950	100	670	100	35	60
13	21/12/87	62	26	*	-	-	-	-	-	-
14	04/01/88	273	520	247	2900	140	850	160	45	110
15	20/01/88	138	170	32	-	-	-	-		
16	08/02/88			dry				dry		
17	22/02/88									
18	09/03/88									
19	23/03/88									
20	12/04/88									
21	26/04/88									
22	10/05/88			dry				dry		
23	23/05/88	68	217	149	-	-	-	-	-	
24	07/06/88	375	582	207	1600	370	480	130	93	108
25	21/06/88	416	455	39	-	-	-	-	-	-
26	18/08/88	186	189	3	760	-	410	-	-	-
27	16/09/88	113	194	81	600	170	-	-	-	-

Site 3 Water Parameters

Wed, 12 Jul 1989 1:20 PM

	Date	Time (mth)	Depth (cm)	pH	Cond/100(25)	TDS (ppm)	Temp (C)	DO (mg/L)	Clarity (cm)	No. Spp.
1	11/08/87	0.35484	-	-	-	-	-	-	-	-
2	18/08/87	0.58064	-	-	-	-	-	-	-	2
3	03/09/87	1.10000	65	8.2	21	1320	13.6	0.7	28	12
4	15/09/87	1.50000	60	7.8	30	1890	18.0	3.6	17	6
5	29/09/87	1.96667	58	7.0	21	1320	14.5	2.1	26	14
6	13/10/87	2.41935	51	-	31	1980	17.0	2.6	27	11
7	27/10/87	2.87097	39	-	24	1540	18.0	7.2	25	-
8	09/11/87	3.30000	45	7.8	19	1200	23.0	-	25	16
9	24/11/87	3.80000	25	7.2	19	1200	17.5	0.7	5	-
10	03/12/87	4.25806	23	7.0	18	1160	23.5	2.4	0	1
11	a21/12/87	4.67742	27	8.6	17	1050	24.0	8.2	17	-
12	a04/01/87	5.12903	21	8.4	16.5	1030	27.0	7.0	15	3
13	a20/01/88	5.64516	14	8.5	17	1050	29.0	7.6	7	-
14	a08/02/88	6.27586	9	8.5	26	1600	33.5	7.1	8	4
15	a22/02/88	6.75862	8	8.6	33	2000	28.0	7.6	5	-
16	a09/03/88	7.29032	9	9.0	40	2600	26.0	8.0	3	2
17	a24/03/88	7.74194	15	7.4	3	200	23.5	8.8	9	-
18	a13/04/88	8.43333	13	-	16	1010	22.5	8.8	2	2
19	a26/04/88	8.86667	8	-	17	1050	23.5	8.6	1	-
20	a10/05/88	9.32258	16	7.4	6	380	15.5	2.0	16	10
21	a23/05/88	9.74194	16	6.3	4	280	17.5	4.6	16	9
22	a07/06/88	10.23333	37	5.7	6	380	14.0	3.0	14	7
23	a21/06/88	10.70000	39	7.2	15	950	16.1	1.2	9	2
24	a16/09/88	13.53333	80	7.3	-	-	-	-	-	-

Site 3 Water Chemistry

Wed, 12 Jul 1989 1:18 PM

	Date	P-PO4(µg/L)	Tot.P(µg/L)	Nonrct P(µg/L)	Cl (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	11/08/87	-	-	-	-	-	-	-	-	-
2	18/08/87	-	-	-	-	-	-	-	-	-
3	03/09/87	14	80	66	-	70	690	40	-	-
4	15/09/87	16	14	*	-	70	630	45	-	-
5	29/09/87	76	210	134	380	-	-	40	-	-
6	13/10/87	11	310	*	460	30	760	40	130	240
7	27/10/87	14	10	*	-	-	-	-	-	-
8	09/11/87	37	3	*	290	10	770	30	85	30
9	24/11/87	0	20	20		-	-	-	-	-
10	03/12/87	1	20	19	630	2	760	20	60	60
11	a21/12/87	15	30	15	-	-	-	-	-	-
12	a04/01/87	55	40	*	240	4	550	40	55	35
13	a20/01/88	40	3	*	-	-	-	-	-	-
14	a08/02/88	40	70	30	825	21	760	80	60	40
15	a22/02/88	80	130	50	-	-	-	-	-	-
16	a09/03/88	570	260	*	10000	910	1100	960	20	280
17	a24/03/88	210	240	30	-	-	-	-	-	-
18	a13/04/88	50	80	30	620	22	920	80	50	45
19	a26/04/88	63	120	57	950	-	-	-	-	-
20	a10/05/88	30	310	280	280	38	360	50	100	40
21	a23/05/88	17	233	216	-	-	-	-	-	-
22	a07/06/88	57	102	45	100	31	270	18	100	30
23	a21/06/88	34	86	52	-	-	-	-	-	-
24	a16/09/88	90	405	315	290	20	-	-	-	-

Site 4 Water Parameters

Wed, 12 Jul 1989 1:23 PM

	Date	Time (Mth)	Depth*(cm)	pH	Cond/100(25)	TDS (ppm)	Temp (C)	DO (mg/L)	Clarity (cm)	No. Spp.
1	11/08/87	0.35484	-	-	-	-	-	-	-	-
2	18/08/87	0.58064	52	7.4	-	-	15.2	8.4	32	10
3	24/08/87	0.77419	-	-	-	-	-	-	-	-
4	03/09/87	1.10000	39	7.8	30.5	1920	16	5.4	40	10
5	15/09/87	1.50000	40	7.8	25	1540	20	5.7	40	8
6	29/09/87	1.96667	40	7.9	30	1890	16	7.8	37	8
7	13/10/87	2.41935	36	-	30	1890	18	2.3	24	11
8	27/10/87	2.87097	24	-	33	2080	18.5	7.3	24	-
9	09/11/87	3.30000	17	7.8	36	2270	22.5	-	15	13
10	24/11/87	3.80000	6	7.6	39	2490	17.5	3.5	4	-
11	08/12/87	4.25806	dry	dry						
12	21/12/87	4.67742								
13	04/01/88	5.12903								
14	20/01/88	5.64516								
15	08/02/88	6.27586								
16	22/02/88	6.75862								
17	09/03/88	7.29032								
18	23/03/88	7.74194								
19	12/04/88	8.40000								
20	26/04/88	8.86667								
21	10/05/88	9.32258								
22	23/05/88	9.74194	dry	dry						
23	07/06/88	10.23333	-9	7.0	36	2270	19.0	9.2	3	10
24	21/06/88	10.70000	2	7.3	42	2650	20.6	2.8	12	9
25	07/10/88	14.22581	50	8.5	27	1700	18	6.0	-	-
26	28/10/88	14.90323	43	-	27	1700	21.5	4.5	-	-

Site 4 Water Chemistry

Wed, 12 Jul 1989 1:21 PM

	Date	P-PO4(µg/L)	Tot.P(µg/L)	Nonrct P(g/L	Cl (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	11/08/87	-	-	-	-	-	-	-	-	-
2	18/08/87	-	-	-	590	80	520	60		-
3	24/08/87	-	-	-	-	-	-	-		-
4	03/09/87	70	72	2	-	80	550	50		-
5	15/09/87	32	110	78	-	110	590	-		-
6	29/09/87	17	137	140	680	-	-	60		-
7	13/10/87	96	460	364	690	80	600	60	55	190
8	27/10/87	82	11	*	-	-	-	-	-	-
9	09/11/87	161	98	*	800	330	600	80	60	60
10	24/11/87	21	83	62	-	-	-	-	-	-
11	08/12/87					dry				
12	21/12/87									
13	04/01/88									
14	20/01/88									
15	08/02/88									
16	22/02/88									
17	09/03/88									
18	23/03/88									
19	12/04/88									
20	26/04/88									
21	10/05/88									
22	23/05/88					dry				
23	07/06/88	59	120	61	800	670	490	95	250	90
24	21/06/88	52	59	7	-	-	-	-	-	-
25	07/10/88	-	-	-	-	-	460	-	-	-
26	28/10/88	148	-	-	630	140	460	-	28	46

Centre Sites

Wed, 12 Jul 1989 1:08 PM

	Site	Date	pH	Conduct(25)	Temp (C)	DO (mg/L)	P-PO4(µg/L)	Tot.P(µg/L)	SO4 (mg/L)	Cl (mg/L)
1	CEO	16/09/88	8.8	-	-	-	125	240	175	600
2		28/10/88	-	27	21.8	7.5	123	-	145	610
3	CER	16/09/88	8.7	-	-	-	93	238	195	600
4	CW	28/10/88	-	27	-	-	125	-	160	610

Bore 1 Water Properties

Wed, 12 Jul 1989 1:01 PM

	Date	Depth (cm)	pH	Conduct(25)	P-PO4(µg/L)	Tot.P(µg/L)	Cl (mg/L)	SO4 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	09/10/87	20	-	-	99	302	-	40	-	-	-
2	13/10/87	22		-	46	230	-	44	-	-	-
3	27/10/87	28		38	55	10	-	-	-	-	-
4	09/11/87	34	7.1	34	125	120	750	70	65	240	80
5	24/11/87	45	7.5	39	105	101	-	-	-	-	-
6	08/12/87	54	7.9	40	44	101	-	12	-	-	-
7	a20/01/88	70	7.4	37	9	0	-	-	-	-	-
8	a08/02/88	104	7.2	35	12	17	1020	1	54	90	40
9	a22/02/88	125	7.2	48	33	40	-	-	-	-	-
10	a09/03/88	156	7.2	43	52	63	2600	19	140	70	90
11	a23/03/88	152	6.8	40	44	69	-	-	-	-	-
12	a12/04/88	122	7.2	68	26	4	1500	390	124	188	140
13	a26/04/88	151	7.0	43	26	4	-	-	-	-	-
14	a10/05/88	138	7.4	26	3	380	4700	24	180	60	300
15	a23/05/88	78	7.5	103	18	234	-	-	-	-	-
16	a08/06/88	53	7.5	48	36	126	1200	590	72	320	120
17	a21/06/88	44	7.3	42	17	59	-	-	-	-	-

Bore 2 Water Properties

Wed, 12 Jul 1989 1:03 PM

	Date	Depth(cm)	pH	Conduct(25)	P-PO4(µg/L)	Tot.P(µg/L)	Cl (mg/L)	SO4 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	27/10/87	204	-	23.00	409	120	-	-	-	-	-
2	09/11/87	210	7.8	17.00	106	164	110	12	10	11	5
3	24/11/87	208	7.4	22.00	64	11	-	-	-	-	-
4	08/12/87	208	7.5	23.00	41	81	-	332	-	-	-
5	21/12/87	211	7.6	24.00	78	120	-	-	-	-	-
6	04/01/88	211	7.5	23.00	50	46	440	38	26	83	40
7	20/01/88	207	7.6	24.00	38	26	-	-	-	-	-
8	08/02/88	208	7.6	24.00	0	76	720	15	33	33	14
9	22/02/88	206	7.8	25.00	27	46	-	-	-	-	-
10	09/03/88	206	7.9	28.00	109	163	800	108	44	56	13
11	24/03/88	208	7.8	22.00	40	57	-	-	-	-	-
12	12/04/88	208	8.0	32.00	210	250	890	34	30	32	48
13	26/04/88	206	7.6	21.00	40	66	-	-	-	-	-
14	10/05/88	207	7.5	0.79	280	950	820	104	27	35	22
15	23/05/88	198	7.5	30.00	51	155	-	-	-	-	-
16	07/06/88	198	7.0	29.00	44	160	840	94	6	40	23
17	21/06/88	186	7.0	16.00	30	32	-	-	-	-	-

Bore 3 Water Properties

Wed, 12 Jul 1989 1:05 PM

	Date	Depth (cm)	pH	Conduct(25)	P-PO4(µg/L)	Tot.P(µg/L)	Cl (mg/L)	SO4 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	23/10/87	117	-	17	15	10	-	-	-	-	-
2	27/10/87	66	-	19	7	110	-	-	-	-	-
3	09/11/87	38	7.3	26	2	3	1400	130	22	730	20
4	24/11/87	49	7.2	24	12	11	-	-	-	-	-
5	08/12/87	50	7.2	25	0	14	1880	15	42	130	40
6	21/12/87	63	7.6	25	88	37	-	-	-	-	-
7	04/01/88	78	7.4	27	9	40	270	0.6	60	50	55
8	20/01/88	96	7.5	32	0	0	-	-	-	-	-
9	08/02/88	98	7.1	27	0	9	560	6	64	60	50
10	22/02/88	100	7.2	26	34	26	-	-	-	-	-
11	09/03/88	128	7.3	22	17	18	560	0.4	90	30	55
12	24/03/88	125	7.4	25	14	1	-	-	-	-	-
13	13/04/88	80	-	11	107	18	240	18	68	95	70
14	26/04/88	123	7.2	26	14	0	-	-	-	-	-
15	10/05/88	79	7.6	14	45	200	350	109	40	90	50
16	23/05/88	58	7.5	11	37	150	-	-	-	-	-
17	07/06/88	49	6.2	12	44	102	140	63	26	130	45
18	21/06/88	44	6.9	13	20	18	-	-	-	-	-

Bore 4 Water Properties

Wed, 12 Jul 1989 1:07 PM

	Date	Depth (cm)	pH	Conduct(25)	P-PO4(µg/L)	Tot.P (µg/L)	Cl (mg/L)	SO4 (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	09/10/87	30	-	-	45	312	-	60	-	-	-
2	13/10/87	31	-	-	14	165	-	50	-	-	-
3	27/10/87	36	-	80	20	10	-	-	-	-	-
4	09/11/87	43	7.2	85	15	14	235	400	50	170	125
5	24/11/87	55	7.4	95	39	43	-	-	-	-	-
6	08/12/87	63	8.0	94	44	620	-	2	-	-	-
7	a22/02/88	172	6.8	30	30	63	-	-	-	-	-
8	a09/03/88	175	7.0	30	30	5	2000	370	100	150	60
9	a24/03/88	124	7.2	30	30	0	-	-	-	-	-
10	a12/04/88	166	7.8	29	50	335	440	140	? 24	125	80
11	a26/04/88	119	[illegible]	28	40	0	-	-	-	-	-
12	a10/05/88	129	7.3	46	30	188	2900	1820	270	430	250
13	a23/05/88	80	6.8	75	14	187	-	-	-	-	-
14	a07/06/88	67	6.5	75	31	79	1700	1814	225	290	250
15	a21/06/88	56	6.9	65	23	101	-	-	-	-	-

8.4 Appendix

Results of invertebrate sampling

Key: F(ew)<15; L(ow) 15-30; M(edium) 30-50; G(reat)>50 animals per litre.
* eggs or "young" present

TAXON	COMMON NAME	DATE 18.8.87				24.8.87				3.9.87				15.9.87			
	SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PLATYHELMINTHES																	
Turbellaria																	
?*Tricladida sp.*	Flat worm																
ANNELIDA																	
Oligochaeta					F		F					F	F				F
? Tubificid sp.																	
Hirudinea sp.	Leech																
MOLLUSCA																	
Gastropoda																	
?Gabbia sp.	Water snail												F				
ARTHROPOD																	
Crustacea																	
Daphnia carinata	Water flea				F*	G	G			M		G		F	F		
Simocephalus sp.	" "				F							M		F			
Ceriodaphnia quadrangula	" "										F	F					
Chydoridae							F				L				F		F
Copepoda																	
Calanoid sp.				L		L	L			F		G	L	F		F	F
Cyclopoid sp.					F							G					
Ostracoda	Seed shrimp																
Mytilocypris ambiguosa											F						
Sarscypridopsis aculeata			F		F		F			F	F	G	G	F	F	F	G
Candonocypris novaczelandiae				F	F								F			F	F
Bennelongia Australis																	
Kennethia cristata												G					
Isopoda																	
Paramphisopus palustris	Scud		M		F		M			F	F	L	F		L		F
Arachnida																	
Hydracarina	Water mite																
Diplodontus			F			F	F					F	F	F			F
Hydracarina sp.																	

TAXON	COMMON NAME	DATE SITE	18.8.87				24.8.87				3.9.87				15.9.87			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Insecta																		
Odonata																		
Zygoptera sps.	Damsel fly					F*		F*										
Hemiptera																		
Micronecta robusta	Water boatman			F		F						F		F		F		F
Agraptocorixa hirtifrons	" "											F		F				
Anisops sp.	Backswimmer													F				
Merragata sp.	Pond skater												F				F	
Coleoptera																		
? Dytiscidae	Diving beetle																	
Orange spotted sp.																		
Black sp.																		
Larval forms																		
Diptera																		
Chironamidae sp.	Midges										F*	F*	F*				F*	
Culicidae sp.	Mosquito			F*		F*							F*				F*	
Stratiomyidae sp.	Soldier fly larva																	
Trichoptera sp.	Caddis fly larva																	

TAXON	DATE	29.9.87				13.10.87				9.11.87				8.12.87		
	SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PLATYHELMINTHES																	D
Turbellaria																	R
?*Tricladida sp.*								F				F	F				Y
ANNELIDA																	
Oligochaeta													F				
? Tubificid sp.																	
Hirudinea sp.												F					
MOLLUSCA																	
Gastropoda																	
?Gabbia sp.							F		F		F		F				
ARTHROPOD																	
Crustacea																	
Daphnia carinata					F	F		M*	L	L	F	M	L				
Simocephalus sp.																	
Ceriodaphnia quadrangula			F				F	F	F			F*	F			G	
Chydoridae			F	F			M	F	F	F	F	L	L	L		L	
Copepoda																	
Calanoid sp.		F	F	M	L	L	F		M	L	L	L	M	G	L	G	
Cyclopoid sp.				F				F				F			F		
Ostracoda																	
Mytilocypris ambiguosa							F				F		F				
Sarscypridopsis aculeata		F		F	F	F	M	F	M	F	L	L		F	F	F	
Candonocypris novaezelandiae				F	F		F		F		F	F	F	F	F	F	
Bennelongia Australis				F													
Kennethia cristata		F			F		F	F	F			L	L		F		
Isopoda																	
Paramphisopus palustris		F	F	F	F	F	F		F	M	M*		F	M	G*	L	
Arachnida																	
Hydracarina																	
Diplodontus		F		G	F	F	F	F	F		F	F					
Hydracarina sp.		F															

TAXON	DATE 29.9.87				13.10.87				9.11.87				8.12.87			
	SITE 1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Insecta																D
Odonata						F										R
Zygoptera sps.																Y
Hemiptera																
Micronecta robusta			F	F*		F	F*	F			F*	F		F	F	
Agraptocorixa hirtifrons	F								F		F					
Anisops sp.									F						F	
Merragata sp.			F												F	
Coleoptera																
? Dytiscidae																
Orange spotted sp.			F							F						
Black sp.							F				F					
Larval forms			F												F	
Diptera																
Chironamidae sp.			F*				F*		F*		F*		F*		F*	
Culicidae sp.			F*			F*					F*		F*		F*	
Stratiomyidae sp.															F	
Trichoptera sp.						F					F					

TAXON	DATE	4.1.88				8.2.88				9.3.88				12.4.88			
	SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PLATYHELMINTHES					D		D		D		D		D		D		D
Turbellaria					R		R		R		R		R		R		R
?<u>Tricladida sp</u>.					Y		Y		Y		Y		Y		Y		Y
ANNELIDA																	
Oligochaeta																	
? Tubificid sp.																	
Hirudinea sp.																	
MOLLUSCA																	
Gastropoda																	
?Gabbia sp.																	
ARTHROPOD																	
Crustacea																	
<u>Daphnia carinata</u>																	
<u>Simocephalus sp.</u>																	
<u>Ceriodaphnia quadrangula</u>																	
Chydoridae		L															
Copepoda																	
Calanoid sp.		G	M	G		L		M									
Cyclopoid sp.		G	G			L		L									
Ostracoda																	
<u>Mytilocypris ambiguosa</u>																	
<u>Sarscypridopsis aculeata</u>		L															
<u>Candonocypris novaczelandiae</u>		L	F			F		F						F			
<u>Bennelongia Australis</u>																	
<u>Kennethia cristata</u>																	
Isopoda																	
<u>Paramphisopus palustris</u>		L	L														
Arachnida																	
Hydracarina																	
<u>Diplodontus</u>																	
<u>Hydracarina sp</u>.																	

TAXON	DATE	4.1.88				8.2.88				9.3.88				12.4.88			
	SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Insecta																	
Odonata					D		D		D		D		D		D		D
Zygoptera sps.					R		R		R		R		R		R		R
Hemiptera					Y		Y		Y		Y		Y		Y		Y
Micronecta robusta		F		F								F				F*	
Agraptocorixa hirtifrons		L				L						F*				F	
Anisops sp.																	
Merragata sp.																	
Coleoptera																	
? Dytiscidae																	
Orange spotted sp.																	
Black sp.																	
Larval forms																	
Diptera																	
Chironamidae sp.		F*	F*														
Culicidae sp.																	
Stratiomyidae sp.			F													F	
Trichoptera sp.																	

TAXON	DATE	10.5.88				23.8.88				8.6.88				21.6.88			
	SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PLATYHELMINTHES			D		D				D								
Turbellaria			R		R				R								
?*Tricladida sp.*			Y		Y				Y								
ANNELIDA																	
Oligochaeta																	
? Tubificid sp.								F				L	G				
Hirudinea sp.																	
MOLLUSCA																	
Gastropoda																	
?Gabbia sp.				F			F	F			F	F	F				
ARTHROPOD																	
Crustacea																	
Daphnia carinata		G				M*				G*	G		G	G	G		G
Simocephalus sp.																	
Ceriodaphnia quadrangula		F															
Chydoridae		F															
Copepoda																	
Calanoid sp.				M		F									F		F
Cyclopoid sp.				M		F								F			F
Ostracoda																	
Mytilocypris ambiguosa											F						
Sarscypridopsis aculeata		G*				G*	G	F		G	G		G	F	M		L
Candonocypris novaczelandiae		M				G*	G	F		G	G		G	F	F		F
Bennelongia Australis																	
Kennethia cristata		L										F	G				L
Isopoda																	
Paramphisopus palustris																	F
Arachnida																	
Hydracarina																	
Diplodontus							F	F		F	F	F	G				F
Hydracarina sp.																	

TAXON	COMMON	DATE	10.5.88				23.5.88				8.6.88				21.6.88			
	NAME	SITE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Insecta																		
Odonata				D		D				D								
Zygoptera sps.				R		R				R								
Hemiptera				Y		Y				Y								
Micronecta robusta					L		F*		L*			F	L*				F	
Agraptocorixa hirtifrons					F													
Anisops sp.					F													
Merragata sp.					F													
Coleoptera																		
? Dytiscidae									F									
Orange spotted sp.																		
Black sp.					F													
Larval forms								F					F					
Diptera																		
Chironamidae sp.			F*		F*				F*		F*	F*	F*	G*				F*
Culicidae sp.					F*			F*	F*			F*					F*	
Stratiomyidae sp.					F									F				
F																		
Trichoptera sp.																		

8.5 Appendix

Records of water-bird sightings made by:

D and C CLIFTON

(Honorary Lake Claremont Wardens)

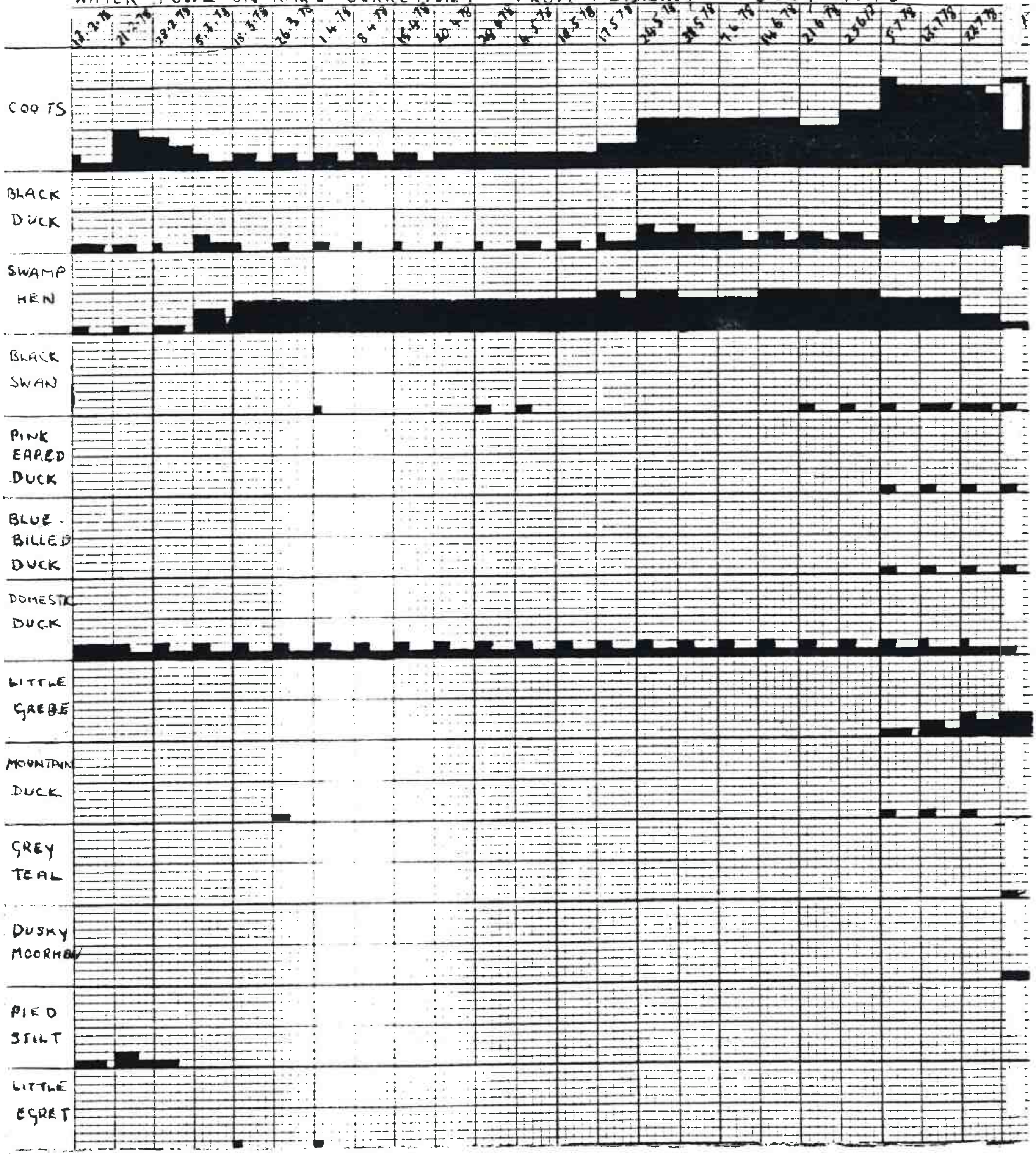
A summary of bird numbers in the periods:

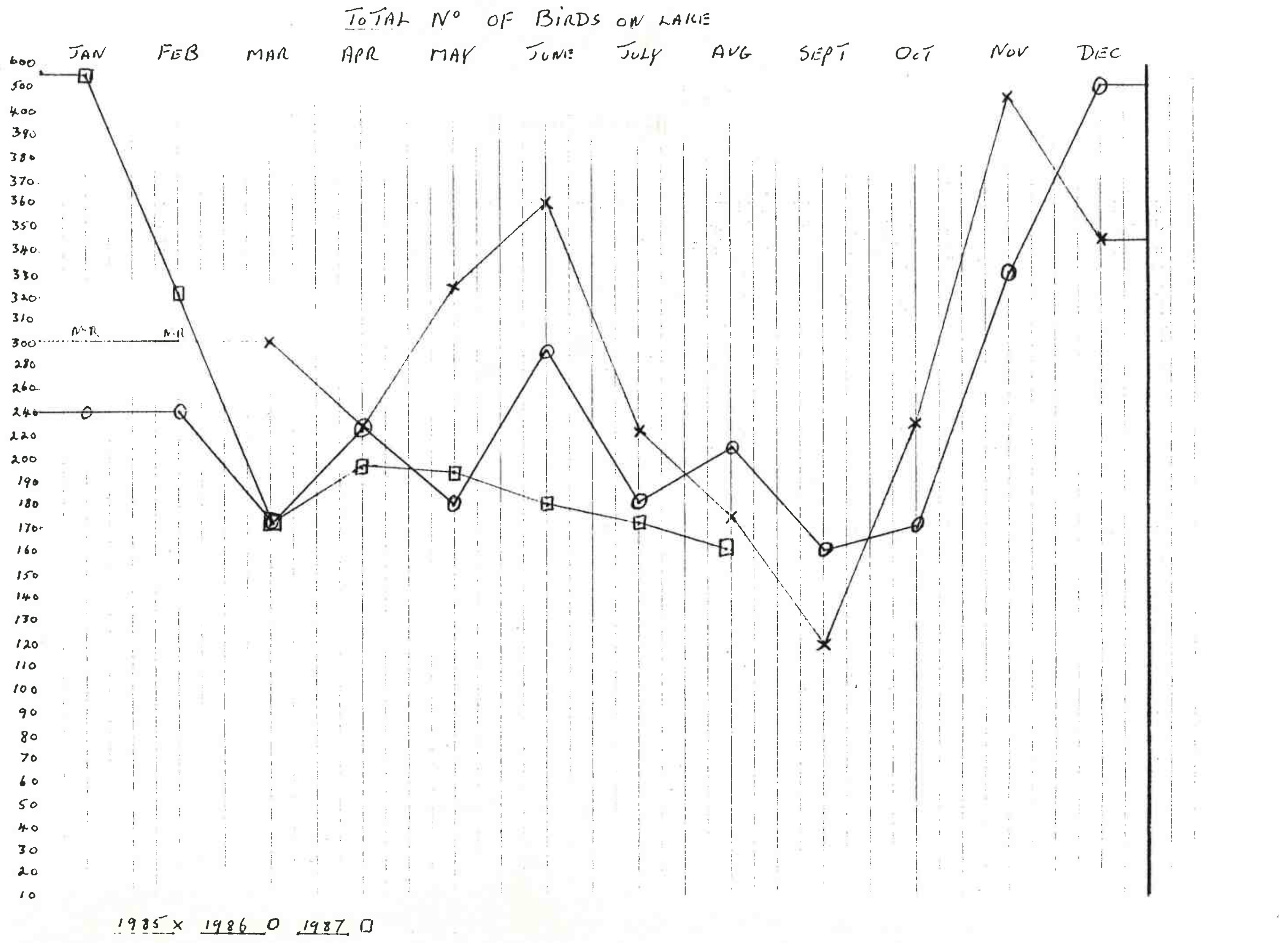
February to July 1978

and

March 1985 to August 1987

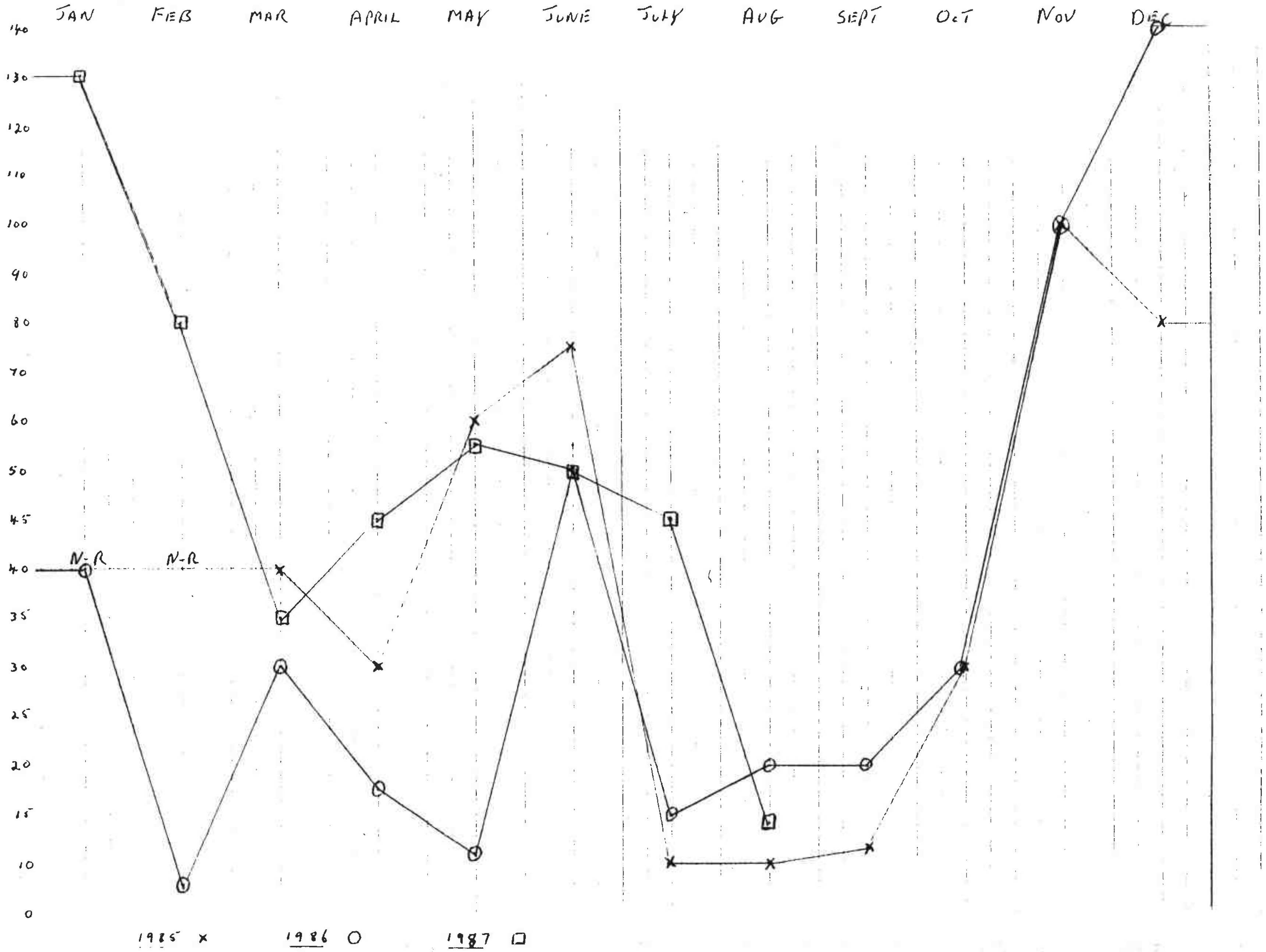
WATER FOWL ON LAKE CLAREMONT FROM FEBRUARY - JULY 1978



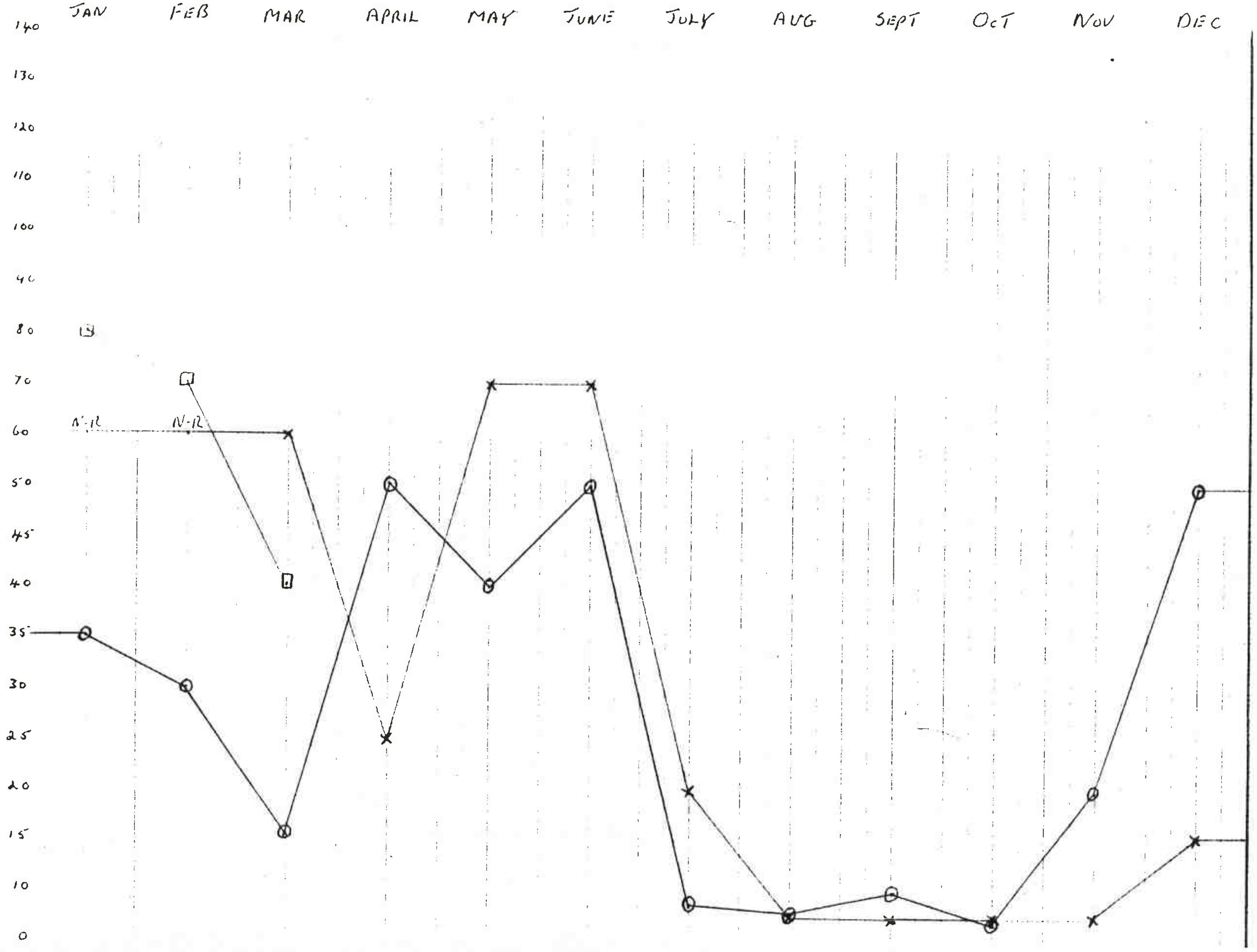


TOTAL No OF BIRDS ON LAKE
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
600 500 400 390 380 370 360 350 340 330 320 310 300 280 260 240 220 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
N-R
N-R
1985 x 1986 O 1987 □

BLACK DUCK

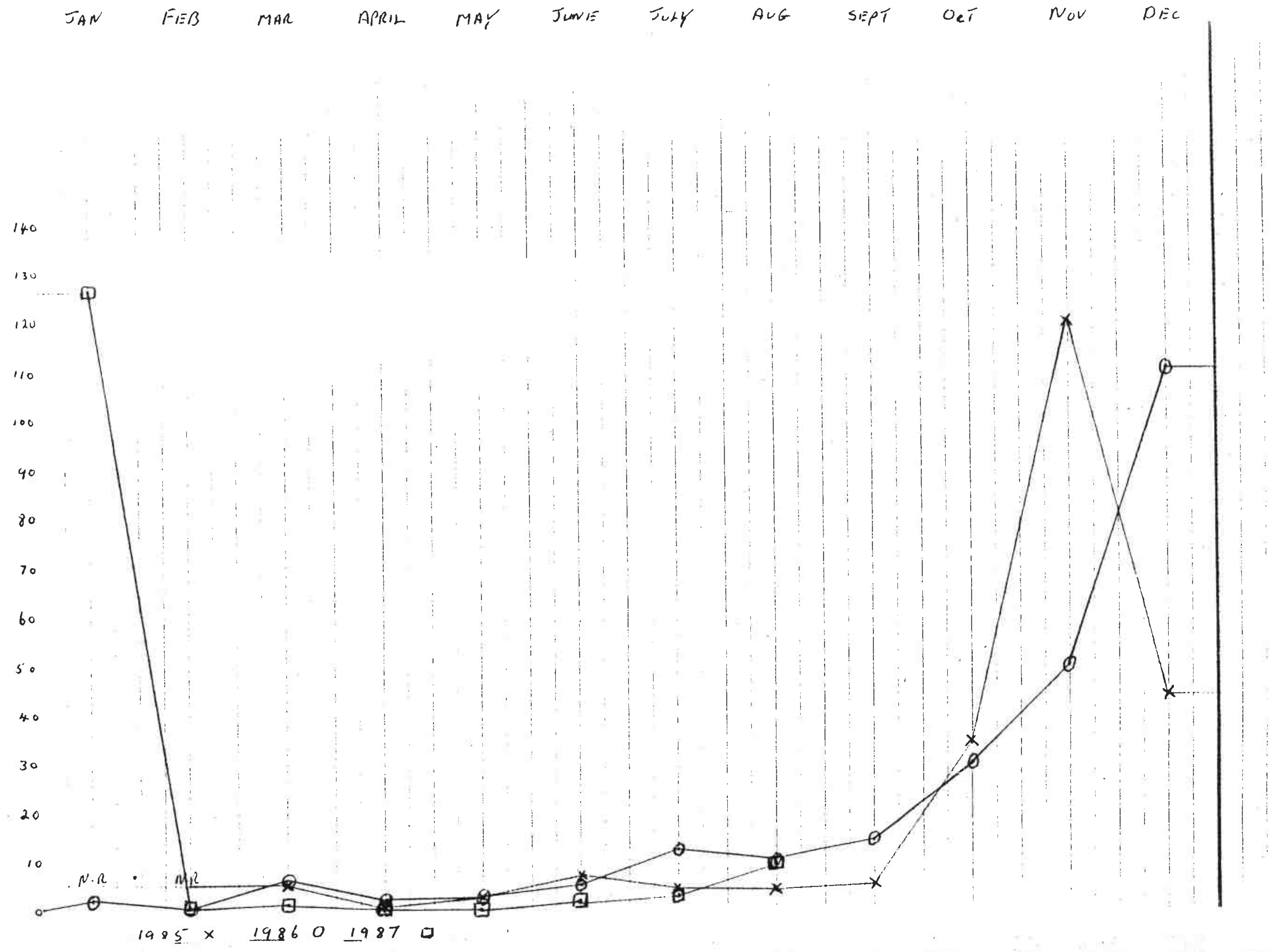

JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
140
130
120
110
100
90
80
70
60
50
45
40
35
30
25
20
15
10
0
N-R
N-R
1985 x
1986 O
1987 □

GREY TEAL

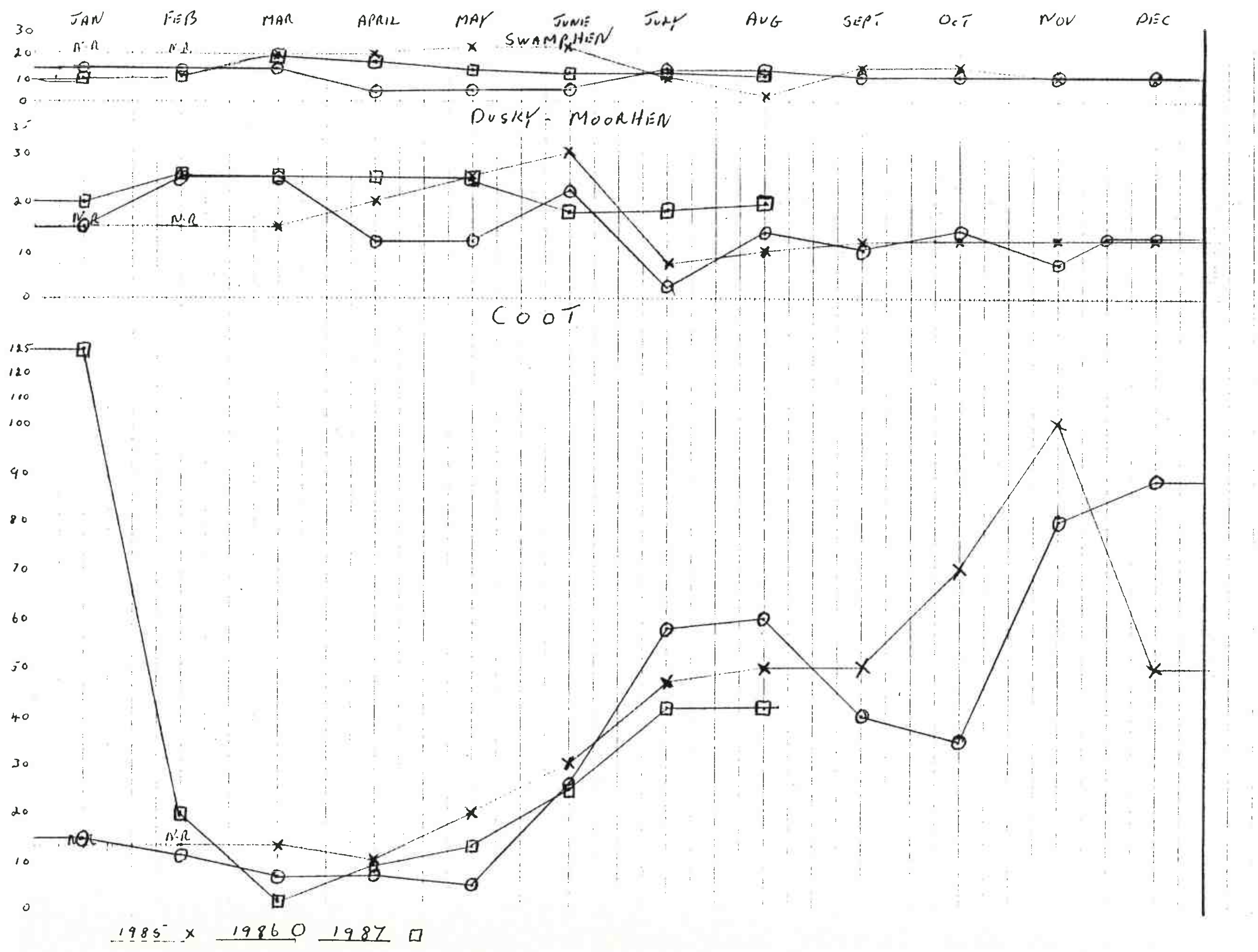


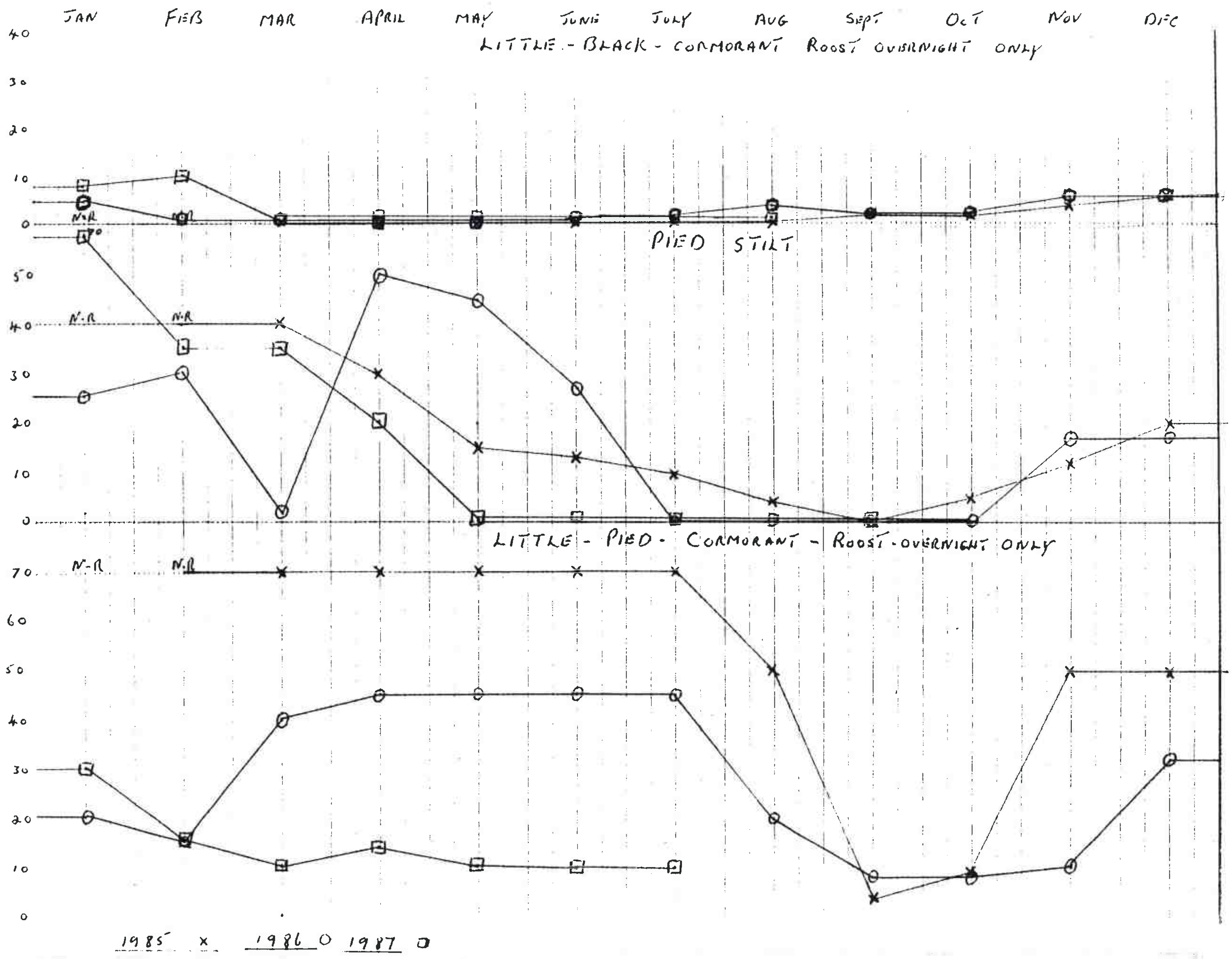
1985 × 1986 O 1987 □

BLACK SWAN



JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
140
130
120
110
100
90
80
70
60
50
40
30
20
10
N.R
N.R
1985 ×
1986 O
1987 □


JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
SWAMPHEN
DUSKY - MOORHEN
COOT
N.R
1985 x
1986 O
1987 □


JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
LITTLE - BLACK - CORMORANT ROOST OVERNIGHT ONLY
PIED STILT
LITTLE - PIED - CORMORANT - ROOST - OVERNIGHT ONLY
N-R
1985 x 1986 O 1987 □

3812X:CH

LAKE CLAREMONT

BIRD SURVEY 1987-88

by PHILLIP GABRIEL
RESEARCH OFFICER FOR THE
TOWN OF CLAREMONT

July, 1989

CONTENTS

LIST OF FIGURES AND TABLES

INTRODUCTION

This report forms part of an overall attempt to understand some of the principal ecological variables operating at Lake Claremont. The Claremont Town Council commissioned the Lake Claremont Project in July of 1987 and it formally commenced on August 10, 1987.

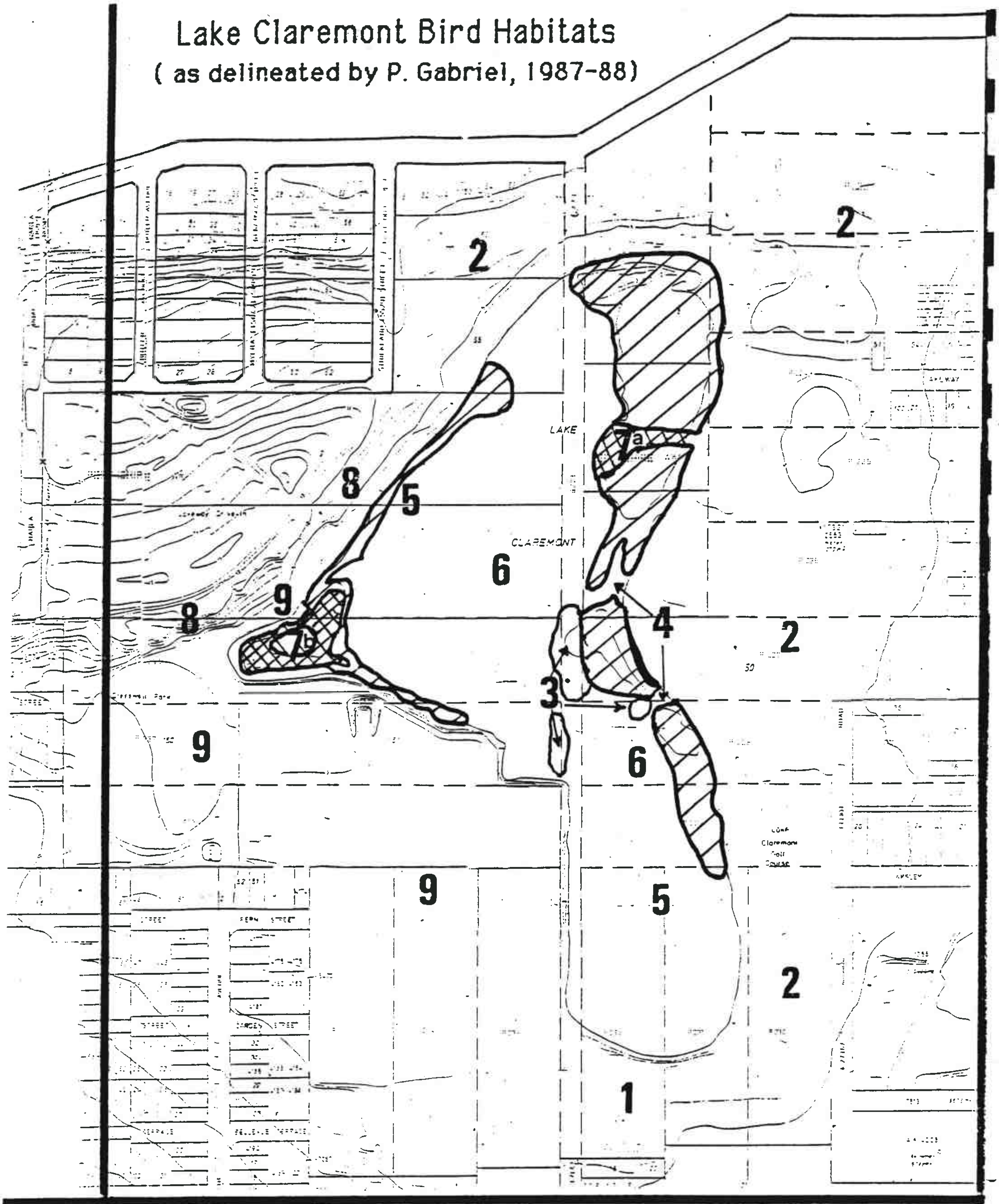
The principle objectives of the bird survey were:

1. Using a monthly surveying programme to identify the birds that occurred in the terrestrial and wetland habitats of the Lake Claremont catchment area as defined by MAP 1.

2. To provide information on bird usage of, and preferences for, the various habitats, (open water, dead tree stands in the lake, bulrush (*Typha orientalis*), Tuart (*Eucalyptus gomphocephala*) woodland and open recreational areas.)

3. To provide quantitative information on the bird populations which used the region.

FIGURE 1



KEY: SEE OVERLEAF

MAP 1

KEY

1.	STIRLING ROAD PARK	– Open parkland, few tall trees – exotic.
2.	GOLF COURSE	– Open grassland, undulating topography, lines of small trees mainly exotic.
3.	PAPERBARK STANDS (*Melaleuca rhaphiophylla*)	– Live trees in water body.
4.	BAYS	– Small stretches of open water joining main body of the lake to the land surface and surrounded by bulrushes (*Typha orientalis*).
5.	OPEN WATER	– Lake water body where very few or no dead tree skeletons are visible.
6.	DEAD TREE STUMP ZONE	– Located in varying densities, mainly paperbark (?) skeletons
7.	'ISLANDS'	– 7a : Connected via land bridge and covered by exotic grasses and few exotic trees. – 7b : Surrounded by bulrush stands with varied grass community in centre.
8.	REMNANT NATIVE WOODLAND	– Degraded woodland of main Tuart – Peppermint Tree Association with Veldt Grass understorey. Some paperbarks near lake's edge. Steep sloping topography.
9.	OPEN GRASSED FIELDS	– Few trees except those bordering the areas of grassland.
	BULRUSH STANDS (*Typha orientalis*)	Dense where burning has taken place especially on the east side. Some *Schoenoplectus validus* interspersed with *Typha* on East side.

BACKGROUND INFORMATION

Published references on the bird life of Lake Claremont are few. However, Rook (1963), Emory, et al (1975), Morris and Knott (1979) provide some information on a more limited scale than this study. In addition the following references provide information on the social and biogeographical changes of the Lake Claremont region.They are Bekle (1980 and 1984), Smith (1980), Smith and Marchant (1961), Evans and Sherlock (1950) and Hillbrick (1976).

Since 1950 considerable filling of the wetland region has occurred (Emory, et al (1975), Hillbrick (1976). An 18-Hole golf course was established (1963-70) which now surrounds more than 50% of the lake, bordering the north west, north and east sides. In 1964 Scotch College and Claremont Town Council, by-way of a landswap, created two large recreational ovals to the west and south west boundaries of the lake. These landswap events have profoundly changed the character of this wetland ecosystem. Infilling with rubbish and sand dumping accounted for about 20% of the near permanent water as well as large areas of rush and sedge communities and terrestrial bushland to the north. These activities also created steep ($40-80^{o}$) margins around much of the lake which do not support native marginal plants and are not used by marsh birds.

The open recreational grounds amount for about 90% of the surrounding land. These consist of Stirling Road Park, Claremont Public Golf Course, Scotch College sporting grounds and Cresswell Park. These areas provide for opportunistic feeding and roosting for many birds. Native and exotic bush birds make use of any trees in these areas but rely most on the remnant woodland to the north west of the lake.

BIRD HABITATS OF THE LAKE CLAREMONT REGION

The habitat types listed below are readily identifiable on the basis of vegetation type and hydrological status. Table 1 displays species and preferred habitat, and species abundance observed throughout the survey. Notes on bird species usage of the habitat types presented below are detailed in Section 6, page 31.

HABITAT TYPES:

1. TERRESTRIAL

   1. Golf Course
   2. Stirling Road Parkland
   3. Scotch College Playing Fields
   4. Cresswell Park Playing Fields
   5. Open Tuart - (*Eucalyptus gomphocephala*) - Peppermint Tree (*Agonis flexuosa*) woodland.

2. LAKE/MARSH

   1. Paperbark (*Melaleuca rhaphiophylla*)
   2. Open water, free of tree stumps
   3. Dead tree stumps in open water
   4. Bulrush (*Typha orientalis*), reeds and sedges
   5. Bays (open waters between shore and *Typha*)
   6. Islands
   7. Open banks/mudflats

1. TERRESTRIAL

   1. Golf Course: 23 bird species

      This open grassland with single lines of small to medium trees and pockets of trees in some parts, harboured moderate to high numbers of 11 species of parrots and honeyeaters, especially when the, mainly, exotic *Eucalypts* species were in flower. The Golf Course occupies about 60% of the land surface and it provided opportunistic feeding for Pacific

Black Ducks, Coots, Swans and Swamphens, particularly when grass growth was lush. Aerial species such as Crows, Silver Gulls and Swallows also used this large habitat for roosting and feeding.

2. <u>Stirling Road Parkland: 21 bird species</u>

A small open wooded parkland lying at the south end of the region made up of exotic trees and plants that supported small numbers of introduced Dove species, and indigenous species such as Twenty Eight Parrots and Singing Honeyeaters. Overlap between the Golf Course and tree bearing sections of Scotch College Playing Fields occurred for other species such as Wattlebirds and other honeyeaters. Opportunistic feeding and roosting for several duck species, especially the domestic ducks, occurring near the small jetty at the south end of the lake.

3&4. <u>Scotch College and Cresswell Park: 15 bird species</u>

Wide expanses of grassed lands with few trees and shrubs except for a line of exotic trees and shrubs and a line of exotic *Eucalypts* planted parallel to western banks of the lake. These trees provided food and shelter for up to 8 nectivorous birds and others.

Aerial species such as Swallows, Magpies, Crows and Silver Gulls exploited the spaces for roosting and aerial display. Several native duck species used the grassed lands for food.

5. <u>Woodland - 27 bird species</u>

The most important terrestrial habitat. It's multi-storey native vegetation, mainly of a Tuart (*Eucalyptus gomphocephala*) - Peppermint Tree (*Agonis flexuosa*) complex and proximity to partly wooded lake banks of paperbark (*Melaleuca rhaphiophylla*) provided feeding, nesting and roosting resources for many of the native and exotic terrestrial bird species.

Cockatoos, Parrots, Magpies, and Red Wattlebirds occupied the tall tree tops. Butcherbirds, all Honeyeaters and Dove species used the middle storey trees, such as the Peppermint tree or Acacias; closer to ground and lake level, Willie Wagtails and New Holland Honeyeaters could be found. Even some Domestic and Pacific Black Ducks used the woodland to feed in.

The woodland is divided into two parts by a cleared, degraded area which rises steeply to a height of 15 metres (AHD) to the Lake-Way Drive-In site. This area is partially grassed with exotic Kikuyu (*Pennisetum clandestinum*) grass like all the surrounding areas, and contains three introduced *Eucalyptus* species. This area appeared to offer little to birds.

The woodland also acted as a platform for up to four species of raptors (Hawks and Eagles) which hunted mice (*Mus musculus*) and sick and young birds.

Overall however the woodland is quite disturbed with veldt grass (*Erharta calycina*) and other exotic grasses totally dominating the lower vegetation storey while many of the native trees appeared to be old or diseased.

2. <u>LAKE/MARSH HABITATS</u>:

1. <u>Paperbark (Melaleuca rhaphiophylla) stands: 12 bird species</u>

These are the last remnants of a once large stretch of paperbarks which covered most of the present lake and surrounds at an earlier time - the large stretches of tree stumps throughout the lake are the skeletons of the old forest.

In the central part of the lake about 8 small trees exist in two areas. They provided a space for Doves and several Honeyeaters including Singing Honeyeaters, White Cheeked Honeyeaters, Brown Honeyeaters and New Holland Honeyeaters.

During drier months they provided ground level shelter for Rails and Wading birds. When the lake water body was deeper than about 60cm, Coots, Bluebill Ducks, White eyed Ducks and Pacific Black Ducks roosted under their branches. Cormorants roosted overnight in one of the stands closest to the east side, as it was surrounded by the central lake open water on the west side and bulrushes on the east side, about 30 metres from the banks. The other stand is very close to the west side.

By March, 1988 when the lake was almost dry these stands were accessible to people, dogs and mice. At this time though, no waterbirds were present. By June, 1988 there was enough surface water to isolate these trees from the bank.

2. Open Water : 19 bird species

During the cooler periods when the lake contained sufficient water, the open water regions - a large area in the north west part of the lake and most of the southern half of the lake, provided areas for feeding and display for all duck species, Pelicans, Gulls, Coots and Grebes. In November and December Cormorants used the area to hunt fish and clean themselves. At their deepest the open areas were used by Bluebilled Ducks, Musk Ducks, Swans and Grebes. As they dried and became marshier (with spread of introduced grasses such as *Rumex vasicarius* and *Cynodon dactylon*) Coots, Herons and Black Winged Stilts foraged there.

By March 1988, the lake was devoid of surface water except in the south end where a shallow saline pool persisted (see Table 2; Section 2). Swamphens and Moorhens moved through the area whilst masses of Silver Gulls roosted there. Migratory waders such as the Black Winged Stilt, Black Fronted Dotterels, Greenshank and Wood Sandpiper utilized the mudflats and shallows for feeding.

These areas began to fill with water by early April 1988 and by June the duck species and other diving birds began to reappear in numbers.

3. <u>Dead Tree Stumps: 19 bird species</u>

The areas with standing and fallen tree stumps provided a transition/overlap for open water species and marsh species - giving roosting display and protection to many species and nesting opportunities to others.

The Welcome Swallows and Tree Martins were observed nesting in hollows and Pink-Eared Ducks may have also. Many water birds and terrestrial birds used the stumps to perch and roost, in particular the cormorants during late afternoons and evenings, flocks of Cockatoos during the day, and low number of Silver Gulls at all times.

The Bulrush - Stump interface provided a valuable area for feeding and breeding for many ducks and rails, such as Dusky Moorhens, Coots, Grey Teals, Blue Winged Shovelers and Blue Bill Ducks.

4. <u>Bulrushes and Reeds: 15 bird species</u>

A very large 'sea' of bulrushes and to a lesser extent (*Shoenoplectus validus*) rushes, exists on the eastern side of the lake. Stands skirting the northern and western shorelines exist though the plants have not extended to the southern half of the lake. Overall the bulrush stands cover about 10% of the lake surface, according to its present boundaries.

From August 1987 to January 1988 the bulrushes gradually extended their range. As warmer conditions prevailed the bulrushes dried out, and about five to ten percent of the area was burnt out. In 1986 the Claremont Town Council attempted to burn out the bulrushes on the eastern side near the golf course. The bulrushes appeared to have regenerated to very dense levels. It appeared as if the denser areas, away from access to the open waters and shorelines, offered little to birds, as few were sighted (although these areas were difficult to observe broadly and quietly except over much longer periods than were practicable). At the outskirts of these expanses the bulrushes were younger, greener and less dense. Little Grassbirds, Clamorous Reed Warblers, Swamphens used these areas for breeding.

During late winter and spring 1987, populations of Grey Teal, Pacific Black Duck, Black Swan, Purple Swamphen, Dusky Moorhen, Pink Eared Duck, Bluebill Duck, Eurasian Coot and Australian Little Grebe successfully bred in the bulrush areas close to deeper water.

As waters receded during summer 1987/88 many exotic grasses flourished under the bulrushes and this habitat diversified, offering opportunities to Herons and other waders. This period provided opportunities for human intrusion and disturbance which occurred regularly with boys searching for golf balls.

5. <u>Bays: bird species</u>

During winter and spring several small bays of open water existed between the eastern side (golf course); bulrush stands and the paperbarks. These offered varied habitat qualities with a water depth, such that most duck species, Coots and Swans used them for feeding, breeding and shelter. As they dried out they assumed more of a marshland-scape with Swamphens, Moorhens and Wading birds such as Black Winged Stilts in attendance. The shallower parts provided food for these birds. The recession of the waters coincided with the spread of bulrushes, and to a lesser extend the reeds, into the bays and beyond.

6. <u>Islands - Duck Island: 11 species; Bird Island: 3 species</u>

These areas were essentially artificially created in the 1960's by Claremont Town Council. 'Duck' Island is now mostly covered in bulrushes with the central part covered by introduced grasses and one paperbark tree. It is surrounded by a thin dredged channel separating it from the land surface, at the very western part of the lake. It becomes accessible as the lake dries.

Several rare species at the lake use this island, such as Buff Banded Rails, Marsh Crakes and Little Grass birds. Nests of Reed Warblers were discovered in March, 1988. Dusky Moorhens, Swamphens, Coots and Australian Little Grebes were all observed to breed there. White Egrets and White Faced Herons foraged nearby during the early summer and, of course, during winter-spring many Pacific Black Duck and Grey Teal roosted there, hence the title.

'Bird' Island - by comparison offers far less opportunities to birds. It was created via sanitary landfill and is covered in very dense high Kikuyu grass (*Pennisetum clandestinum*). Several exotic palm trees (*Washingtonia spp*) have been planted and it is connected with the golf course allowing human and other mammal traffic, thus reducing its value as a breeding centre. Most of its shoreline is covered by bulrushes (it lies in the vast expanse of bulrush on the eastern side of the lake which provide a habitat for Rails, Reed Warblers, Little Grassbirds and so on). The only birds to use the island were Black Swans, Dusky Moorhens and Silver Gulls, all of which seemed to roost there after day break in spring, 1987.

7. <u>Open Lake Banks: 14 bird species</u>

For most of the lake the banks are very steep (40-80^{o} incline) except at low water levels at the southern end of the lake. At the south end many species of Ducks in winter, and spring, and Waders in summer used these more shallow banks to roost.

All banks are grassed in thick Kikuyu and Couch (*Cynodon dactylon*) and are open to human and other disturbance. The grasses provide a food source for Coots and Duck species.

SUMMARY OF FINDINGS

A total of 71 species were observed at the lake during the study. Thirteen species were observed to have reared young and five of these species were observed to have young reaching juvenile and /or adult stages. Table 1 lists the species, their monthly counts (including young) and preferred habitats. In addition to the species with young, four other species were observed in mating behaviour:

1. Spotted Turtle Dove
2. Blue Winged Shovelor
3. Domestic Duck
4. Black Shouldered Kite

Another four species were seen with juveniles in their numbers, but breeding probably occurred elsewhere, or at the lake prior to this study. These species were:

1. Black Cormorant
2. Black Winged Stilt
3. Western Magpie
4. Silver Gull

Although 71 species were observed, the ten most common species of birds (listed in Table 2), accounted for almost 80% of the bird population, on average, over the course of the survey. Only five of these 10 most common species were observed to rear hatchlings/juveniles in the region. The total breeding species (25) made up an average 37% of all the observed species. The breeding birds in Table 2 constituted 30% of all species.

TABLE 1

Monthly counts of birds observed in the Lake Claremont region between 0630 and 1015 hours October 1987 - June 1988

SPECIES COMMON NAME	MAJOR HABITAT	OCT		NOV		DEC		JAN		MAR		APR		MAY		JUN	
		No.	Y	No.	Y	No.	Y	No.	Y	No.	Y	No.	Y	No.	Y	No.	Y
Black Swan		29	8	57	8	89	8	11						10		6	
Pacific Black Duck	Open, shallow	27	17	61	10	139	6	123		8		5		90		17	
Grey Teal	to deep water	4		3		27	4	148						58			
Blue Bill Duck	surrounded by	1		5		11	5	11									
Pink Eared Duck	dense marginal	5	4	6	4	15	7	16								2	
White Eyed Duck	vegetation	1				2											
Blue Winged Shovelor		2				2											
Musk Duck		2															
Mountain Duck		1				4		4						10		4	
Domestic Duck*	Open water near south end	10		6		13		14		18		3		2		2	
Australian Little Grebe	Open deep waters			5		2											
Hoary Headed Grebe	near dense marginal vegetation	1				1										4	
White Egret	Open shallows							2									
White-Faced Heron	near tall woodland					1		2						2			
Black Winged Stilt	Open shallows			1		4		70		2		7		16			
Black Fronted Dotterel	and mudflats					1		12		12		8		22			
Wood Sandpiper	protected by									2							
Green Shank	dense marginal									2							
Banded Plover	vegetation									2							
Silver Gull	Open waters	188		451		448		520		160		110		306		202	
Caspian Tern	near beaches	1															
Australian Pelican	and low vegetation	1		1												4	
Little Pied Cormorant	Paperbarks in	1		3		2											
Little Black Cormorant	open water	1		3		3										1	
Black Cormorant		1		1		1											
Eurasian Coot	Open water near marshland	86	3	153	10	147	9	145	6					2		50	
Dusky Moorhen	Dense marginal	3		18	3	10	5	14	4	14		2		1		13	
Western Swamphan	vegetation and	17	5	9	2	16	5	27		13		7		15		23	
Buff Banded Rail	marshland							1#									
Marsh Crake				1													
Clamorous Reed Warbler	Low Density	20		32		25		34		4				4		7	
Little Grassbird	marginal	1		5		2		4						1		5	

SPECIES COMMON NAME	MAJOR HABITAT	OCT No.	OCT Y	NOV No.	NOV Y	DEC No.	DEC Y	JAN No.	JAN Y	MAR No.	MAR Y	APR No.	APR Y	MAY No.	MAY Y	JUN No.	JUN Y
King Quail*	Dense Grassland							1									
New Holland Honeyeater	Marshland with low dense tree cover	4		3		3		9		10		7		17		17	
										20		29		16		7	
Sacred Kingfisher	waters, surrounded by tall trees in woodland							1									
Singing Honeyeater		29		55		48		60		46		22		109		93	
Brown Honeyeater		5		10		19		4		8		55		54		32	
Red Wattlebird	Medium to tall trees in dense woodland	27		35		28		56		58		42		74		64	
Little Wattlebird		1		1		1		6		2				6		13	
Western Thornbill	Medium to high trees in open woodland															1#	
Silver Eye												16		31		59	
Striated Pardelote	Open, low trees and shrubs			1													
Willie Wagtail		3		7		11		23	3	10		10		18		14	
Rufous Whistler																2	
Welcome Swallow	Aerial species using open grass-land and medium to tall trees	88		89		84		230		140		92		251		68	
White Backed Swallow																	
Tree Martin		21		36		38		136		68				56		20	
Rainbow Bee-Eater	Medium to tall trees on undulating land							2									
Pallid Cuckoo	Tall trees in woodland			1		1											
Black Faced Cuckoo-Shrike		1		1		1				2				1			
Pee Wee	Wooded Marshland	1		2		2		4									
Western Magpie	Tall open woodland	2		5		4		6		16		14		17		12	
Pied Butcherbird	Dense woodland									2							
Grey Butcherbird																1	
Australian Crow	Open tallwoods and grassland	4		6		9		5		4		3		10		4	
Laughing Kookaburra*	Open Woodland with tall trees			1		1		2		2							
Pink and Grey Galah				1						2		2				2	
White Tailed Black Cockatoo				13								1					
Yellow Tailed Black Cockatoo		7#															

SPECIES COMMON NAME	MAJOR HABITAT	OCT		NOV		DEC		JAN		MAR		APR		MAY		JUN	
		No.	Y	No.	Y	No.	Y	No.	Y	No.	Y	No.	Y	No.	Y	No.	Y
Twenty Eight Parrot	Medium to tall trees in open woodland	9		8		6		14		8		19		10		10	
Red Capped Parrot				1		2											
Rainbow Lorikeet*						1		4						2		2	
Owlet Nightjar	Dense low marginal trees							1									
Brown Falcon	Open marsh, grassland, shrubs near tall trees			1		1											
Nankeen Kestral						1#											
Black Shouldered Kite														2			
Little Eagle	Open marsh near woodland													1			
Senegal Turtle Dove*	Dense low trees near grassland	21		40		29		56		30		3		12		4	
Spotted Turtle Dove*	Parkland, Golf Course	2		3		2		2		6				4		6	
Domestic Pidgeon*	Open grassed areas few trees			1								1					
TOTAL BIRDS/MONTH		619		1138		1259		1786		683		464		1230		772	

NOTES:

1. all young (Y) included in total numbers (No.) species.

2. * - Exotic bird species, introduced by humans directly or indirectly to the regions.

3. # - Species only observed during afternoon/evening observation.

4. Bird numbers for OCTOBER to DECEMBER 1987, are average figures derived from multiple samplings over seven days.

   Subsequent figures are from single day's samples each month.

TABLE 2

THE TEN MOST COMMON BIRD SPECIES AROUND LAKE CLAREMONT

SPECIES	PERCENTAGE OF EACH MONTH'S BIRD POPULATION							
	O	N	D	J	M	A	M	J
Silver Gull	30.4	39.7	35.6	29.4	23.4	23.7	24.9	26.2
* Welcome Swallow	14.2	7.9	6.6	13.0	20.5	19.8	20.4	8.8
* Eurasian Coot	14.0	13.4	11.7	8.2	0	0	9.2	6.5
Singing Honeyeater	4.7	4.8	3.8	3.4	6.7	4.7	8.9	12.9
Red Wattlebird	4.5	3.2	2.2	3.2	8.5	9.0	6.0	8.3
Pacific Black Duck	4.4	5.4	11.1	7.0	1.2	1.1	7.3	2.2
Tree Martin	3.4	3.0	3.0	7.7	10.0	0	4.6	2.6
Brown Honeyeater	0.8	0.9	1.5	0.2	1.2	13.1	4.4	4.1
* Black Swan	4.8	5.1	7.1	0.6	0	0	0.8	0.8
Senegal Turtle Dove	3.4	3.5	2.3	3.2	4.4	0.6	1.0	0.5
TOTAL PERCENTAGE OF ALL (BIRDS FOR THE MONTH)	84.6	86.9	84.9	75.9	75.9	72.0	78.5	72.0

* Observed with hatchlings or juveniles at Lake Claremont 1987-1988.

Breeding occurred between October 1987 and January 1988. The key nesting areas were as follows:

1. Bulrush (*Typha orientalis*) stands : 10 species

1.	Black Swan	-	3 nests/clutches
2.	Pacific Black Duck	-	15 clutches
3.	Grey Teal	-	2 clutches
4.	Blue-bill Duck	-	2 clutches
5.	Pink eared Duck	-	4 clutches
6.	Australian Little Grebe	-	1 nest/clutches
7.	Eurasian Coot	-	10 nests/clutches
8.	Dusky Moorhen	-	9 nests/clutches
9.	Western Swamphen	-	5 nests/clutches
10.	Clamorous Reed Warbler	-	4 nests

2. Dead Tree Stumps in central regions of the lake (especially in tree hollows) - 2 species:

1.	Welcome Swallow	-	3 nests/clutches
2.	Pink eared Duck	-	4 nests/clutches

3. Remnant Native Woodland on the north west side of the lake - 5 species:

1.	Singing Honeyeater	-	3 nests (middle storey trees)
2.	Willie Wagtail	-	3 nests (middle storey trees)
3.	Red Wattlebird	-	5 nests (upper storey trees)
4.	Western Magpie	-	7 nests (upper storey trees)
5.	Senegal Turtle Dove	-	2 nests (middle storey trees)

4. Golf course/Parkland - open grassed areas with clumps of trees and shrubs.

- 3 species

1.	Willie Wagtail	-	10 nests	-	Golf course
2.	Senegal Turtle Dove	-	2 nests	-	Stirling Road Park
3.	Rainbow Bee-eater	-	1 nest	-	Scotch College Shooting Range

Other areas/habitats that may have hosted nesting sites were:

1. Live paperbark (*Melaleuca rhaphiophylla*) trees in the centre of the lake.

2. Large, dense trees on the golf course allowing very limited visibility into the foliage, such as Moreton Bay Fig (*Ficus spp*) and Tasmanian Blue Gum (*Eucalyptus globulus*).

The region also acted as a refuge for migratory wading birds. From October 1987 to May 1988 waders used the drying banks of the lake. These include:

1. Caspian Tern
2. Black Cormorants
3. Wood Sandpiper
4. Greenshanks
5. Black-winged Stilt
6. Black Fronted Dotterel
7. White Egret

Table 3 details their abundance.

TABLE 3

MIGRATORY BIRD SPECIES ABUNDANCE - OCTOBER 1987-MAY 1988

SPECIES	MONTH (1987-1988) 6.30 - 10.15 am						
Common Name	Oct.	Nov.	Dec.	Jan.	Mar.	April	May
Caspian Tern	1						
Black Cormorant	1	1	1				1
Wood Sandpiper					2		
Greenshanks					2		
Black winged Stilts		3	2	70	2	7	16
Black Fronted Dotterels			5	12	12	8	22
White Egret				2			

Although 71 species were observed at the lake many of these were represented by relatively few birds. Table 4 displays the general variation of total species and total numbers per month, and the small number of species providing more that 5% of each month's bird population. Table 4 displays general variation of total species and total numbers per month. As described in Section 2 (Phosphorus Budget) the region, in particular the lake, underwent dramatic physico-chemical changes over the survey and hence there were changes to habitat types and accompanying species populations.

The seasonal variations in species present at the lake is shown in Figure 2. The percentage of species observed varied from 60.6% (43 species) in early summer (December), to 31% (22 species) in autumn (April - just after the first rains for 1988). The richest period for bird observation was the November to January period when species numbers and species abundance were at their highest. This was due to the changing of the lake to a more shallow-marshy character, whilst still offering food and habitat to the birds such as duck species that prefer deeper water.

It is noteworthy from Table 4 that at least five species in most months managed to account for between 69 and 81% of the total bird population. The presence of open area dwellers such as Silver Gull (29%) and Welcome Swallow (14%) clearly make the other species seem less significant. However about 90% of the landscape is open grassland with few trees, so larger populations of open area birds is to be expected.

TABLE 4

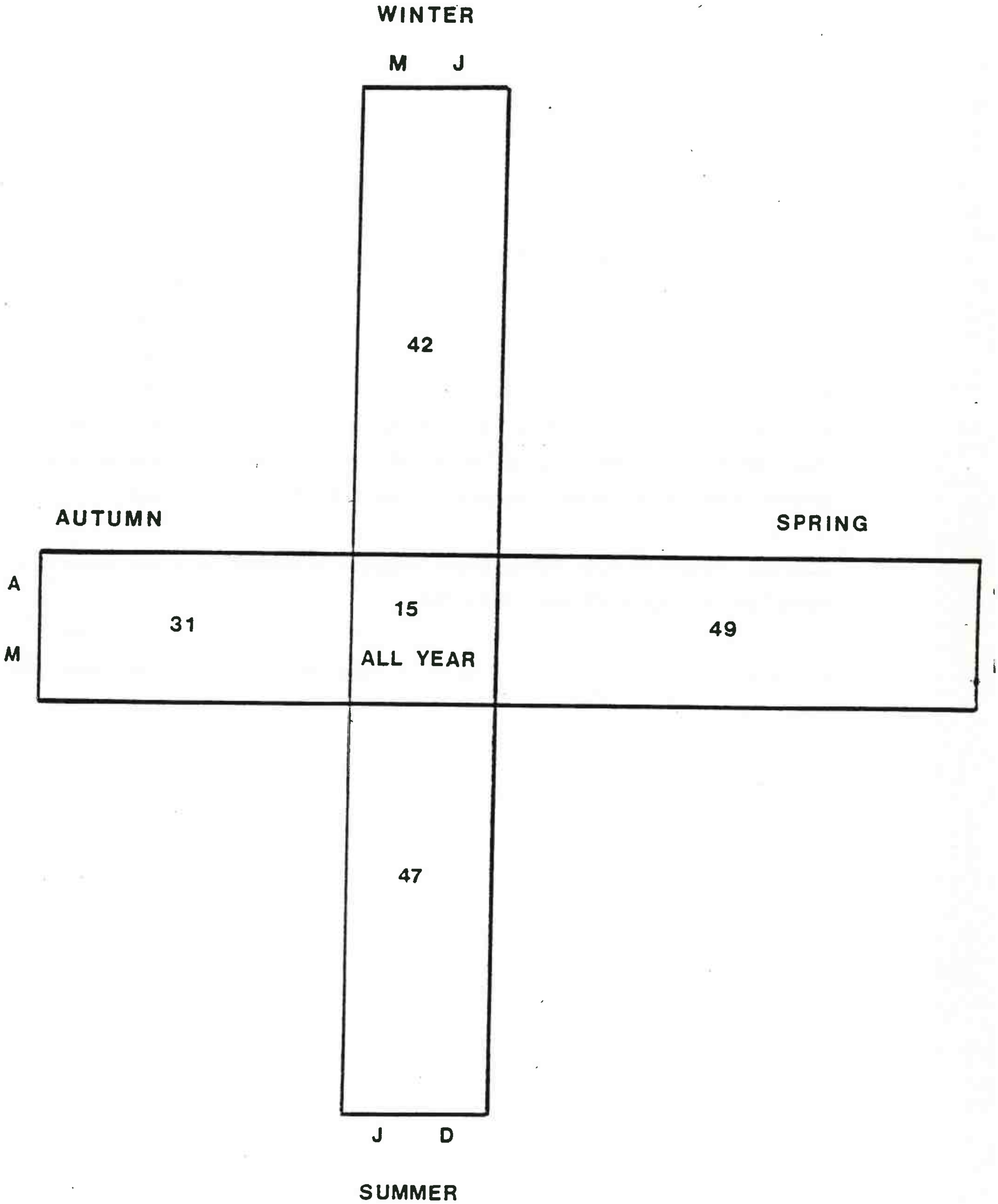
BIRD SPECIES DIVERSITY AND ABUNDANCE IN THE LAKE CLAREMONT REGION

1987 - 1988 FROM MORNING SURVEYS (6.30 - 10.00 am)

MONTH	MONTHLY TOTAL OF		MONTHLY % OF TOTAL SPECIES[1]	NO. OF SPECIES (% OF MONTH'S BIRD TOTAL) COMPRISING		% OF MONTHLY BIRDS IN ≥5% CATEGORY
	BIRDS	SPECIES		5-10% OF BIRDS	>10% OF BIRDS	
OCTOBER	619.8[2]	53.5	38	0	3 (58.6%)	58.6
NOVEMBER	1138.2[2]	57.7	41	3 (18.4%)	2 (53.1%)	71.5
DECEMBER	1259[3]	60.6	43	2 (13.7%)	3 (58.4%)	72.1
JANUARY	1786	53.5	38	4 (31.3%)	2 (42.4%)	73.7
MARCH	683	39.4	28	2 (15.2%)	3 (53.9%)	69.1
APRIL	464	31.0	22	2 (15.2%)	3 (66.6%)	81.8
MAY	1230	46.5	33	3 (22.2%)	2 (45.3%)	67.8
JUNE	772	49.3	35	4 (31.2%)	2 (38.2%)	69.4

1. Total species observed over morning, afternoon and evening surveys was 71.
2. An average figure from 7 samplings.
3. An average figure from 4 samplings.

SEASONAL VARIATION IN BIRD SPECIES AT LAKE CLAREMONT 1987 - 1988. (After Curry,1981)



COMPARISON WITH OTHER STUDIES

There has been no prior bird study of the Lake Claremont Region undertaken with the broad target of establishing bird counts for all possible sedentary and migratory species. Other known workers have either concentrated on specific species or groups (Rook (1963), Emory et al (1975), Morris et al (1977) and Clifton Appendix 8.5; Section 2, Phosphorous Budget (unpublished)) or simply counted different species (Mackay-Skollay et al (1985)).

The Royal Australian Ornithological Union (RAOU) have undertaken bird counts in March 1986 and March 1988, relevant parts of which are reproduced in the appendices. These counts concentrated on aquatic birds such as Black Swan, Eurasian Coot and Pacific Black Duck and no notes on prevailing conditions, observation time, or number of young, are present. However it is possible to infer that the 1986 data indicates more water in the lake than for 1988 March due to the greater number of duck numbers in 1986 compared with 1988. The 1988 RAOU figures are commensurate with those obtained for waterfowl in this study.

Clifton (Appendix 8.5; Phosphorous Budget) provides data for major waterfowl during 1978 and 1985-1987.

Combining all these observations with those of this study provides the bird list in Table 5.

TABLE 5

BIRD LIST FOR THE LAKE CLAREMONT REGION

COMMON NAME	SCIENTIFIC NAME	REFERENCE
BIRDS OF THE OPEN WATER		
Coot, Eurasian	Fulica atra	1, 4, 5, 5a
Cormorant, Black	Phalacrocorax carbo	1
Cormorant, Little Black	Phalacrocorax sulcirostris	1, 4
Cormorant, Little Pied	Phalacrocorax melanaleucos	1, 4
Duck, Blue Billed	Oxyura australis	1, 4
Duck, Domestic (hybrid)	Anas platyrhynchos X	1, 4
Duck, Mountain	Tadorna tadornoides	1, 4, 5, 5a
Duck, Musk	Biziura lobata	1, 4
Duck, Pacific Black	Anas superciliosa	1, 4, 5
Duck, Pink Eared	Malacorhynchus membranaceus	1, 4, 5
Duck, White Eyed	Aythya australis	1, 4
Grebe, Australian Little	Podiceps novaehollandiae	1
Grebe, Great Crested	Podiceps cristatus	2
Grebe, Hoary Headed	Podiceps poliocephalus	1, 4
Gull, Silver	Larus novaehollandiae	1, 4
Pelican, Australian	Pelacanus conspicillatus	1, 4
Shoveler, Blue Winged	Anas rhynchotis	1, 4, 5
Swan, Black	Cygnus atratus	1, 4, 5
Teal, Chestnut	Anas castanea	3
Teal,, Grey	Anas gibberifrons	1, 4, 5, 5a
Tern, Caspian	Hydroprogne caspia	1
BIRDS OF THE RUSHES		
Bittern, Little	Ixobrychus minutus	2, 4
Crake, Australian (spotted)	Porzana fluminea	5
Crake, Marsh	Porzana pusilla	1
Crake, Spotless	Porzana tabuensis	5
Grassbird, Little	Megalurus gramineus	1

COMMON NAME	SCIENTIFIC NAME	REFERENCE
Moorhen, Dusky	Gallinula tenebroza	1, 4
Native Hen, Black Tailed	Tribonyx ventralis	5
Rail, Buff Banded	Rallus philippensis	1
Reed Warbler, Clamorous	Acrocephalus stentoreus	1, 4
Swamphen, Western	Porphyrio porphyrio bellus	1, 4
LARGE WADING BIRDS		
Egret, Great	Egretta alba	1, 4
Egret, Little	Egretta garzetta	4
Heron, Nankeen Night	Nycticorax caledonicus	4
Heron, Pacific	Ardea pacifica	4
Heron, White Faced	Ardea novaehollandiae	1, 4
Spoonbill, Yellow Billed	Platalea flavipes	4
SMALL WADING BIRDS		
Avocet, Red Necked	Recurvirostra novaehollandiae	4
Dotterel, Black Fronted	Chradrius melanops	1, 4
Dotterel, Red Kneed	Charadrius cinctus	4
Godwit, Black Tailed	Limosa limosa	5b
Greenshank	Tringa nebularia	1, 4
Plover, Banded	Vanellus tricolor	1
Plover, Red Capped	Charadrius alexandrinus	5
Sandpiper, Wood	Tringa glareola	1
Stilt, Banded	Cladorhynchus leucocephalus	5
Stilt, Black Winged	Himantopus himantopus	1, 4
MARINE AERIAL BIRDS		
Osprey	Pandion halioetus	4

COMMON NAME	SCIENTIFIC NAME	REFERENCE
AERIAL BIRDS		
Bee Eater, Rainbow	Merops ornatus	1, 4
Cuckoo Shrike, Black Faced	Coracina novaehollandiae	1, 4
Eagle, Little	Hieraoetus morphnoides	1
Falcon, Brown	Falco berigora	1
Goshawk, Brown	Accipiter fasciatus	4
Kestral, Nankeen	Falco cenchroides	1
Kite, Black	Milvus migrans	4
Kite, Black Shouldered	Elanus notatus	1
Martin, Tree	Cecropis nigricans	1
Swallow, Welcome	Hirundo neoxena	1
Swallow, White Backed	Cheramoeca leucosternum	1
Thornbill, Western	Acanthiza inornata	4
TERRESTRIAL BIRDS		
Black Cockatoo, White Tailed	Calyptorhynchus baudinii	1
Black Cockatoo, Yellow Tailed	Calyptorhynchus funereus	1
Butcherbird, Grey	Cracticus torquatus	1
Butcherbird, Pied	Cracticus nigropularis	1
Corella, Little	Cacatua sanguinea	4
Crow, Australian	Corvus orra	1
Cuckoo, Pallid	Cuculus pallidus	1
Frogmouth, Tawny	Podargus strigoides	4
Galah	Cacatua roseicapilla	1
Honeyeater, Brown	Lichmera indistincta	1
Honeyeater, New Holland	Phylidonyris novaehollandiae	1
Honeyeater, Singing	Lichenostomus virescens	1
Honeyeater, White Cheeked	Phylidonyris nigra	1
Kingfisher, Sacred	Halcyon sancta	1, 4
Kookaburra, Laughing	Dacelo novaeguineae	1
Lorikeet, Rainbow	Trichoglossus haematodus	1
Magpie, Western	Gymnorhina dorsalis	1

COMMON NAME	SCIENTIFIC NAME	REFERENCE
Nightjar, Owlet	Aegotheles cristatus	1
Pardelote, Black Headed	Pardelotus melanocephalus	4
Pardelote, Striated	Pardelotus substriatus	1
Parrot, Red Capped	Purpureicephalus spurius	1
Parrot, Twenty-eight	Barnardius zonarius semitorquatos	1
Pee Wee	Grallina cyanoleuca	1
Pidgeon, Feral	Columba livia	1
Quail, King	Excalfactoria chinensis	1
Silvereye, Western	Zosterops gouldi	1
Turtle-dove, Senegal	Streptopelia senegalensis	1
Turtle-dove, Spotted	Streptopelia chinensis	1
Wagtail, Willie	Rhipidura leucophrys	1
Wattlebird, Little	Anthochaera chrysoptera	1
Wattlebird, Red	Anthochaera carunculata	1
Whistler, Rufous	Pachycephala rufiventris	1

SOURCES

1. This study (1987 - 1988)
2. Emory, K. et al (1976)
3. Morris, K. and Knott, B. (1979)
4. Mackay-Skollay, E. et al (1985)
5. Royal Australasian Ornithologist Union (1986)
5a. Royal Australasian Ornithologist Union (1988)
5b. Royal Australasian Ornithologist Union (1989)

SOME MANAGEMENT OPTIONS

Lake Claremont contains several semi-natural and artificial habitats for birds, with roles described earlier. Like all metropolitan lakes, Lake Claremont bears the signs of human modification. With the majority of the surrounding land being devoted to active recreation, management practises are devoted to their optimization, and have been so since the early 1960's. Thus the value of this area to indigenous species has diminished. In particular the lake margins and the Tuart woodland have been greatly altered where once stood a continuous vegetation belt. Dredging and fire have occurred at the lake in recent times.

Dredging of a channel around the central to north-eastern perimeter of the lake occurred in the mid-1970's to create an open water observation point for birds and 'beautification' of the lake area. This move was initiated by Claremont Town Council (Jeffries pers. comm. 1988) to remove bulrushes (*Typha orientalis*) from the banks of the lake, adjacent the Claremont Public Golf Course.

Fire has probably occurred frequently in the bulrush stands, especially in the months from January to April when large tracts of these stands have dried out. It is known from Council records (June, 1985) that the northern part of the bulrush stands (see Map 1) were burnt in a bid by Council to remove these extensive bulrush stands. Several small fires caused by arson, occurred from April to May 1988 during this survey, in the southern and central parts of the bulrush stands.

The overall effect of both dredging and fire on bulrush stands at Herdsman Lake was noted by Curry (1981), as allowing for more dense regrowth with a depauperate bird fauna. It is quite plausible to suggest a similar scenario for Lake Claremont.

The Lake Claremont region is therefore in need of very careful management if it is to remain a viable refuge and nesting area.

It is the opinion of the author that the diversity and abundance of bird species could be maintained and enhanced by the following:

1. Protecting existing stands of bushland, paperbark trees and bulrushes from fire and other forms of degradation.

2. Planting of indigenous trees, shrubs and groundcovers of the area around as much of the lake perimeter as possible. This may require the reclaimation of parts of the golf course margins. Appendix 4 provides a current list of native and exotic plants of the region. Smith (1973) summarizes the plant ecology of the coastal, and near coastal native vegetation, and is relevant to planning replantings. Smith has also provided the Council with a list of appropriate plants for the area. (Council Archives)

3. Reconstructing the banks, particularly around the open golf course margins, to reduce their gradient and so favour the specialized feeding requirements of ralline marsh birds. It would be necessary to minimize water and nutrient runoff and control exotic plants. These factors could be aided by planting native rushes and sedges.

4. Removing the landbridge that connects the golf course to the artificial island in the north east part of the lake, and the replanting of the island with indigenous trees and shrubs.

5. Starting environmental education initiatives for the public and council workers, particularly on the hazards caused by the dumping of refuse, sand and lawn clippings at the lake margins. Public education could also include organization of tours (in conjunction with the other interesting sites in Claremont), displays, encouragement of dog owners to keep dogs on leads near lake margins etc. The tours could occur at appropriate times as the lake dries and fills from summer to winter.

6. Developing a residents/council committee for the organization of compatible activities for the lake and surrounds, so as to aid in the social, historical and environmental appreciation of the region.

7. Providing facilities for tourists and passive recreators such as public amenities, for example at Stirling Road Park and John Mulder Park.

8. The active discouragement of domestic duck owners (perhaps in conjunction with the RSPCA and CALM) from dumping domestic ducks at the lake: plus their removal to those who can support them.

9. Restructuring of pesticide, herbicide and fertilizer management on grassed areas, so as to reduce the impact of chemicals (eg slow release fertilizer, rapidly biodegradable pesticides).

10. Council in conjunction with other groups, and government bodies, supporting further research into ecological understanding of the lake, e.g. monitoring of water quality of the lake and drain inputs, paying particular attention to the flow of nutrients and pollutants, and their effects on the flora and fauna.

11. Monitoring groundwater uses in conjunction with water quality and water depth of the lake. (Attention needs to be paid to public and private groundwater use). Residents could be encouraged, as part of a programme of involvement with a "Lake Claremont" or "Natural Heritage" Committee, to monitor their own ground water use and to see how it may effect the lake.

12. Engage the services of a person who could fulfill the roles of research officer, ranger and coordinator of management of the Lake Claremont region. This person could also act as a guide for events such as tours, morning bird watches etc, and also be involved with other areas of environmental and recreational significance in the Town of Claremont.

BIRD USAGE OF MARSH AND LAKE HABITATS AT LAKE CLAREMONT

1. BLACK SWAN - *Cygnus atratus*

Months: October, November, December January, May and June.

Habitats - South Arm, Jetty, Typha, Bays

Max. concentration in December 1987 (average over 4 mornings of 95 birds). Populations increased from October - December when young cygnets had matured. Three families noted from beginning bearing 4, 3 and 1 cygnets. No fatalities noted. These families along with majority of adults left as lake levels dropped dramatically from December to March.

Swans concentrated in the open water areas especially in the tree stump areas. They fed in these areas and at the edges of bulrush (*Typha*) thickets. Appeared to feed exclusively on submerged macrophytes eg *Potamogeton pectinatus* and *Chara fragilis*.

2. PACIFIC BLACK DUCK - *Anas superciliosa*

Months: September 1987 - June 1988

Habitats: Stirling Road Park, Jetty, South Arm, Shoreline of Golf Course, Duck Isle, all open waters and stumps, *Typha* margins

Max. concentrations - December, January, May. When in large numbers, roosting occurred at Duck Isle, Stirling Road Park, Golf Course shorelines in south east corner and north east corner near extensive Bulrush tickets. Partial to hand feeding as were the domestic ducks. This led to obvious cross-breeding with Domestic Duck males and Pacific Black Duck females. Prolific breeders in the months from September to December. High mortality rates left only 4 young making maturity out of approximately 50 young (6 clutches). Long necked tortoise (*Chelodina oblonga*), Silver gulls, may have caused deaths though none seen. Algal poisoning possibly claimed up to a dozen birds observed between March and May.

grass on the Golf course being left uncut and the drying of Bulrush (*Typha orientalis*) beds, however this did not seem to affect marshbird populations except perhaps to hasten the departure of little Grassbirds and Clamorous Reed Warblers to greener wetlands (as also suggested by Slater (1974)).

The presence of bird parasites and disease is probably indisputable however a separate study would be required for specific analyses. Algal poisoning by blue-green algae in the shallow, saline water, accounted for about twentyfive birds (Black ducks, Mountain Ducks and most significantly, Domestic Ducks), during the January-March period. These occurred at the southern end of the lake near the remaining water.

Bird deaths were noted during the project period. Throughout the survey several Silver Gull and Senegal Turtle Dove were apparently killed by flying golf balls. Mortality amongst young was high during the months from October to December.

Mortality is very difficulty to gauge accurately in field situations. It was most noticeable in aquatic species such as Black Duck and to a lesser extent, Eurasian Coot and Grey Teal. Frequent observation during the first three months of the survey, the breeding season - revealed high fecundity and mortality, in the space of days amongst Black Duck families.

I did not directly observe the killing of any species of aquatic or terrestial species, however it is possible to infer causes.

There was a large population of Long-necked Tortoises (*Chelodina oblonga*) extant in the lake over the period of the survey, and these are predators of young birds. For example the seemingly sudden deaths of up to 10 Black Duck young in one day over November 5 and 6 was possibly due to predation by tortoises in the thickets of Bulrush (*Typha orientalis*) on the eastern side of the lake or the high, dense exotic Kikuyu grass (*Pennistetum clandestinum*) which covers all lake margins.

The presence of predatory birds such as Kookaburra, Australian Crow, Western Magpie, Silver Gulls and Hawk species suggests possible causes of death in aquatic and terrestrial breeding birds. Two Grey Teal chicks were found mutilated near the jetty protruding from Stirling Road Park, on January 12. They appeared to be the victims of a dog(s). Two dogs were also noted chasing flocks of ducks on January 13 at the north end of the lake, when the waters had receded sufficiently to allow for easy access. Domestic dogs were always a constant disturbance to bird observation.

Other predatory mammals such as domestic cats and rats were observed. No sampling programme was implemented for any mammals bar humans, however on two occasions cats were observed in the woodland and rats in the bulrushes in December and January respectively. Mice (*Mus musculus*) populations reached plague proportions during March due to areas of long

The more overt species such as Silver Gull, Welcome Swallow, Black Swan and Eurasian Coot occupied many habitats and in large numbers. They were also inclined to move regularly between them. This habit enforced the need for repeated counts on many occasions. Some species were similar in size or calls or colouration to others, such as the Grey Teal and Black Duck; Tree Martin and Welcome Swallow; New Holland Honeyeater and White-cheeked Honeyeater and the Brown Honeyeater and Singing Honeyeater. In some cases multiple counts were required.

Topography, bird movement and vegetation density combined to create difficulties in some areas like the woodland and parts of the Claremont Golf course. Coverage via extensive walks necessary at all times.

For the majority of the survey period the weather conditions proved to be very conducive to bird observation. Inclement weather occurred only once, in June, 1988 and this was just very light rain. Strong winds occurred on two mornings in November 1987 (2nd and 7th). These were from a south-westerly direction and blocked out in some areas, and accentuated in others, bird movement, calls and visibility.

Localized disturbances probably accounted for decreases in bird species diversity and abundance throughout the morning survey periods. The types of disturbances that were noteworthy included:

1. The presence and noise from machinery used by the greenkeepers of the golf course, Scotch College fields and Cresswell park. Such machinery included lawn mowers, tractors, vans and trucks.

2. Dogs and their owners walking around the lake margins.

3. Traffic noise, especially along the northern perimeter of the Golf course, Alfred Road.

4. The presence of golfers especially in large groups and numbers over the course.

5. Joggers and bike riders along the lake margins which include a footpath skirting the western side of the lake, very close to the lake.

APPENDIX TWO

SOURCES OF ERROR IN BIRD POPULATION MEASUREMENT

There were a variety of conditions that hindered a true assessment of bird species diversity and abundance. These included:

1. Degree of visibility/time of day
2. Bird behaviour (overtness/secretiveness)
3. Bird movement across different habitats
4. Seasonal change
5. Topography
6. Vegetation density
7. Human and other disturbances/and
8. Death and Disease

All of these factors, individually or collectively, may hinder accurate population counts. During the morning surveys the degree of sunlight and heat available varied considerably. In the cooler months such as October 87, May and June of 1988 sunrise occurred about 7.00 am. This limited bird movement and visibility during the first 30 minutes of surveying especially at the sites in the southern part of the region. These were open areas both terrestrially and aquatically and as such they offset to varying degrees the reduced visibility.

In several of the other habitat zones, for example the woodland and bulrush stands, the amount of light was only one hinderance to observation, the behaviour and movement of some species of birds, such as the ralline marsh birds and some bushbirds, limited their countability. Birds such as Dusky Moorhen, Little Grassbird, Buff banded Rail and Marsh Crake proved to be elusive in the tall bulrushes for most of the survey. Other species such as the Little Bittern, Spotless Crake and Blacks Tailed Native Hen may have occurred during the survey period, as they had done in previous surveys, however the survey methods employed during this project were inadequate for their population measurement.

APPENDIX ONE

SAMPLING METHODS

Sampling began in October, 1987 after habitat zones were designated around the lake and surrounds, See Map 1. From there six major points were chosen which when used could give visual coverage of certain sets of habitat zones. Where there were zones that could not be viewed easily from one of these points, short walks were made so as to give maximum coverage. Each set of zones was observed for 30 minutes with 5 minutes in between. Observation was carried out by taking sweeps with binoculars (x 10 magnification) and the naked eye.

During the months from October 1987 to December 1987 sampling took place over one week/month for the following time period/day, for seven days:

1. 6.30 - 10.00 a.m.
2. 11.30 - 3.00 p.m.
3. 3.30 - 7.00 p.m.

In December, 1987, the number of observation sessions/day was reduced to 2/day using the above time periods. From January 1988 to June 1988 the number of observation days was reduced to one/week for each month.

Only the morning samples were collated for this report, because of greater bird abundance and a time limitation on data collation. All young were included in the totals of species/zone/time.

APPENDICES

1. Sampling Methods.

2. Sources of error in bird population measurement.

3. Bird species and their abundance at Lake Claremont, March 1986 and March 1988, as observed by RAOU (Jaensch, R.P. and Vervest, V.M.)

4. Major native and exotic plant species of the Lake Claremont region.

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The advice and help of the WACAE (Claremont Campus) staff, in particular Dr Ian Lantzke and Dr Bruce Haynes, and Claremont Town Council staff for help in preparation of this report.

34. <u>NEW HOLLAND HONEYEATER - *Phylidonyris novaehollandiae*</u>

Low numbers observed throughout year. Population size probably larger however, due to the occupations of dense areas of Bulrush and the constant movement between low trees and Bulrushes especially near the golf course. Mating behaviour observed, and pairs noted, especially from October to January.

35. <u>WHITE CHEEKED HONEYEATER - *P. niger*</u>

Very similar in appearance to *P. novaehollandiae*. May have been overlooked and included in *P. novaehollandiae* counts in first 4 months. Occurred in flowering exotic *Eucalypts* on the Golf Course, and Paperbarks in the wetland.

28. WESTERN SWAMPHEN - *Porphyrio porphyrio bellus*

As many as 27 individuals including young, of these sedentary birds, existed at the lake. Up to 7 pairs seen to successfully breed with at least 5 young reaching maturity.

29. BUFF BANDED RAIL - *Rallus philippensis*

One pair of this secretive bird observed in afternoon of April at the western island 'Duck Island'.

30. MARSH CRAKE or BAILLONS CRAKE - *Porzana pusilla*

One probable individual observed, (but no guarantee possible), on 'Duck Isle' in November. As with Buff Banded Rail and other rails the survey methods proved inadequate for population determination of this species.

31. CLAMOROUS REED WARBLER - *Acrocephalus stentoreus*

Common from October to January, when breeding occurred, and when Bulrushes were green. Nests observed in areas of sparce Bulrush stands and to a lesser extent in *Schoenoplectus validus* reeds close to Lake margins. The large stretch of Bulrushes in the North East seemed to be very popular but was impossible to accurately sample.

32. LITTLE GRASS BIRD - *Megalurus grammineus*

This very secretive relative of the Reed Warbler observed about 5 times in flight, but mostly heard via its distinctive plaintive cry. No nests observed. Most common when Bulrushes dry/brown in colour.

33. KING QUAIL - *Excalfactoria chinensis*

One male observed in January at eastern side of lake near the Lapsley Road drain. Probably an escaped pet.

22. AUSTRALIAN PELICAN - *Pelecanus conspicillatus*

Up to 4 present in groups or pairs using northern parts of lake both in open water and the northern central margin of tree stump area.

23. LITTLE PIED CORMORANT - *Phalacrocorax melanoleucos*

Observed in first few months of the survey when up to 30 birds were seen to move to and from their roosts, in live and dead *Melaleuca raphiophyla* trees, from and toward the Swan River.

24. LITTLE BLACK CORMORANT - *P. sulcirostris*

Observed in similar numbers over the study period as the Little Pied Cormorant. No breeding observed. Used the lake for roosting, washing and fishing.

25. BLACK CORMORANT - *P. carbo*

Observed in very low numbers, though several juveniles seen. Used the lake for roosting, washing and fishing, notably small tortoises and carp in December.

26. EURASIAN COOT - *Fulica atra*

Most common during periods where lake water and supporting submerged vegetation extant. Breeding occurred from October to January. With 8 young reaching near maturity before the mass exodus occurred in January - March. Nests in Bulrushes and in Stump areas. Opportunistic feeding occurred in grassed areas close to open lake margins.

27. DUSKY MOORHEN - *Gallinula tenebrosa*

Occurred in low but relatively constant numbers. Increase in populations occurred with successful breeding, the largest clutch being of 4 chicks. Up to 6 reached maturity. Used grassed areas for grazing. Most noticeable in January, March when lake was a drying marshland.

16. BLACK WINGED STILT - *Himantopus himantopus*

Months: November 1987 to May 1988

The most common migratory wading bird observed at Lake Claremont. Most common in January (70) when marsh conditions prevailed and long stretches of open shallows existed. No breeding observed although some juvenile birds observed especially in January.

17. BLACK FRONTED DOTTEREL - *Charadrius melanops*

This tiny wader was observed in low numbers between December and May when the lake was shallow. No breeding observed although apparent courting behaviour observed.

18. WOOD SANDPIPER - *Tringa glareola*

One pair observed in March around water margins when large stretches of marginal habitat were exposed.

19. BANDED PLOVER - *Vanellus tricolor*

One pair observed during an April afternoon on dry lake mud flats.

20. SILVER GULL - *Larus novaehollandiae*

The most common bird observed. Accounted for an average 30% of population over the survey. Lake Claremont, and surrounds acted as a roost for large flocks of birds in transit between the coast and Brockway Rubbish Tip. No feeding observed except at Stirling Road Park when ducks were being hand fed by visitors.

21. CASPIAN TERN - *Hydroprogne caspia*

One vagrant observed in a large flock of Silver Gulls in October 1987.

Occurred almost totally at the jetty and Stirling Road Park end of the "South Arm". Welcomed hand-feeding from park visitors. One group of three lived in the woodland to the north west of the lake and only ventured to the lake when disturbed. All but 2 died of algal poisoning or were otherwise removed by March 1988.

11. AUSTRALIAN LITTLE GREBE - *Tachybaptus novaehollandiae*

Occurrence in November and December, were seen to breed.

Up to six at any one time were seen in breeding plumage and in the process of breeding. One nest occupied over November and December yielded 2 chicks but their fate is unknown. Breeding took place in *Typha* thickets on Duck Isle and feeding in the open deeper parts of the lake north and south.

12. HOARY HEADED CREBE - *Poliocephalus poliocephalus*

Noticed in breeding colours in October and December and non-breeding colours in June. Like the Australian Little Grebe it preferred open water to feed. No breeding observed.

13. WHITE FACED HERON - *Ardea novaehollandiae*

No more than 2 individuals seen at any time in survey. This species observed catching small fish like *Gambusia spp.* in December, January and May when water levels were very shallow, ie marsh conditions prevailing.

14. WHITE EGRET or GREAT EGRET - *Egretta alba*

Two observed on one morning in January when the lake was effectively a marsh. Preferred area near Bulrush stands. Fed on small fish and frogs.

15. GREENSHANK - *Tringa nebulana*

One pair observed in March, wading near water line when the lake was at its lowest level and very saline.

6. WHITE EYED DUCK - *Aythya australis*

Months: October - January

Habitats - Open and stump filled waters of the northern half of the lake where lake is also fringed by bulrushes.

Major concentrations occurred in January when 7 pairs were observed on one morning. No broods observed. On this day all birds showed a preference for marshy shallows in the north eastern part of the lake adjacent to extensive bulrush thickets.

8. MUSK DUCK - *Biziuara lobata*

Observed only in the cooler months of 1987 on an October morning. This species was represented by one male and one to two females when the lake level was still highest in October. No breeding seen to occur.

9. MOUNTAIN DUCK or AUSTRALIAN SHELDUCK - *Tadorna tadornoides*

Months: October, December, January, March, April.

Occurred mainly in open and stumped water throughout the lake. Along with Pacific Black Duck and the Mallard - hybrid domestic ducks, this species was affected by algal poisoning in January, March and April (these were noted as non-bird sampling days) indicating that some tried to stay over the very hot and dry conditions which dried the lake to a shallaw pool over the summer of 1987/88.

10. DOMESTIC DUCK (MALLARD HYBRID) - *Anas platyrhynchus X*

Occurrence all year, October to June

Up to 22 individuals observed in December at the tail end of breeding season. Several distinctly Mallard males mated with female Pacific Black Ducks. Population increased from October to January (apparently by deliberate additions from people). No birds were capable of flying, their flight feathers were all too small.

3. GREY TEAL - *Anas gibberifrons*

Months: September - January - May.

Major concentrations - December, January, May, when waters of lake at depths between 30 and 5 cm, 1m out from September shoreline (high water mark) and as water became more brackish/saline. Only 2 broods observed. One brood of 2 may have been successful but the other brood of 2 died in January, probably killed by a dog. Like most water birds, Grey Teals left lake during February, March, April when lake was at its driest, hottest and saltiest. Large numbers returned by May when surface water covered a significant area.

4. BLUE BILL DUCK - *Oxyura australis*

Months: October - January.

Highest numbers in November, December when temperatures moderate to warm and waters still deep enough and fresh enough to support them. Several pairs bred up to five young in their clutches but the fate of the majority was probably early death. No juveniles seen. More males observed than females. Preferred the deepest waters and travelled between north and south parts of lake in search of food. Breeding occurred in the interface between tree stumps and bulrushes in the northern part of the lake.

5. PINK EARED DUCK - *Malacorhynchus membranaceus*

Months: October - January and June. Major concentrations in December and January. Breeding occurred from September to January with some pairs rearing up to five chicks. However, none survived. Most birds formed pairs at the lake. Roosting occurred on base tree stumps or in marsh areas (January), close to thickets of bulrush and open water.

APPENDIX THREE

BIRD SPECIES AND THEIR ABUNDANCE AT LAKE CLAREMONT, MARCH 1986 AND MARCH 1988 AS OBSERVED BY RAOU,

(Jaensch, R. P. and Vervest R. M.)

WATERFOWL COUNTS FROM LAKES, SWAMPS AND MARSHES
8–16 March 1986

COUNT FOR EACH SPECIES

WETLAND CODE	NAME	LAT-S AND LONG-E	AIR OR GROUND SURVEY	OBSERVERS	Black Swan	Freckled Duck	Aust Shelduck Duck	Pacific Black	Grey Teal	Chestnut Teal	Aust'sn Shoveler	Pink eared Duck	Hardhead	Maned Duck	Blue billed Duck	Musk Duck	Eurasian Coot	TOTALS swans and ducks	TOTALS all species
136	Ewan's		G	RPJ	232		80		205									517	517
438	Ewlyanartup		G	DRul	173		165		4200									4538	4538
433.	Eyrie		G Dry	WDG														0	0
430D	Fitches Lake, (Fitzes Swamp)		G	NAB,PB,WZ	65		200	33	340	1	16	1	1				65	657	722
357	Flagstaff		G	DGD	128		5											133	133
312	Forrestdale		GDry	JF														0	0
149	Fuss Rd, 1.8km N Springvale Rd		G	RPJ	1		8	5	110	2	45							171	171
181	Gidon		G	RPJ, AD	118		5	10	80	10								223	223
39	Gingin 31241		G	RM				7										7	7
26	Gnangarra Lake		G	RVD, CVD														0	0
164	Gnornbup		G	RPJ				3						3				6	6
497D	Goegrup Lakes System		A, G	DM,GP,JL	9		254	488	564							17	70	1332	1402
346	Goodale Sanctuary		G	RG				1										1	1
315D	Goolelal		G	PS,JB,LBos	50	1	5	200			14	13	1		3	8	130	295	425
182	Gore		G	AD			486											486	486
351	Grasmere/Powell		G	LBro	2		34	206	35		85		2				44	364	408
79	Gull Rock		G	SKeo	1			4	4							6	11	13	24
37D	Guraga		G	RM,GP			1											1	1
341	Gwelup		G	GS	4		2	56	6				1			4	111	73	184
450	Herdsman		G	MicB,ManB	107			18	4						2	4	345	135	480
452	Home Lake, (Bennecke's)		G	NAB, PB	1	8	1											10	10
352	Hope Rd, Swamp		G	NG				2	24		15	4		16			11	61	72
369	Hyde Park		G	PG	2			197						2			57	201	258
334	Indoon		G	JJ, RJ			14	13				11					77	38	115
333	Jackadder		G	IS, BW	160			120					2		6	1	260	289	549
284D	Jasper		A,G	DM,GP,MB	6			16								32		54	54
101	Jeffrey Rd, Swamp		G	OMG				4	12									16	16
337	Joondalup		G	Abur				169	174		10					74	24	427	451
97	Jubilee Rd, Swamp		G	OMG				2									1	2	3
338	Karrinyup Country Club		G	KJ	30		10	50	45		4			4			3	143	146
422	Kevills Lake		G	CH			450		520			60						1030	1030
355	Kidney Swamp		G	DGD														0	0
68	Kogolup		G	PCla														0	0
286	Kwornicup		G Dry	HW														0	0
34D	Lagoon, Namegarra Turnoff		G	RPJ,RM,GP			210	150	20		10			4			53	394	447
32D	**Lake Claremont**		**G**	**WJM, EM**	**11**		**6**	**58**	**26**		**3**	**7**					**8**	**111**	**119**
22	lake Gobba		G	ES				10	6				1				35	17	52

REFERENCE: Jaensch, R.P. & Vervest, R.M. (1988) Ducks, Swans and Coots in South-Western Australia: The 1986 and 1987 Counts: RAOU Report No. 31.

WATERFOWL COUNTS FROM LAKES, SWAMPS AND MARSHES
5–13 March 1988

COUNT FOR EACH SPECIES

WETLAND CODE	NAME	BLOCK REF.	AIR OR GROUND	OBSERVERS	Black Swan	Freckled Duck	Aust Shelduck Duck	Pacific Black	Grey Teal	Chestnut Teal	Aust'sn Shoveler	Pink eared Duck	Hardhead	Maned Duck	Blue billed Duck	Musk Duck	Eurasian Coot	TOTALS swans and ducks	TOTALS all species
438	Burswood Is Pools		G	JF1				56									32	56	88
600	Camel Lake	119F	G	ARo														0	0
158D	Canning School		G	JDo,Rsm, PHo,GAg			49	328	21					125				523	523
563D	Canning Pool		G	GAg,JDo				24						29				53	53
915	Carbul	110F	G	DMu,PFu														0	0
96	Cardiminup	122I	G	BNe	77		36	16	30		77	136			11	28	20	411	431
170	Carine (both)		G	GSh	47		185	221	14							5	254	472	726
553	Centennary Pk		G	PHa	2		4	40	2					1			95	49	144
566	Chandala	45C	G	GAg				2	128					20				150	150
376	Charles Veryard Reserve		G	PGo			6		25									31	31
609	Cheepanup	119F	G	ARo														0	0
265	Chittering	40G	G	8Kn	99		55	1075	859								204	2088	2292
562	**Claremont**		**G**	**TMi**				**8**	**2**								**1**	**10**	**11**
308	Clarke's Lake(A)	41G	G	JMa et al	2		1200		700		100	250			1	1	40	2254	2294
309	Clarke's Lake(B)	41G	G	JMa et al			41	4	16				7	174	15	5	36	262	298
28D	Clifton	67D	G/A	BBa et al ADa,DMu,SHa	88		11	204	494		4					1980	25	2781	2806
919	Cobinup	110D	G	DMu,PFu	253		2170											2423	2423
1016	Cokelup Swamp	82G	G	PLa														0	0
119	Collier Park G/C		G	HC1				2										2	2
105	Coode/Catherine		G	H&RJa			4	39	33					4				80	80
75D	Coogee	52B	G	DNa/NGo				12	22									34	34
155	Coogee		G	DBe														0	0
559	Cooks Lakes (Moora)	32C	A	RVa														0	0
137	Cooloongup	52E	G	JDa														0	0
501	Coomalbidgup	110F	G	R&R				16	33					6			6	55	61
357	Coomberdale Salt Lakes	25I	G	CMe														0	0
637	Corimup	129D	G	SKe														0	0
473	Coxall/Bedford H. Rd	109E	G	R&R	2											2		4	4
112	Crackers	32G	G	SHa			10	100	60		2		1					173	173
181	cnr. Forrest/ Tapper		G	DJa				3	14								1	17	18
122	cnr. Manning/ Gillon		G	HC1				1										1	1
121	cnr. Manning/ Kent		G	CH1														0	0
521	cnr. Middle/ Bedford H.	109D	G	R&R					2									2	2
365	Cnr. Stirling Kalamunda		G	GAg					3					90				93	93
120	Curtin Uni Lake		G	HC1				56									8	56	64

APPENDIX FOUR

MAJOR NATIVE AND EXOTIC PLANT SPECIES OF THE LAKE CLAREMONT REGION

WETLAND SPECIES

EMERGENT

Yanget or Bulrush	-	*Typha orientalis*
Jointed Twig Rush	-	*Baumea articulata*
Lake Club Rush	-	*Shoenoplectus validus*
Knotted Club Rush	-	*Isolepis nodosa*

SUBMERGED

	-	*Chara fragilis*
	-	*Potamogeton pectinatus*

FLOATING

Green Algae	-	*Chlorophyte spp.*
Blue Green Algae	-	*Anacystis aeruginosa*
	-	*Anabaena spiroides*

MARGINAL VASCULAR VEGETATION

a) Over Storey

Freshwater Paperbark	-	*Melaleuca rhaphiophylla*
Flooded Gum	-	*Eucalyptus rudis*
Giant Reed (*)	-	*Arundo donax*
Castor Oil Tree (*)	-	*Ricinus communis*
Pepper Tree (*)	-	*Shinus terebinthifolias*
Wattle	-	*Acacia cyclops*
Moonah Paperbark	-	*Melaleuca priessiana*
Blood Flower Bottlebrush	-	*Calothomnus sanguineus*
Moreton Bay Fig (*)	-	*Ficus macrophyllia*
Tasmanian Blue Gum (*)	-	*Eucalyptus St Johnii*
Sydney Blue Gum (*)	-	*Eucalyptus globulus*
Washington Palm (*)	-	*Washingtonia filifera*
Sheoak (I)	-	*Allocasuarina fraseriana*
Weeping Willow (*)	-	*Salix sp.*

b) <u>Understorey</u>

Dock (*)	-	*Rumex spp.*
Water Couch Grass (*)	-	*Paspalum paspalodes*
Salt Water Couch Grass (*)	-	*Paspalum distichum*
Kikuyi Grass (*)	-	*Pennistetum clandestinum*
Fennel (*)	-	*Foeniculum vulgare*
Wireweed (*)	-	*Polygonum spp.*

WOODLAND VASCULAR SPECIES

a) <u>Overstorey</u>

Tuart	-	*Eucalyptus gomphocephala*
Marri	-	*Eucalyptus calophylla*
Jarrah	-	*Eucalyptus marginata*
Salmon Gum (*)	-	*Eucalyptus salmonophloia*
Lemon Scented Gum (*)	-	*Eucalyptus woodwardii*
Coral Gum (*)	-	*Eucalyptus torquata*

b) <u>Middle Storey</u>

Rottnest Island Pine	-	*Calytris robusta*
Western Peppermint	-	*Agonis flexusa*
Wattle	-	*Acacia cyclops*
Wattle	-	*Acacia saligna*
Menzies Banksia	-	*Banksia Menziesii*
Swamp Banksia	-	*Banksia littoralis*
Flame Tree (*)	-	*Erythrina caffra*

c) <u>Lower Storey</u>

Prickly Moses	-	*Acacia pulchella*
Staghorn bush	-	*Daviesia sp.*
Zamia Palm	-	*Macrozamia reidlei*
Geraldton Wax (*)	-	*Chamaelaucium uncinatum*
Stink Bush	-	*Jacksonia furcellata*
	-	*Jacksonia sternbergiana*

d) Understorey

Veldt Grass (*)	-	*Ehrharta calycina; E longiflora*
Hairs Tail Grass (*)	-	*Laganis ovatus*
Clover (*)	-	*Oxalis pes-caprae*
Summer Grass (*)	-	*Digitaria sanguinalis*
Buffalo Grass (*)	-	*Stenotaphrum dimidiatum*
Watsonia (*)	-	*Chasmanthe floribunda*
Clover (*)	-	*Trifolium spp.*

* (*) Exotic
(I) Introduced to the habitat