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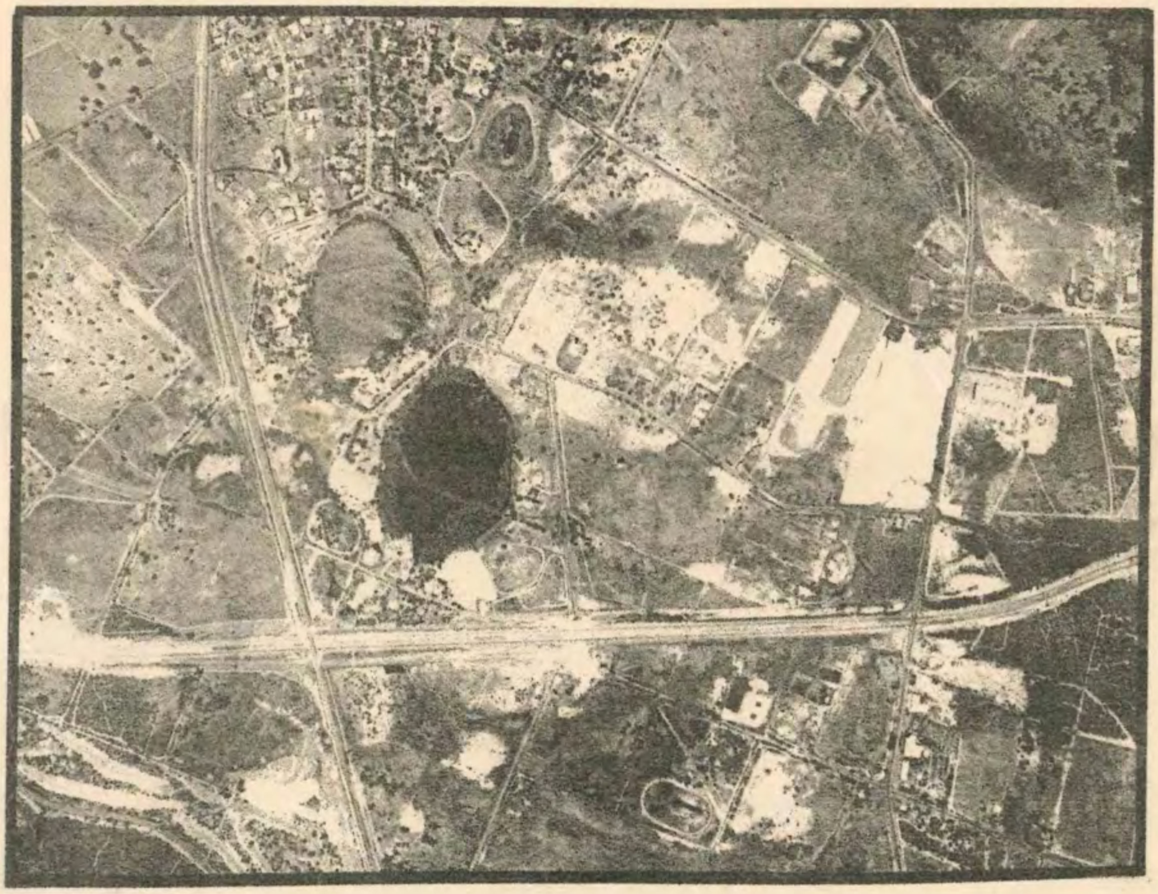
Eutrophication of the Hazelmere Lakes 1991



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Eutrophication of the Hazelmere Lakes 1991

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This investigation of the Hazelmere Lakes was conducted jointly by the Shire of Swan, Environmental Protection Authority and the Waterways Commission. It was initiated in response to the work of Mr D Walsh which indicated high nutrient inputs to the lakes.

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Preface

The Hazelmere Lakes represent the remainder of a larger wetland system that existed before clearing and land development in the area south of Midland. The lakes are considered to have regional conservation values and consequently were included in the System Six Study Report to the Environmental Protection Authority in 1981. Subsequently the System Six Red Book which was released by the EPA and endorsed by Cabinet in 1984 recommended the protection of the lake's conservation and recreation values.

Since that time there has been no progress in the protection of the lake's attributes and consequently further degradation of their environment has occurred, most visibly as clearing of the fringing vegetation and the increasing midge infestation.

In 1989 the Shire of Swan recognised that water quality in the lakes had deteriorated substantially and that algal blooms were occurring. The Shire initiated a monitoring programme to determine the extent of the problem and the cause. The results of this programme were reported in March 1991 by Mr D. Walsh. The drains feeding the southern lake were found to contain very high nutrient concentrations and the lakes were found to be highly nutrient enriched. It was noted that drainage concentrations appeared to become elevated below two animal waste rendering plants located in the eastern catchment.

These results indicated that the Environmental Protection Authority's licence conditions for the two industries may need to be reviewed if the conservation values of the lakes were to be preserved. A more intensive lake and catchment monitoring programme was initiated jointly by the Shire of Swan and the Environmental Protection Authority to more accurately determine the nutrient losses from the catchment and to enable nutrient assimilative capacity for the lakes to be estimated. The objective was to provide the base line information required to ensure that activities within the catchment were managed to reflect the lake's conservation and recreation values.

Summary and conclusions

Excessive nutrient loads in coastal plain rivers, streams and artificial drains have contributed to the degradation of many of the associated wetlands in south-west Western Australia including estuaries and lakes in the metropolitan region. The main sources for these nutrients are fertilisers and domestic, agricultural and industrial effluents leached, or in some cases directly discharged, from the typically sandy coastal plain soils on which they have been applied.

The Hazelmere Lakes are situated in the Perth metropolitan region but the predominant landuse in their catchment is agricultural and industrial. The lakes themselves have been entirely subdivided and are in private ownership. The lakes have recognised regional conservation and recreational values and hence were included in the System Six 'Green Book' study in 1981 which recommended that their conservation and recreational values be preserved. This was later included in the System Six 'Red Book' which was endorsed by Cabinet in 1984.

Following a report by the Shire of Swan outlining the poor condition of the Hazelmere Lakes, the Shire of Swan and the Environmental Protection Authority jointly initiated this investigation to examine in more detail lake water quality and nutrient loads from the inflowing drains. The objective was to determine the current condition of the lakes, determine the sources of the nutrients and to provide the background information necessary to recommend appropriate management practices for their maintenance as healthy resilient aquatic ecosystems.

Both lakes were found to be severely nutrient enriched (hyper-eutrophic) and contained large algal blooms at different times of the season. Nutrient input to the northern lake from surface drainage was very high, the phosphorus input accounted for a loading of 0.4 grams of phosphorus per square meter (gP/m^2) of lake area. The southern lake was receiving substantially more nutrients with a phosphorus loading of 9.3 gP/m^2 of lake area. The drain nutrient concentrations and export rates from the catchment of the northern lake are consistent with general agricultural fertiliser use. The main nutrient sources in the catchment for the southern lake appear to be two licensed animal waste rendering plants situated about 1 kilometre from the lakes. The assimilitive capacity of the lakes for phosphorus was estimated using the Vollenweider approach. A target of no more than 18 and 22 kgP/yr for nine out of 10 years was calculated for the northern and southern lakes respectively. These estimates are not considered to be absolute since the model has not been tested or calibrated for Perth's coastal plain lakes and should be further refined as more information becomes available.

Substantial reductions in the nutrient load and significant changes in management for both lakes are required if their regional values to both the community and conservation generally are to be preserved.

The conclusions based on the results of this investigation are summarised below:

1. **Monitoring of water quality in the lakes and of nutrient inputs via surface drainage indicate that both lakes are severely nutrient enrichedand in need of rehabilitative work to protect their values for conservation and to the community.**

2. **It would be appropriate for the Shire of Swan to coordinate planning and management within the lakes and their catchments to achieve rehabilitation of the lakes and to maintain their conservation and recreational values. This may best be achieved by the development of a management plan.**

3. **A Catchment Group should be formed consisting of the local landholders, representatives of interested community groups and the Shire of Swan. Other Government agencies could be involved as the need arises.**

4. The Shire of Swan would be the most appropriate agency to initiate and service the group.

5. The Catchment Group could have a major role in assisting with the development of a management plan and its implementation. It could also ensure that land use activities within the lake catchments are consistent with the agreed conservation and recreational objectives for the lakes.

6. To achieve the objective of reducing the nutrient loads to the lakes until the assimilative capacity is achieved, management mechanisms such as those listed below should be investigated for inclusion and implementation as part of the management plan. Such mechanisms may include:

   - No further drain construction within the catchments.
   - Reduce or stop surface flows entering the lakes (eg. filling in or diversion of drainage, use as an irrigant, planting rapidly transpiring trees at strategic locations).
   - Introduce appropriate management to prevent excessive animal stocking rates and fertiliser use and to reduce or prevent leaching of fertilisers.
   - Appropriate management of current waste disposal, and rehabilitation of old waste disposal sites, by the animal waste rendering works to achieve a level of off-site discharge consistent with target nutrient load for the lakes.
   - Construct shallow artificial wetlands with emergent vegetation, including paperbarks, strategically along remaining drainage lines.

7. The feasibility of removing the excessive nutrient store in the sediments of both lakes should be investigated if build up of organic material and nutrient recycling continues to cause algal blooms and poor water quality;

8. Grazing should be excluded from the lake fringes and adjacent areas and a revegetation programme implemented using locally native species.

9. The contribution of groundwater to the lakes should be investigated to complete the information base on inputs and our understanding of the processes contributing to the condition of the lakes.

1. Introduction

Eutrophication of waterbodies resulting from agricultural and industrial landuses, urbanisation and other human-related activities in the surrounding catchment is well documented throughout the world. In Western Australia several studies have specifically considered this issue in both Swan coastal plain lakes (Congdon, 1986; Bayley et al, 1989; Lantzke, 1989) and estuaries (Lukatelich, 1986; EPA, 1988; McAlpine, 1989; EPA, 1990).

The problem of eutrophication is of particular concern in the Perth metropolitan region and surrounding area because of the sandy infertile nature of many of its soils coupled with the intensity of landuse. Many of the soils have low nutrient retention capacities and are very porous.

The Hazelmere Lakes are two shallow freshwater lakes located three kilometres south-west of Midland. The lakes are about 100 metres apart, roughly oval shaped and have a maximum diameter of about 350-400 metres each (map 1).

The lakes have been identified as wetlands of regional conservation and recreational significance by their inclusion in the System Six "Red Book" (EPA, 1983) which recommends the protection of these values. A wide variety of bird species are supported by the lakes. Although degraded, the system also provides some good examples of remnant vegetation, including species such as swamp paperbark, moonah paperbark, flooded gum, marri, banksia and sheoak.

Hazelmere Lakes have also been included in the Lakes Environmental Protection Policy of the Environmental Protection Authority. The policy is not retrospective but its intent is to provide some protection for the remaining lakes on the Swan Coastal Plain from further environmentally degrading activities such as filling, mining, draining and effluent discharges.

As can be seen from the aerial photograph (map 2) the lakes generally have permanent open water, although the northern lake has dried several times, including the summer of 1991.

The geology of the area immediately surrounding the lakes shows superficial formations of sand and clay overlying the impermeable sandy-clay Osborne formation at around 13m (G.R.C. 1983). This geology provides for a high water table in the superficial sands, particularly the winter months. A study conducted in 1983, (G.R.C. 1983) found the southern lake to be in direct hydraulic relationship with the upper sand.

The general regional groundwater flow in the area appears to be west - north west. Based on the findings of recent CSIRO research, (Townley and Turner 1990) it appears that water in the surface aquifer would flow from the southern lake into and through the northern lake. This has yet to be validated in the field; however work is currently being undertaken to qualify this relationship.

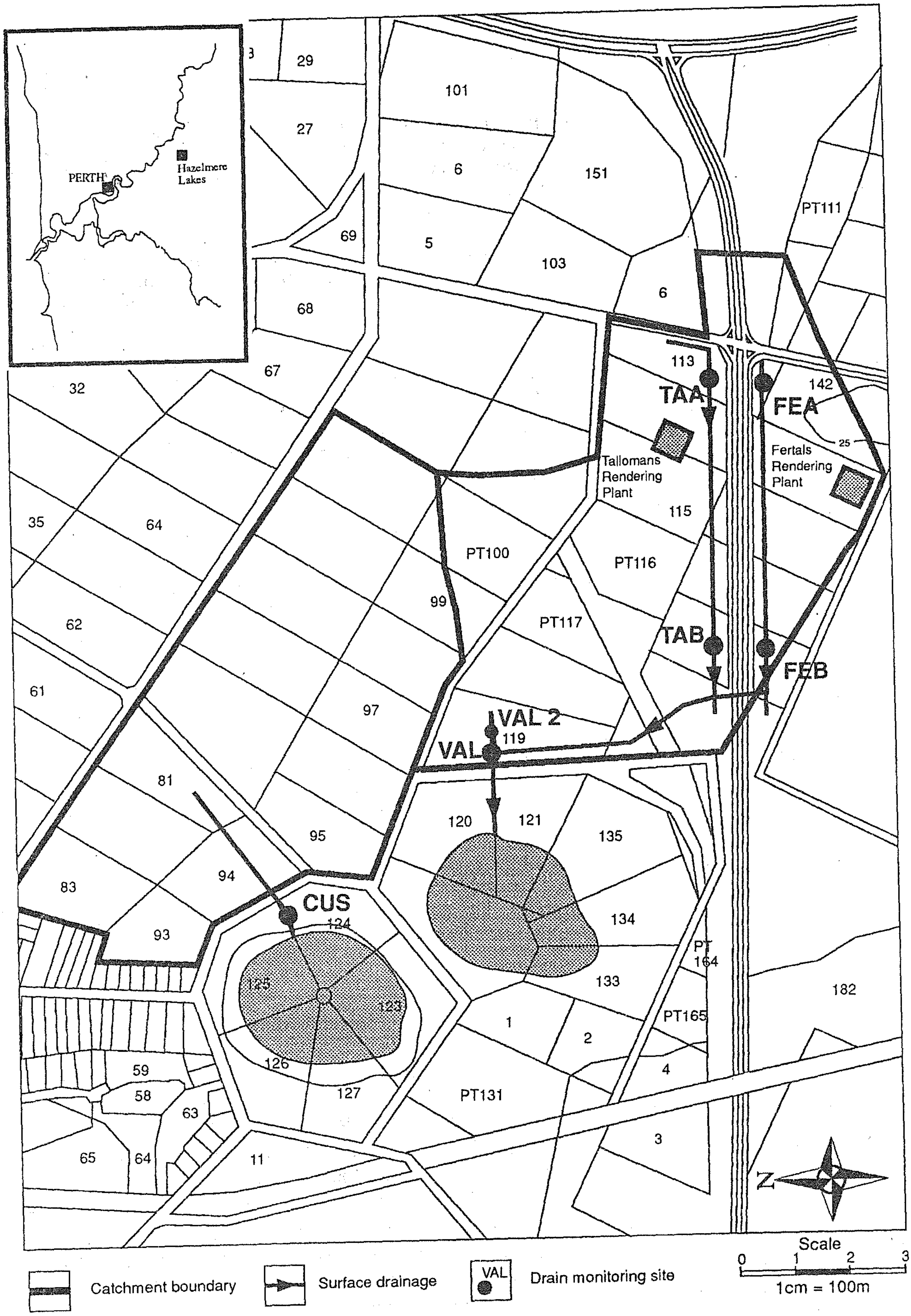
Surface water from the surrounding catchment is directed into the lakes via a series of stormwater channels (Map 1). A surface connection exists between the lakes, with the southern lake overflowing to the northern during periods of high water levels.

The land over which the lakes lie is privately owned by several landowners. Lot sizes are generally about four hectares in size. Most of the surface catchment to the lakes is also divided into blocks of about 4 ha under private ownership with the remainder in road reserves.

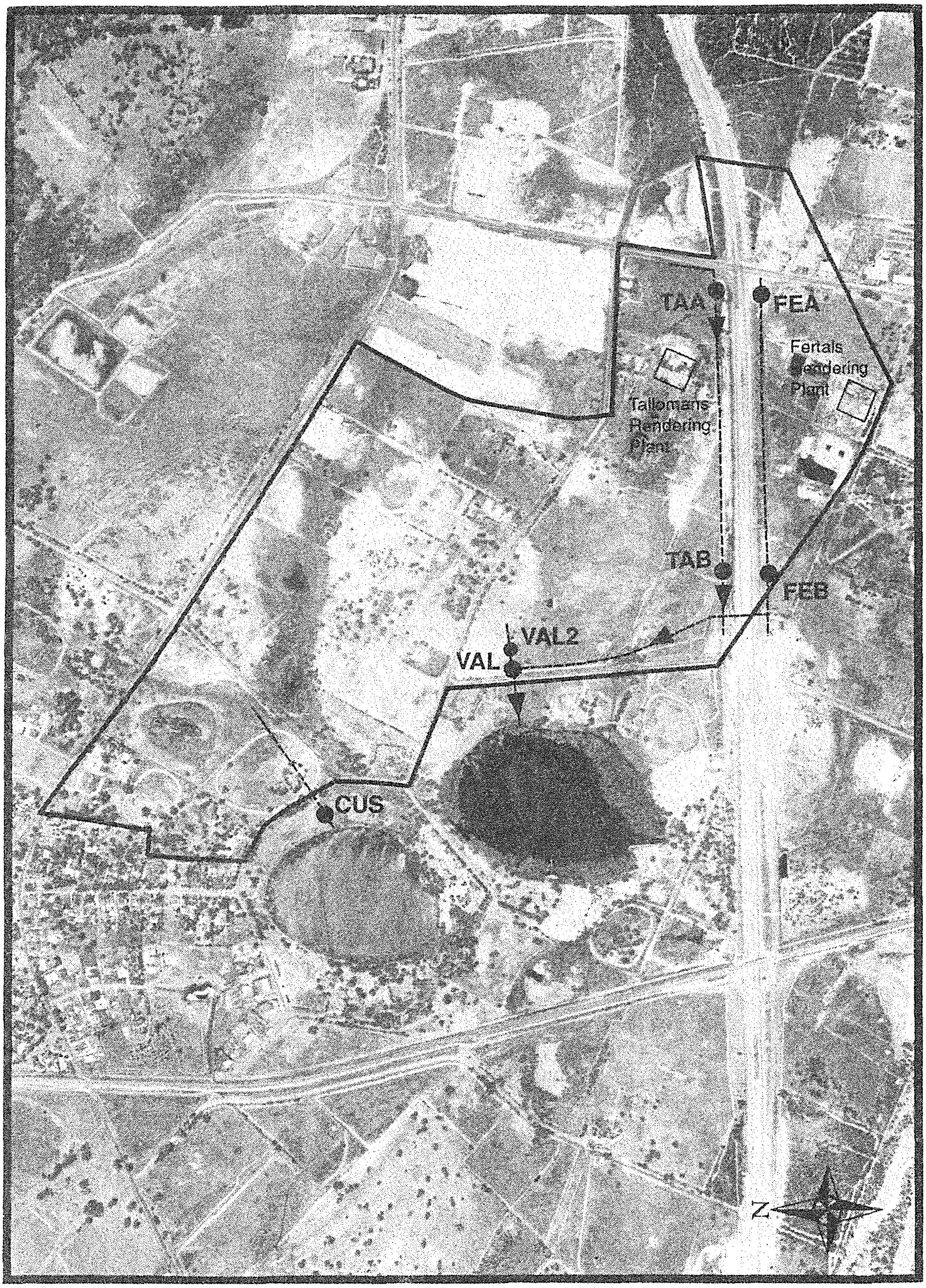
Landuse in the catchment is generally semi-rural with small scale livestock grazing and stables being predominant. Two animal by-products industries are located less than 1km east-south-east of the southern lake and have existed in this location for about 20 years.

Much of the catchment has been cleared of native vegetation, and replaced largely with annual pastures and residential gardens. The fringing vegetation of the northern lake has been extensively cleared while the vegetation of the southern lake has been kept comparatively intact. Map (3) shows the vegetation currently surrounding the lakes. A conceptual plan of vegetation in the vicinity of the lakes before clearing is shown in map (4).

Several major changes have occurred in the catchment which have had a major impact on the area's hydrology.



Map 1. The Hazelmere Lakes and their surface drainage catchment.



Map 2. Aerial photograph of the Hazelmere Lakes and their catchment. (taken 3 January 1992)

Scale
0 1 2 3
1cm = 80m

Old subdivision maps show a third interconnected lake to the north of the northern lake. This lake now consists of a small compensating basin which has no observed surface connection to the other lakes. This maps also appears to show an outflow from the northern lake into a wet area which drains to the south-west. This outflow no longer exists.

In the late 1980s, the Great Eastern Highway Bypass was built in the lake's catchment. This road passes within 200 metres of the southern lake.

Although the impact of its construction on the local groundwater regime is largely unknown, the drainage associated with the roadway has dramatically altered the drainage into the lakes.

Drainage channels were built along the bypass road south-east of the lakes, which interconnect and flow into the southern lake. These drains are relatively deep and channel superficial groundwater in the vicinity of the rendering works, as well as surface run-off from, the roadway and surrounding land.

Severe algal blooms were observed in the lakes by Shire of Swan staff during a midge monitoring exercise in 1989. Initially these blooms appeared to be confined to the northern lake turning the water a soupy-green, however, further observations revealed similar blooms in the southern lake.

Identification of the algae revealed the presence of blue-green *Anabena sp* and *Microcystis sp*.

Analysis of water nutrient levels in the lakes in February 1990 revealed that both lakes were heavily nutrient enriched. Based on the lake trophic status criteria used by Davis and Rolls (1987), both lakes were found to be in a severely enriched state and could be classified as eutrophic to hyper-eutrophic.

To identify the source and magnitude of nutrient inputs to the lake system from the surface drainage, a detailed monitoring programme was conducted during the winter of 1990 (Walsh 1991).

This investigation found that extremely high concentrations of nitrogen and phosphorus were entering the southern lake. Inputs to the northern lake were found to have concentrations that were significantly lower and of the magnitude expected from the surrounding land use.

Ongoing monitoring of water quality in the lakes revealed that nutrient levels in both lakes remained very high, particularly when compared to other metropolitan freshwater lakes.

In addition to the algal blooms evident in the lakes, these high nutrient levels have been associated with an excessively large midge population in the northern lake.

In response to the findings of these initial investigations, the Shire of Swan initiated several investigations, including this report to provide the information needed to develop a management plan for the lakes. The management plan would be prepared by the Shire of Swan in consultation with the local community and the EPA.

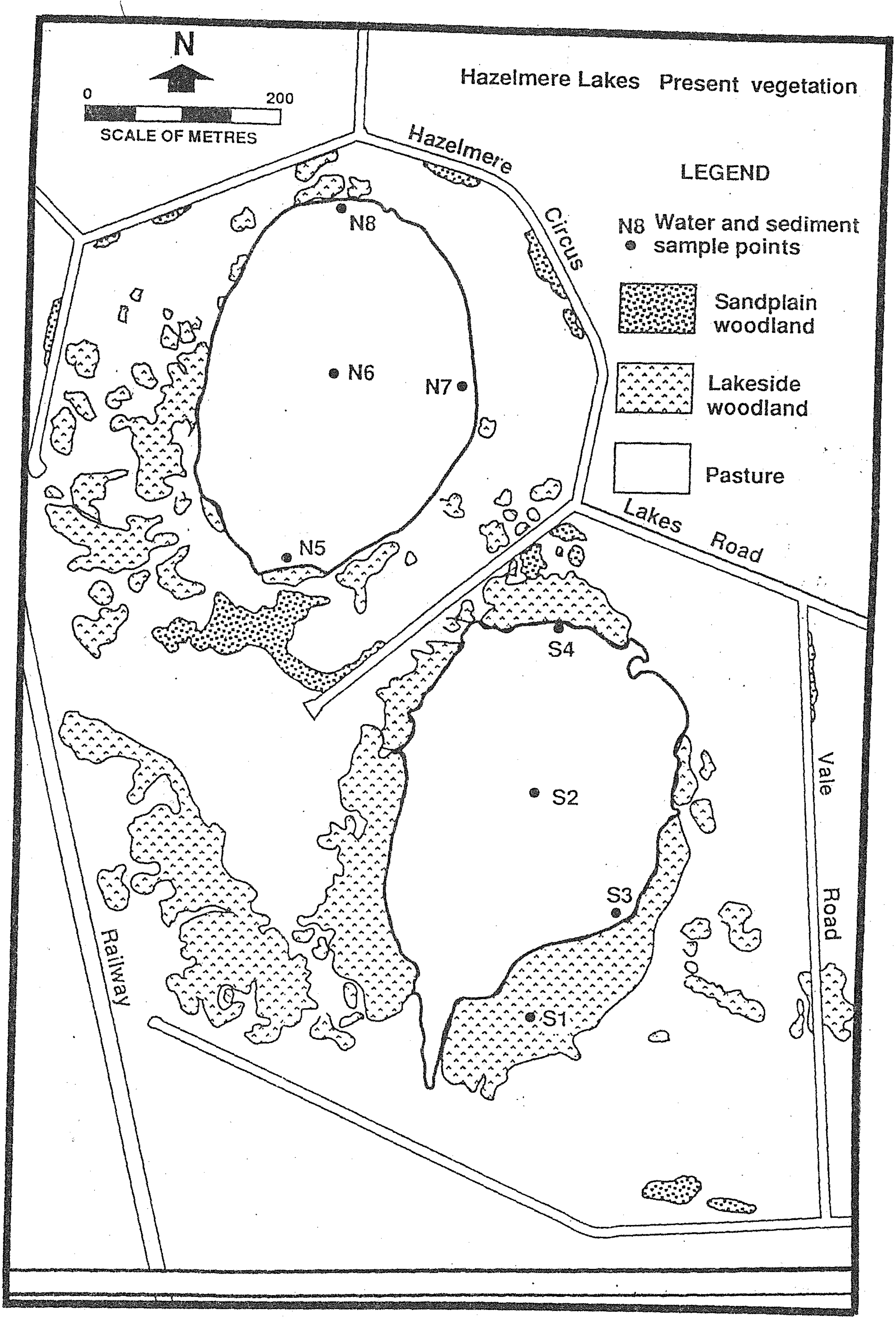
2. Investigation programme

2.1 Lake monitoring programme

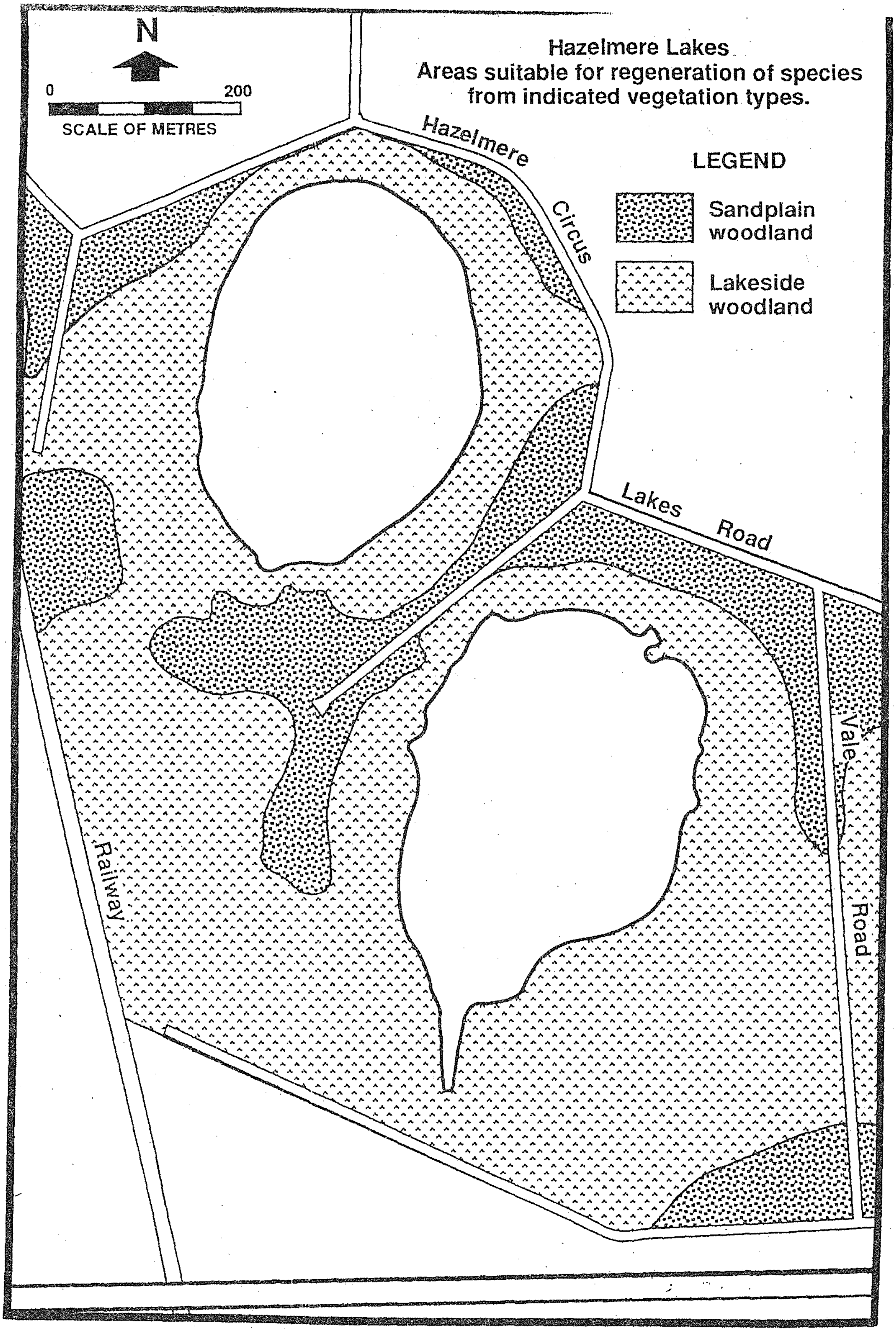
Regular monitoring of physical and chemical parameters has been conducted by the Shire since early 1990.

A biological survey was carried out by staff and students of Murdoch University during the winter and autumn of 1991.

The findings of this work is summarised in the following sections.



Map 3. The extent of the natural vegetation complexes currently surrounding the Hazelmere Lakes (from Newsome and Ladd, 1991).



Map 4. A conceptual plan showing the extent of the natural vegetation complexes originally surrounding the Hazelmere Lakes prior to clearing (from Newsome and Ladd, 1991).

Water quality

- **Depth**

Water depth has been monitored regularly for each lake using measuring stakes installed in the centre of each lake. The results are shown in figures (1a) and (2a).

Lake depths vary seasonally in response to winter filling and summer drying. The southern lake is generally 0.5 - 1.0m deeper than the northern lake, and retains permanent open water while the northern lake dries periodically. The northern lake completely dried out for about three months in the summer early in 1991.

- **Temperature**

Surface temperatures have been measured at the lake centre regularly during sampling trips. Initial measurements temperatures were made using maximum - minimum thermometers installed on the measuring stakes in each lake. This method was replaced in 1991 with a hand held Hanna electronic meter.

Temperatures have been found to vary from 10 - 12°C during the winter months through to 20 - 25°C in summer. Maximum temperatures of 32 - 33°C have been recorded in both lakes during the summer months. Temperature data for the two lakes have been graphed in figures (1a) and (2a).

Temperatures in the northern lake average 1 - 2°C higher than those in the southern lake, probably because of it's shallower depth.

- **Colour**

There is some circumstantial evidence to indicate that coastal plain lakes with highly stained water from leached humic acids may be more tolerant to the effects of nutrient enrichment. It appears that algal growth may be inhibited in these lakes but there has been no investigation to determine the mechanism. The term Gilvin is used to describe this yellow/brown staining of the water by dissolved substances and is determined as absorbance at 440nm on filtered water (Wrigley et al; 1988).

The lakes display a marked difference in colour. The southern lake is an amber brown colour due to tannin staining while the northern lake often has a khaki colouration due to the presence of algal blooms.

Gilven levels measured in the lakes on two occasions during winter/autumn 1991, show an average of around $40g_{440}$ for the southern lake and 25 - $30g_{440}$ for the northern lake (Page 1991).

- **Conductivity**

Conductivity measurements have been carried out regularly using a HANNA electronic conductivity meter. Measurements were taken at the centre of each lake.

The results of the conductivity monitoring are shown in Figures (1b) and (2b).

Under normal conditions both lakes are fresh. The northern lake however, became saline during the late summer of 1991 as the lake dried up concentrating the salts. Upon re-filling in winter the conductivity was seen to return to the freshwater range.

The northern lake generally displays a higher conductivity than the southern, with both lakes showing a similar patter of rising conductivities during summer due to concentration of the salts resulting from evaporation.

- **pH**

Measurements for pH have been conducted regularly at the centre of each lake using a HANNA electronic pH meter.

pH values for the southern lake range from 7.2 - 9.0 (fig. 2b), with the northern lake ranging from 7.2 - 9.9 (fig. 1b).

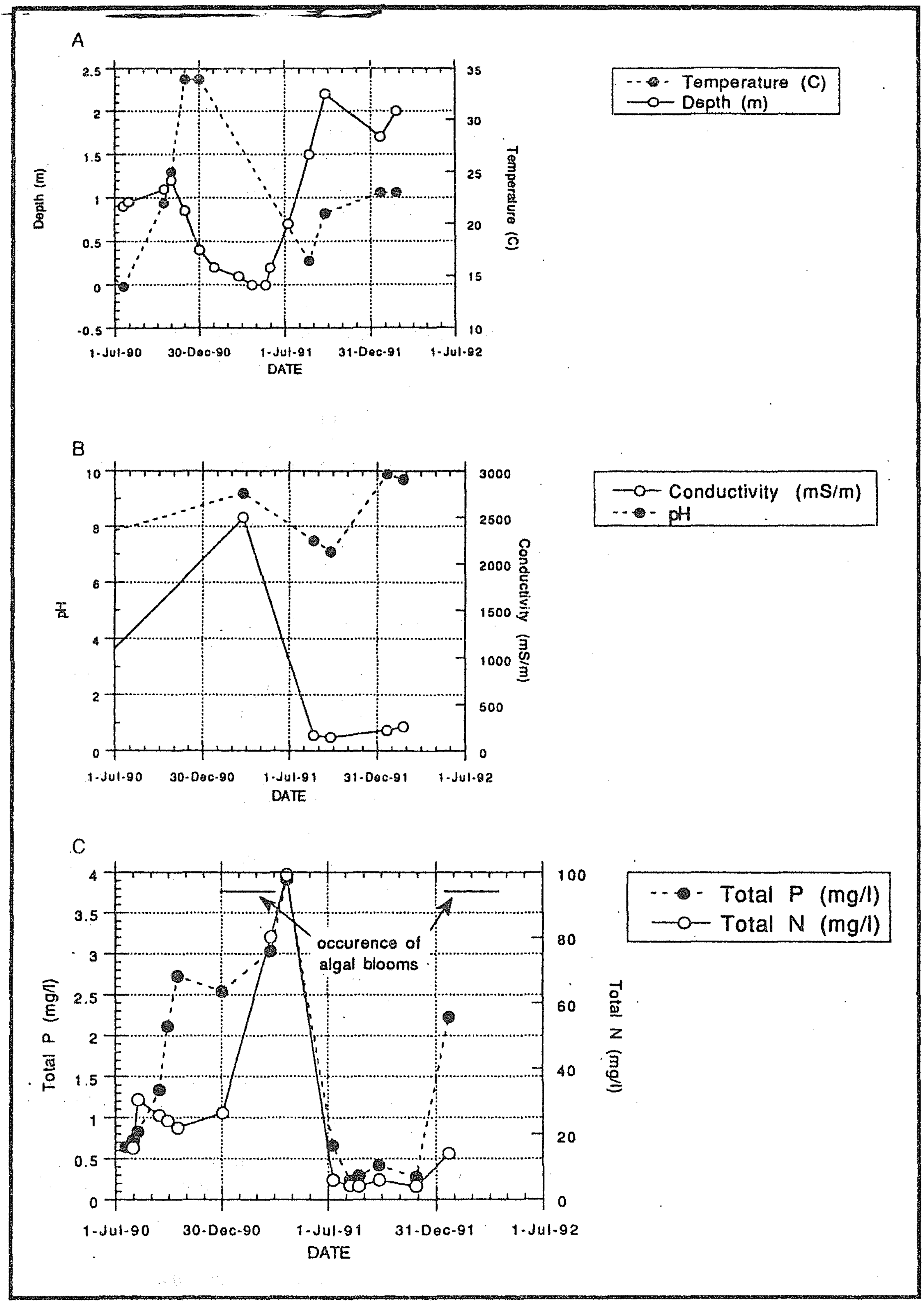


Figure 1. Seasonal variation in water quality for the northern Hazelmere Lake (a) Depth and Temperature, (b) Conductivity and pH, (c) Total Phosphorus and Total Nitrogen.

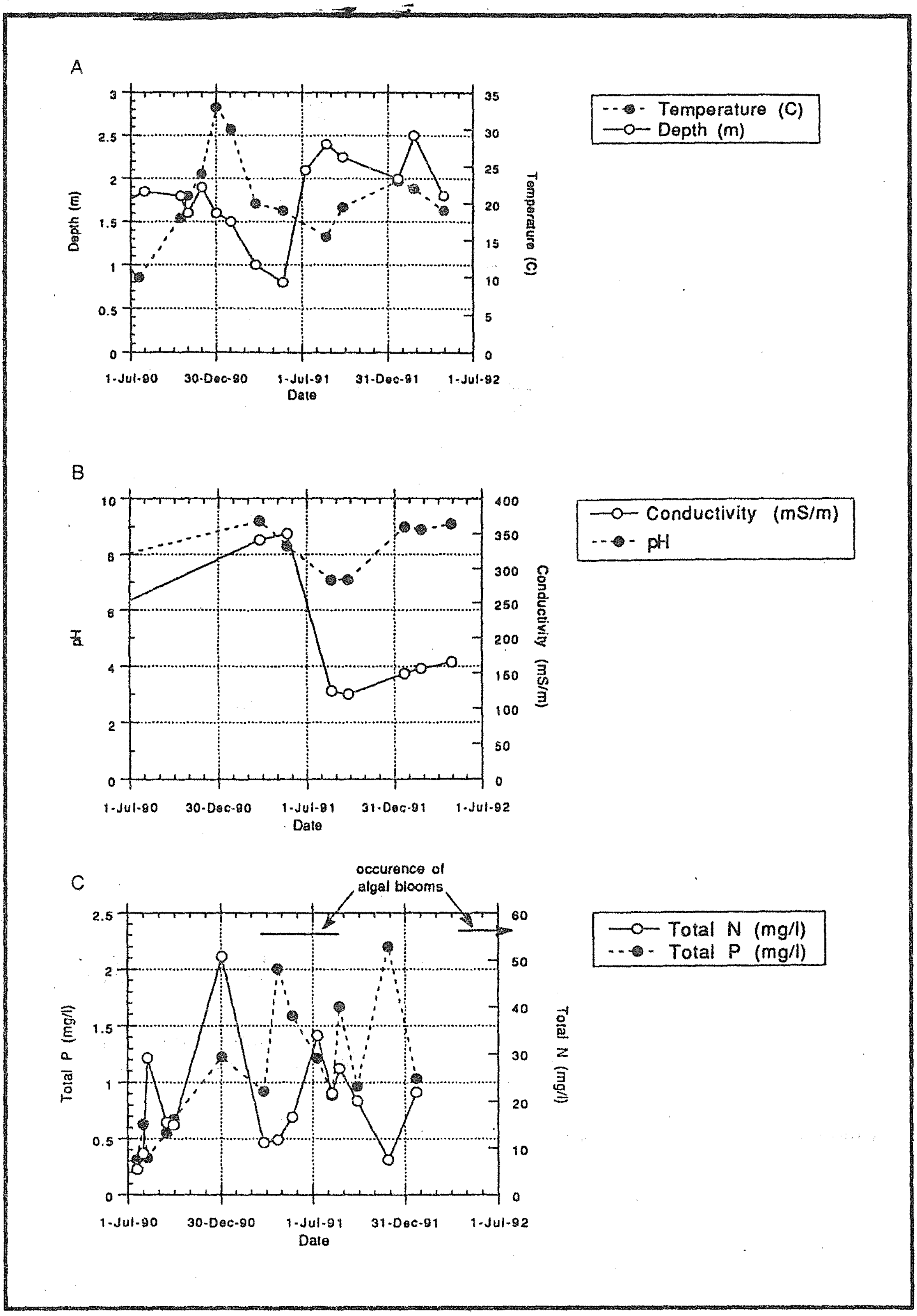


Figure 2. Seasonal variation in water quality for the southern Hazelmere Lake (a) Depth and Temperature, (b) Conductivity and pH, (c) Total Phosphorus and Total Nitrogen.

Nutrients

Samples for nutrient analysis were taken regularly from the centre of each lake at a point 30cm from the surface. Analysis of nutrient levels at various depths and locations in the lakes in February 1990 revealed little variation in levels between sites suggesting the lake waters are well mixed.

Samples were collected in 300ml plastic bottles and frozen immediately upon return from the field.

Nutrient analysis was carried out in line with the methods in EPA Technical Bulletin 39 (Hillman, 1991). Specifically these were as follows:

Orthophosphate Phosphorus	-	single solution method.
Total Phosphorus	-	determined after sulphuric and perchloric acid digests respectively, followed by the analysis for orthophosphate described above.
Organic Phosphorus	-	difference between orthophosphate and total phosphorus.
Ammonia Nitrogen	-	isocyanurate method.
Nitrate plus Nitrite Nitrogen	-	determined after copper - cadmium reduction with a Technicon Autoanalyser II.
Total Kjeldahl Nitrogen	-	determined after sulphuric and perchloric acid digests respectively, followed by the analysis for ammonia described above.
Total Nitrogen	-	Total Kjeldahl Nitrogen and Nitrate/Nitrite nitrogen.
Organic Nitrogen	-	determined by subtracting ammonia nitrogen from KJELDAHL nitrogen.

- **Northern Lake**

  - **Phosphorus:**

The results for total phorphorus levels in the northern lake are shown in Figure (1c). Levels range from 0.6 - 3.9 mg/l.

Based on Davis & Rolls (1987), peak phosphorus levels exceed the criteria for a hyper-eutrophic lake, and are well in excess of other coastal plain wetlands.

As with conductivity, a pattern of summer peaks due to concentration by evaporation, and winter lows due to dilution is evident. Winter phosphorus levels remain in the hyper-eutrophic classification.

Analysis of orthophosphate and organic phosphorus from samples collected on two occasions in the winter of 1991 show that orthophosphate comprised 20 - 30% of total phosphorus on average.

This relationship is similar to that described for North Lake in the south-west of the Perth metropolitan area by Davis & Rolls (1987) but is in contrast with their findings for other coastal plain wetlands.

  - **Nitrogen:**

Total nitrogen levels in the northern lake varied from 4.1 to 99.0 mg/l (Figure 1c).

These levels peaked in March - April 1991 when lake levels were very low. A more typical upper level would be about 30 mg/l.

These levels are high when compared to other Swan coastal plain lakes, and places the lake in a hyper-eutrophic condition based on total nitrogen for the sampling period. In the months after the refilling of the lake in 1991 nitrogen concentrations were slightly reduced but still indicated that the lake was eutrophic.

Limited analysis of nitrogen fractions indicates substantial variation in organic nitrogen levels, varying from 52 - 75% during the winter months, and up to 97% during an algal bloom in January 1992.

- **Southern Lake**

  - **Phosphorus:**

Variations in total phosphorus levels in the southern lake are shown in Figure (2c). Levels vary between 0.3 - 2.0 mg/l. Although lower than those found in the northern lake, these levels place the southern lake in a hyper-eutrophic condition based on total phosphorus.

Analysis of orthophosphate levels in samples taken during the winter of 1991 (Page 1991) reveals that during algal blooms orthophosphate levels were about 50% of the total phosphorus concentrations, while levels in the absence of blooms were more than 80% of total phosphorus concentrations.

No distinct seasonal patterns were observed for total phosphorus in the southern lake.

  - **Nitrogen:**

Total nitrogen levels in the southern lake ranged from 5.4 - 50.7 mg/l.

Levels tend to rise during winter in response to drainage inputs. As figure (2c) shows, levels tend to peak at the end of winter then drop away. This pattern is likely to be due to the uptake of nitrogen from the water column by algae during spring/summer blooms.

Average levels in the southern lake are slightly higher than those in the northern lake, indicating that the lake may be in a hyper-eutrophic condition.

Analysis of nitrogen fractions conducted during the winter of 1991 revealed that organic nitrogen comprised 40 - 50% of total nitrogen. In contrast, analysis carried out in January 1992 revealed that organic nitrogen comprised 98% of total nitrogen in the absence of an algal bloom.

Ammonia nitrogen levels were found to be highest during the late winter months at which stage it comprised 18 - 20% of total nitrogen.

Sediments

The lake sediments were sampled to determine the concentrations of the nutrient fractions. Sediment nutrients can have a major role in promoting algal blooms if the store of available nutrient is sufficiently large and conditions for recycling are suitable.

Sampling of surface sediments in both lakes for nutrient analysis was carried out by Murdoch University in August 1991.

This sampling exercise found that the southern lake contained centre sediments with very high concentrations of total phosphorus. The highest level of 4617mg/kg total.P. was far above the levels recently reported for 16 Gnangara Mound wetlands (Davis and Rolls 1991).

Of particular note is that non-apatite, or available phosphorus was extremely high in the southern lake sediments, providing a store of available phosphorus for algae. Page (1991) found that dissolved oxygen levels dropped dramatically just above the sediments of this lake, providing anoxic conditions for release of non-apatite phosphorus.

Sediment phosphorus levels in the northern lake were found to be more consistent with other Swan coastal plain wetlands, although levels of non-apatite phosphorus in the lake centre were well elevated. Again, anoxic conditions were found above the sediments (Page 1991), providing conditions ideal for release of the non-apatite fraction.

Total nitrogen concentrations in the lake sediments exhibited a similar trend to the total phosphorus concentrations, with levels in the southern lake high, and levels in the northern lake similar to those found in other coastal plain wetlands.

Algal blooms and chlorophyll *a*

As previously mentioned, both lakes have been observed to contain algal blooms for several years. Initially blooms were confined to the northern lake, but for some years now blooms have also occurred in the southern lake.

Analysis of algal species on several occasions has shown the principal species to be *Microcystis sp* and *Anabena sp*, both blue-green algae.

On observation, blooms in the northern lake were present during summer of 1990/91 until the lake dried in March/April 1991. After re-filling, an algal bloom did not occur until January 1992, and appeared to last until April 1992. The blooms observed in this lake tend to be extensive, with the whole of the water column affected and significant shoreline scumming.

Before March 1991, blooms in the southern lake appeared inconsistent and were isolated to edge scumming. However, from March 1991 until August 1991 an extensive bloom occurred which affected most of the water column and caused a large floating slick of algae with shoreline scumming. This bloom died off in September 1991, with a new, less intensive bloom beginning in April 1992.

There have been some chlorophyll *a* samples taken for analysis since July 1991. Chlorophyll *a* concentrations in the northern lake were relatively low from July to September ranging from 0.01 to 9.1µg/l. However, at the beginning of the algal bloom in January 1992 chlorophyll *a* had risen to 699µg/l.

In the southern lake chlorophyll *a* was generally higher in the winter and spring months increasing from 30.4µg/l in July to a maxima of 800µg/l in August and then falling to 3 - 64µg/l in September. In January chlorophyll *a* in the southern lake was low (0.53µg/l). Chlorophyll *a* samples taken from the southern lake during the main algal bloom later in the year have not been analysed.

Macro-invertebrates

Macro-invertebrates were collected by Murdoch University using sweep nets during the months of August and September in 1991.

This work suggests that the lakes have a large diversity of species. However, this diversity is affected by the nutrient levels in the lakes and the response of algal species to these levels (Page 1991).

A dramatic increase in *Daphnia sp* occurred in the southern lake between August and September 1991. This appeared to play an important role in controlling the algal bloom present in the lake at this time.

The northern lake displayed larger numbers of predators than the southern lake, a relationship which fits with the findings of regular midge monitoring in this lake.

Further work is required to fully understand the changes in species abundance and diversity in both lakes and importantly, the role that macro-invertebrates play in controlling algal blooms.

Discussion

The results show that both lakes are heavily nutrient enriched and are displaying symptoms similar to other enriched metropolitan wetlands.

Nutrient levels in the southern lake are directly attributed to inputs from the drain entering the lake. Levels tend to peak at the end of winter inflows then drop off due to uptake by algae and sedimentation.

The levels within the northern lake do not appear to be in keeping with drainage inputs and are influenced more by summer concentration due to evaporation. It is also likely that this lake receives inputs from groundwater flow through the southern lake.

Both lakes have a substantial nutrient store in the sediments. These nutrients are largely in an available form. The non-available fractions are likely to become recycled during anoxic conditions and periods of high pH.

Extensive algal blooms occur in both lakes but at different times of the year. Despite the greater store of nutrients in the sediments and water column of the southern lake observations indicate that algal blooms in the northern lake are more intense than blooms in the southern lake, but this is yet to be confirmed by the chlorophyll *a* analyses. Algal blooms in the southern lake appear to have been inhibited to some extent by factors such as its dark colouration, better fringing vegetation, lower water temperature and presence of large numbers of grazing macro-invertebrates with the present nutrient loading on this lake. However, it is likely that the capacity of the lake to inhibit extensive algal blooms will diminish if current nutrient inputs continue and very poor water quality, unacceptable odours and even death of the fauna may result.

2.2 Catchment monitoring programme

Method

The lakes' catchment characteristics have been described in the introduction. The main features are reiterated here as they are important to the understanding of the monitoring programme.

The south catchment is cleared, drained and contains two animal waste rendering plants, Fertal Pty Ltd south of the Great Eastern Highway Bypass and Talloman (Derby Industries Pty Ltd) north of the Great Eastern Highway Bypass. Once the catchment is waterlogged flow is highly responsive to rainfall events.

The north catchment is also cleared but less intensively drained which means that flows respond less quickly to rainfall. Other smaller wetlands are distributed along the drainage course and these act as compensating basins, ameliorating flows. The soils take longer to become waterlogged compared to the southern catchment and therefore surface flow begins later.

The objectives of the sampling programme were to determine total nutrient discharge into the lakes and to identify where in the catchments the high nutrient loads were being exported from.

- **Monitoring sites**

To achieve the objectives seven monitoring sites (map 1) were chosen as follows, with reference to the findings of Walsh (1991):

- **Southern lake catchment**

VAL - The main drain to the south lake where it crosses Vale Road. This site receives all surface inflows to the southern lake (location 2 in Walsh (1991));

VAL2 - The overflow from the paddock next to the VAL site. This paddock is used for stock grazing and until 6-7 years ago for the disposal of condensate water from the rendering plant on site (location 8 in Walsh (1991));

TAA - The drain next to the Great Eastern Highway Bypass on the northern side above the adjacent rendering plant but before Stirling Crescent. This site was chosen as a control to determine any nutrient input from above the rendering plant (location 7 in Walsh (1991));

TAB - The drain next to the Great Eastern Highway Bypass on the northern side below the rendering works. This site was chosen to establish whether nutrients were being lost from the operation of the rendering plant (location 3 in Walsh (1991));

FEA - The drain next to the Great Eastern Highway Bypass on the southern side above the adjacent rendering plant. This site was chosen as a control to determine any nutrient input from the rendering plant;

FEB - The drain next to the Great Eastern Highway Bypass on the southern side below the adjacent rendering works. This site was chosen to establish whether nutrients were being lost from the operation of the rendering plant (location 4 in Walsh (1991)).

- **Northern lake catchment**

CUS - This site is on the drain crossing Hazelmere Circus 10m into the paddock. The drain delivers all surface flows to the northern lake (location 1 in Walsh 1991).

- **Sample collection and analysis:**

The Shire of Swan took nutrient samples fortnightly during the monitoring period at all sites. Samples also were taken after major rainfall events. The EPA took nutrient samples opportunistically at all sites when measuring drain flow or checking instrumentation. Sampling method was as outlined by Hewson and McDougal (1990). An ISCO automatic water sampler was installed at VAL on 5 July 1991 to take one sample every 12 hours into a bottle starting at midnight with four samples per bottle. Each bottle therefore contained a sample representing the previous 48 hours (two days). Total phosphorus analysis was performed on the samples after 28 bottles had been filled and/or at the end of the monitoring period.

Samples were analysed for nutrient concentration at the Chemistry Centre of WA (CCWA) and the Centre for Water Research (CFWR) at Murdoch University. The analytical methods used by the CFWR are described in EPA Technical Bulletin 39 (Hillman,1991). The analytical procedures employed by the CCWA were standard CCWA methods No. 431 for Total Nitrogen; No. 421 for Nitrate; No. 411 for Ammonia and No. 512 for Total Phosphorus.

- **Measurement and computation of flows:**

The flow from the catchment to the lakes is highly responsive to rainfall and consequently each drain appeared to respond differently depending on the pattern of rainfall. Therefore to obtain accurate estimates of flow at all monitoring sites would require a continuous recording station on each. Since the resources were not available for a monitoring programme of this intensity a decision was made to only establish a continuous recording station on the major inflow to the southern lake. Drain flow and consequent nutrient load could then be calculated for the VAL site and used to estimate flows in the other drains by extrapolation using instantaneous gauged flows and taking into account relative catchment size, rainfall and site observations.

A float well and inlet structure was installed at Vale Road. Hydraulic control for the site was provided by the two existing 436mm diameter concrete pipe culverts. Necessary clearing of silt, debris and vegetation was carried out upstream and downstream of the installation.

Instrumentation consisted of a UNIDATA model 8509a shaft type water level encoder (manufactured by UNIDATA AUSTRALIA) linked to a UNIDATA model 6003a data logger. The logger program used interrogates the encoder at 30 second intervals and writes average values to record every five minutes.

A discharge rating for the site was based on standard part full sewer design charts (provided by JAMES HARDIE & CO Pty Ltd) calibrated by instantaneous discharge observations. Velocity measurements were made with an OSS B1 current meter (manufactured by HYDROLOGICAL INSTRUMENT SERVICES) using standard procedures, and discharges were calculated manually using the mid-point method.

This rating method has been used successfully elsewhere by the Waterways Commission. Accuracy is, obviously, dependant on the number and quality of discharge measurements available. In this instance, calibrations was based on four measurements only. Further work would be required to confirm that the rating is of reasonable standards.

Data from this station were checked, edited, and computed to daily flows using the HYDSYS time series data management package (HYDSYS Pty Ltd) installed at the Waterways Commission.

The period of the record was from 4 July 1991 to 10 November 1991.

Instantaneous flow measurements using the current meter also were performed at the TAB and FEB sites three times and at the CUS site twice. As the flow at the VAL2 site did not have a section where a metering could be performed gaugings were done on three occasions in the main drain above the VAL site (Refer to map 1 , marked as VAL 3). When this flow is deducted from the flow at site VAL it provides an indication of the flow at site VAL2.

Using the method described above it was decided to apportion flows for the other drains in the south catchment on the following basis:

	Estimated flows as a % of VAL 1991		
	FEB	TAB	VAL2
4 July - 16 July	14%	72%	14%
17 July - 5 August	14%	36%	50%
6 August - 24 September (end of observed flow)	14%	72%	14%
24 September - end of record		72%	

The flow at TAA was below the minimum capacity of the current meter. A cross-section was measured and the movement of entrained particles in the water column timed to give an estimated flow of $0.0025 m^3/s$ for the period 4 July 1991 - 2 October 1991 (end of observed flow).

No flow was observed at the FEA site.

The area of the north catchment is 91% of the south catchment at the VAL site, however, this proportion was not reflected in the flow. Differences in drainage characteristics between the catchments such as drain density and depth probably account for the difference in flow. Using the instantaneous flow measurements and taking into account observations over the flow period it was decided to apportion flow as follows:

	Estimated flow as a % of VAL 1991
	CUS
4 July - 1 August	23%
2 August - 24 September	65%
24 September - 2 October (end of observed flow)	23%

- **Computation of flows and loads:**

Nutrient data were entered into HYDSYS as discrete data points ie. each value associated with a date. Within HYDSYS linear interpolation is used to generate a 'continuous' daily data set. HYDSYS then integrates these interpolated nutrient data with flow data to produce daily nutrient loads.

Other data manipulation was carried out within the EXCEL (MICROSOFT CORPORATION) spreadsheet package.

- **Catchment area determination:**

The catchment boundaries for the lakes were supplied by the Swan Shire Engineer (Map 1). The catchment area was then measured using a planimeter (table 1).

Results

The total quantity of surface drainage water flowing into the southern lake through the VAL site (table 2) appears to be two and half times that entering the northern lake through the CUS site (table 3) despite the similar size in their catchments (table 1).

- **Northern lake drainage catchment**

The nutrient loads discharged into the northern lake (table 2) via the drainage are substantially less than those for the southern lake. The phosphorus concentrations and catchment export rates are within the range typical of rural broad acre agriculture on Swan coastal plain soils (Humphries and Bott, 1988). Nutrient concentrations show a decreasing trend as the winter progresses (Figure 3a and 3b) and the small store of immediately available nutrients in the soils are leached (Schofield et al, 1985). The inorganic nitrogen fraction represents only about 5% of the total nitrogen concentration indicating that the major form is organic nitrogen.

The N:P ratio for discharge from this drain is about 16:1 indicating that nitrogen and phosphorus inputs are suitably balanced for algal uptake and should not be contributing to blue-green algal blooms. Ratios below 12:1 to 16:1 indicate that nitrogen may be a limiting nutrient and this generally contributes to providing ideal conditions for blue-green algal blooms since they can fix nitrogen from the atmosphere. Blue-green algal blooms often cause such problems as unacceptable odours, deoxygenation of the water column, surfacewater scums and shoreline scums.

Table 1. Surface drainage catchment area for the Hazelmere Lakes.

Catchment	Area, (ha)	% of total catchment
Total northern lake catchment	51.2	100
South of Gt. E. Hwy Bypass	14.5	26
North of Gt. E. Hwy Bypass	41.4	74
Total southern lake catchment	55.9	100

Table 2. Flow and nutrient input to the northern lake

	FLOW (m3)	Total P	Total N	NH4-N	NO3	N:P Ratio
CUS	108240					16.5:1
Load (kg)		34.6	571.49	15.58	11.41	
F.W.M.C.*(mg/l)		0.32	5.3	0.14	0.11	
Loss rate (kg/ha)		0.66	11.2	0.30	0.22	

*F.W.M.C.= Flow Weighted Mean Concentration ie. average concentration over the monitored period.

- **Southern lake drainage catchment**

The nutrient flow weighted mean concentrations and loads shown in table 3 for all variables analysed for the VAL monitoring site and for all drains feeding this site are very high. Such high levels generally indicate extreme over use of fertilisers or the discharge of animal waste products directly or indirectly to a water course. The catchment nutrient loss rates far exceed expected values for general broad acre agriculture in sandy soil catchments and are more typical of export rates for catchments which contain intensive animal industries (Humphries and Bott, 1988).

The N:P ratios calculated in table 3 indicate that there is a high phosphorus component in the drainage of the VAL2 and FEB sites, which is often indicative of animal waste sources. However, because of the high N:P ratio for water draining through the TAB site, inputs to the southern lake had an N:P ratio of approximately 18:1 which is considered to be reasonable.

Total phosphorus concentration in drainage water at the instrumented monitoring site appears to show some correlation with drain flow (figure 4a) throughout the flow period. There is no evidence of the decreasing trend in phosphorus concentrations generally observed in rural catchments as the available water soluble phosphorus fractions are leached from the soil. This indicates that there is likely to be a very large source of readily leachable phosphorus in the catchment or perhaps a constant discharge from some source upstream. A comparison of figures 4a and 4c with figure 8 shows that the greater part of the phosphorus load transported into the southern lake via the VAL site corresponds with high rainfall-runoff events in July, August and September 1991. This is particularly evident where the curve in figure 4c takes on a steep gradient.

The corresponding evidence relating to the nitrogen concentrations (figure 4b and 4d) is not so clear because of the more coarse sampling intervals. However, analysis of the data in table 3 indicates that 70% of the nitrogen entering the southern lake is in soluble inorganic form. The ammonia concentrations found in the drainage water entering the southern lake far exceed the recommended criteria for the preservation of aquatic ecosystems (EPA, 1981; USEPA, 1986) and may be of concern in the lake environment. The WA EPA recommends a six month median not to exceed 0.6mg/l and never to exceed 2.0mg/l, and the USEPA recommend a four day average maximum concentration of 1 - 2mg/l depending on temperature and pH.

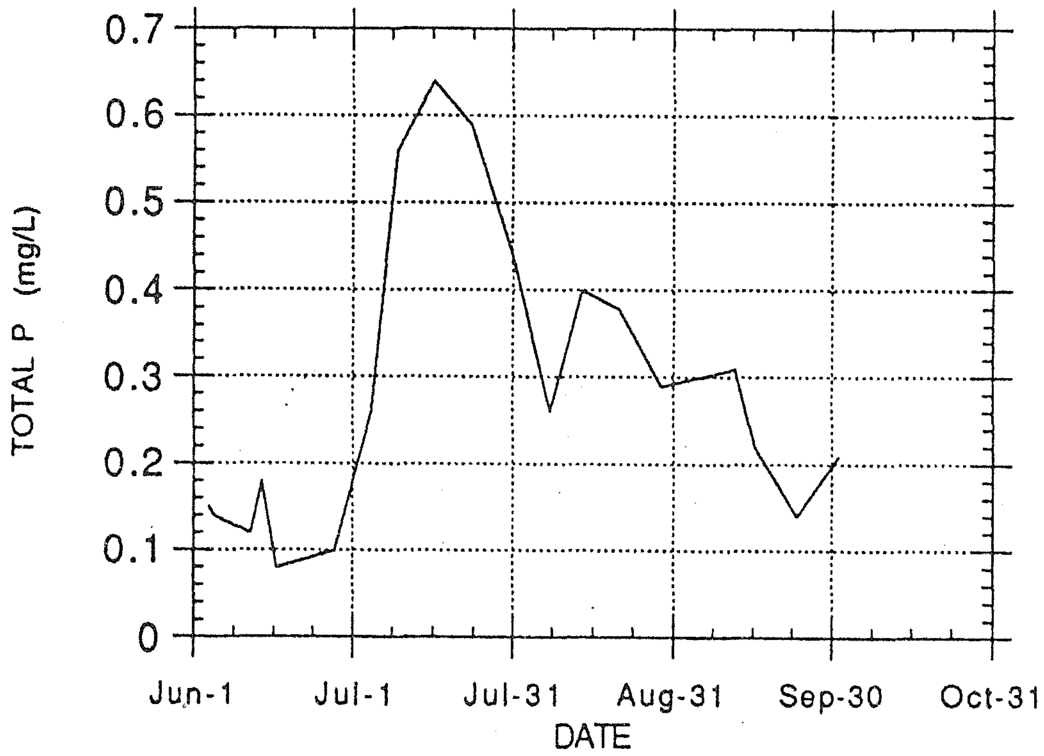
Table 3. Flow and nutrient input to the southern lake.

	FLOW (m3)	Total P	Total N	NH4-N	NO3	N:P Ratio
VAL	276200					18:1
Load (kg)		837.2	14837.9	8766.4	1612.4	
F.W.M.C.*(mg/l)		3.0	53.72	31.7	5.8	
Loss rate (kg/ha)		15.0	265.42	156.8	28.8	
VAL 2	57637					8:1
Load (kg)		211.7	1719.2	651.1	309.3	
F.W.M.C.*(mg/l)		3.6	29.8	11.3	5.4	
TAA	19656					103.:1
Load (kg)		0.75	77.3	4.97	4.04	
F.W.M.C.*(mg/l)		0.04	3.9	0.25	0.21	
TAB	169832					
Load(kg)		443.7	17493.6	10980.3	529.0	39:1
F.W.M.C.*(mg/l)		2.6	103.0	64.7	3.1	
Loss rate (kg/ha)		10.7	422.5	265.2	12.8	
FEB	31609					
Load(kg)		291.6	1638	389.6	1010.3	6:1
F.W.M.C.*(mg/l)		9.2	51.9	12.33	32.0	
Loss rate (kg/ha)		20.11	113.0	26.9	69.7	
FEA**	-	-	-	-	-	-

* F.W.M.C.= Flow Weighted Mean Concentration ie. average concentration over the monitored period

** There was no flow at the FEA site.

A



B

A) Tota Phosphorous concentration (mg/L)

B) Total Nitrogen, Ammonia and Nitrate concentration (mg/L)

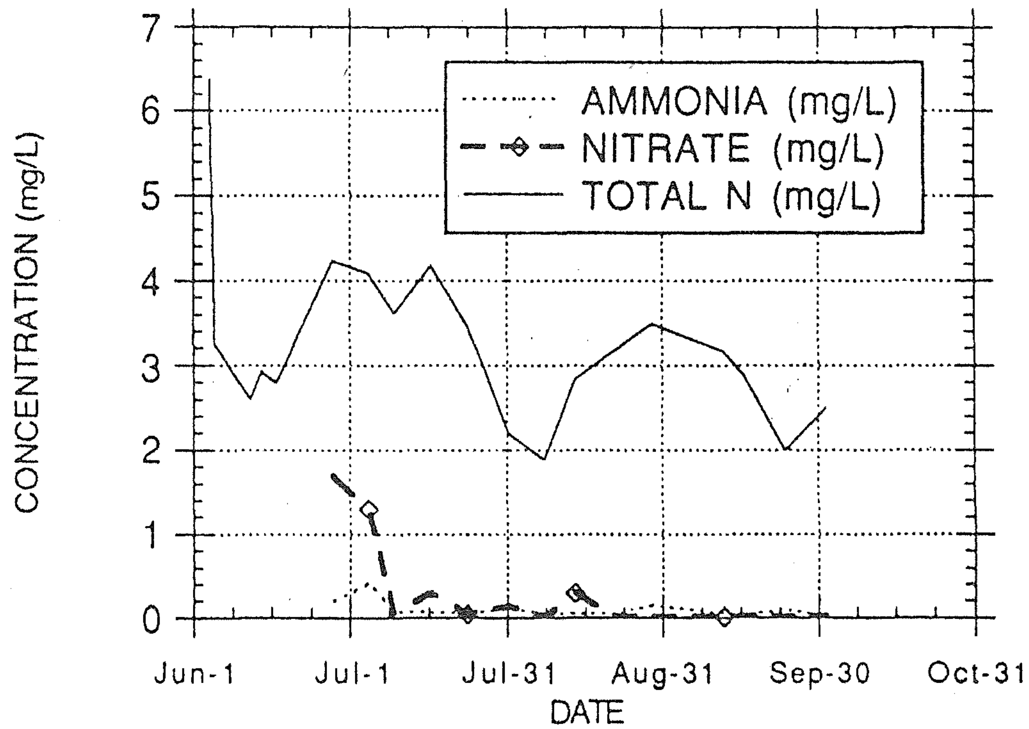
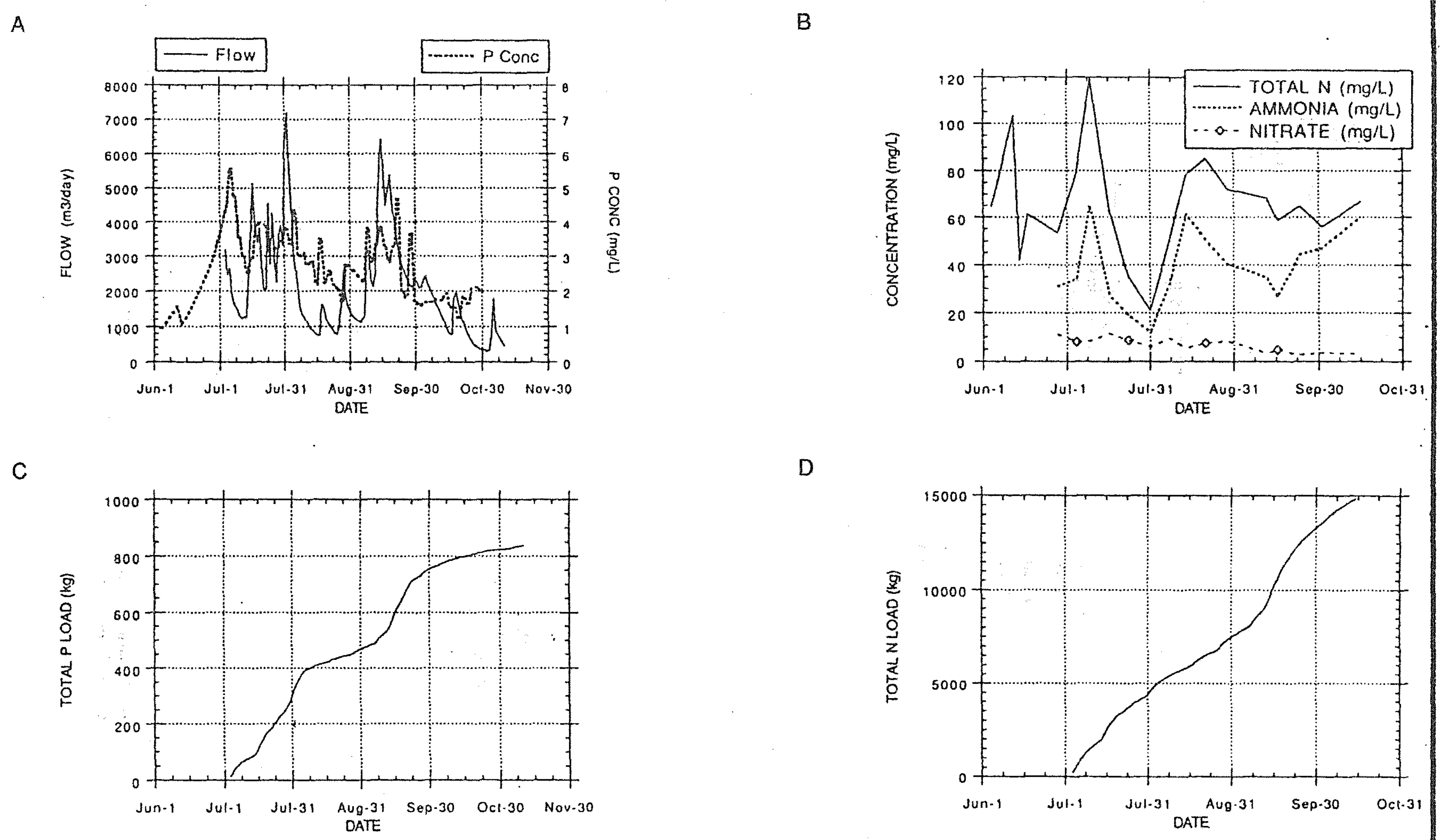


Figure 3. Nutrient concentrations for drainage discharge into the northern lake (CUS)



A) Flow (m^3/day) and total Phosphorus concentration (mg/L) B) Total Nitrogen, Ammonia and Nitrate concentration (mg/L)
C) Total Phosphorous load (kg) D) Total Nitrogen load

Figure 4. Results of monitoring drainage inflows to the southern lake (site VAL).

The nutrient concentrations and loads leaving the water logged paddock west of the rendering plant at the VAL2 site are very significant contributing approximately 25% of the phosphorus load and 20% of the nitrate load to the southern lake. The inorganic nitrogen fractions average 56% of the nitrogen leaving the site with ammonia making up 70%. The analysed nutrient samples have been graphed in figure 5a and 5b.

The drain flowing along the northern side of the highway bypass appears to intercept almost all of its nutrient load, and most of its flow, downstream from the adjacent rendering works (figure 6a,b,c and d). This drain contributes more than 50% of the phosphorus load and about 80% of the nitrogen load to the southern lake. The total nitrogen and ammonia concentrations and loads are particularly high. About 95% of the soluble inorganic nitrogen fractions and 67% of total nitrogen is made up of the ammonia fraction. This contrasts with the drain concentrations upstream of the rendering works at the TAA site. At this site inorganic nitrogen is only about 12% of total nitrogen and the nutrient concentrations generally are typical of water draining broadacre agricultural land.

The drain flowing along the southern side of the highway bypass only contained water in the lower section downstream from the adjacent rendering works and had substantially less flow than the northern drain. The reasons are not known but most likely relate to depth of the drain or perhaps to the direction of groundwater flow in the area. Phosphorus concentrations (figure 7a) were highest in this drain and consequently it delivered about 34% of the phosphorus load to the southern lake despite the low flow rate. Total nitrogen and ammonia concentrations (figure 7b) and loads were substantially less than for the northern drain. However, the nitrate concentrations were very high and consequently the majority of the nitrate input to the southern lake was from this drain. This contrasted with the northern drain where ammonia was the major form of inorganic nitrogen. The inorganic nitrogen fraction was 85% of total nitrogen of which approximately 70% was in nitrate form. No flow was observed in this drain upstream of the rendering works and hence no nutrient sampling was undertaken.

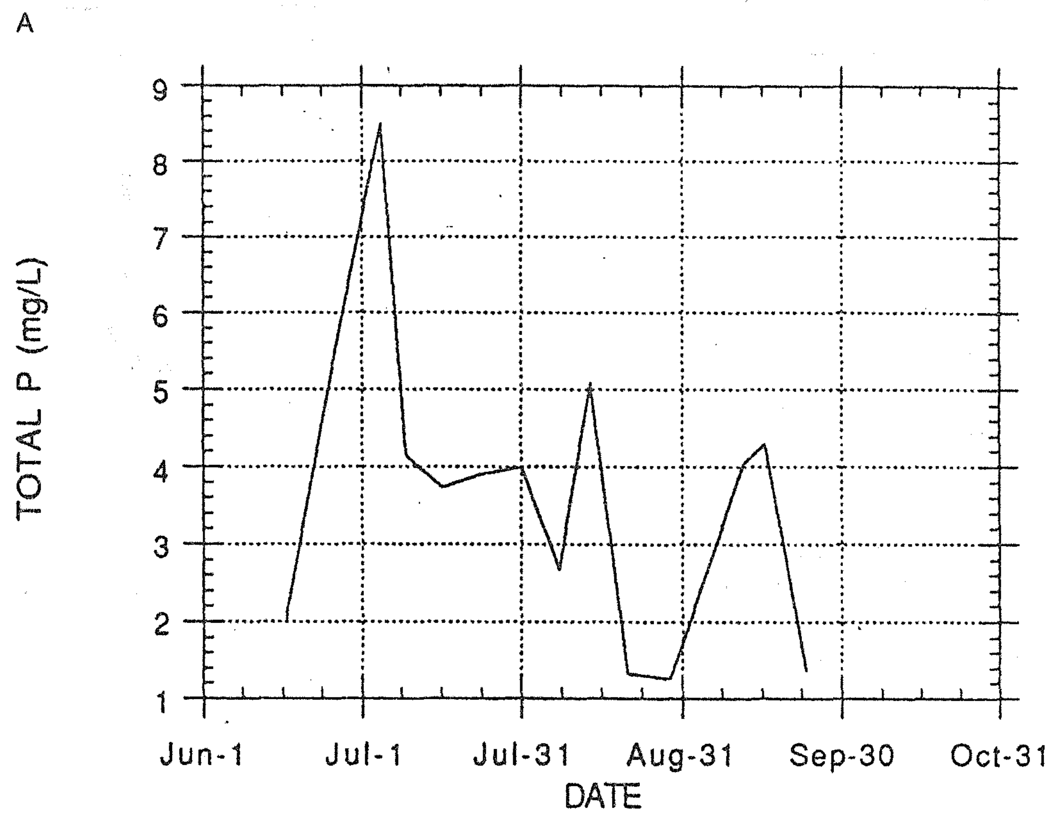
Discussion

The lakes of the Swan Coastal Plain are generally windows in the groundwater where the surface topography dips below the water table (Davis and Rolls, 1987). In almost all cases they do not receive any significant surface runoff from the surrounding land, that is, they do not have an inflowing surface drainage system. As a consequence their ecosystems have evolved under a regime of very low nutrient inputs.

As surrounding land is developed low lying areas are often drained into nearby lakes and fertilisers used to improve the inherently low fertility of the soils. The result is a substantially increased nutrient load to most of the metropolitan lakes. Generally there is no outflow from the lakes and therefore most of the nutrient input is likely to be trapped within the system. Consequently the lakes are very susceptible to the effects of nutrient enrichment and can easily become overloaded.

The Hazelmere Lakes are no exception. Both lakes have constructed drains discharging surface water from the surrounding land which has been developed. Consequently they are receiving substantially more nutrients than would have occurred in their natural condition. The results of this investigation have confirmed the findings by Walsh (1991) in his preliminary investigation of water quality in the drains discharging into the lakes. Nutrient inputs to both lakes are high but the inputs to the southern lake are of greatest concern since they are one or two orders of magnitude more than for the northern lake and their source appears to be the animal waste rendering plants.

Landuse in the drainage catchment to the northern lake is low intensity agriculture and, as already stated earlier, nutrient concentrations and drainage export rates fall within the expected range for this kind of activity (Humphries and Bott, 1988).



B

A) Total Phosphorous concentration upstream (mg/L)
B) Total Nitrogen, Ammonia and Nitrate concentration (mg/L)

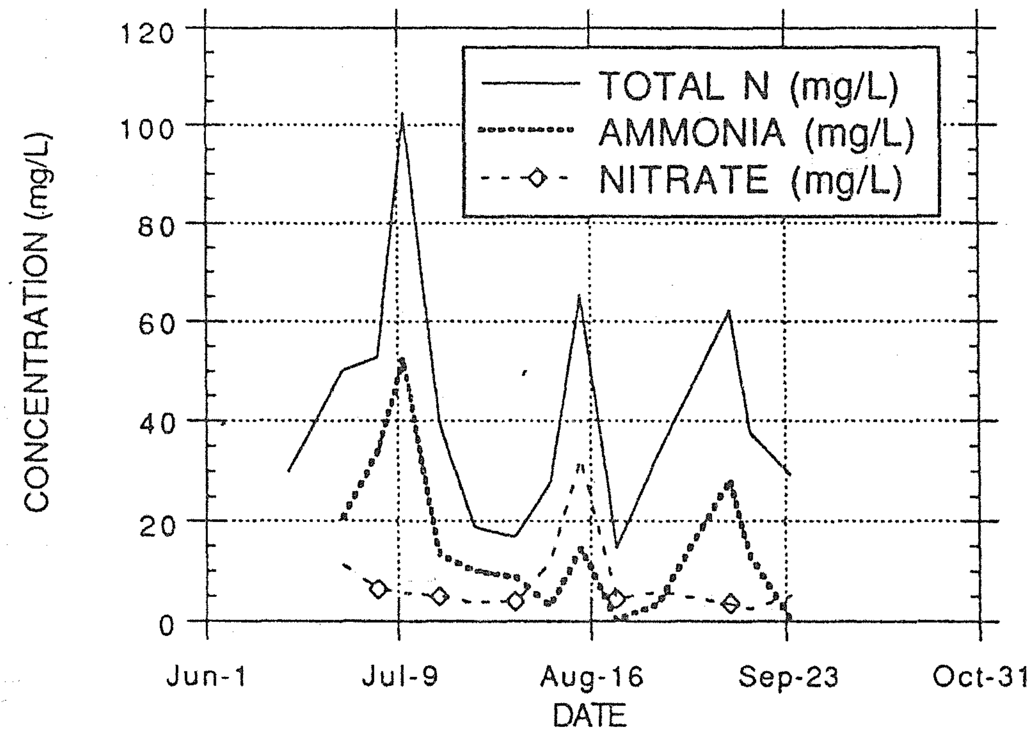
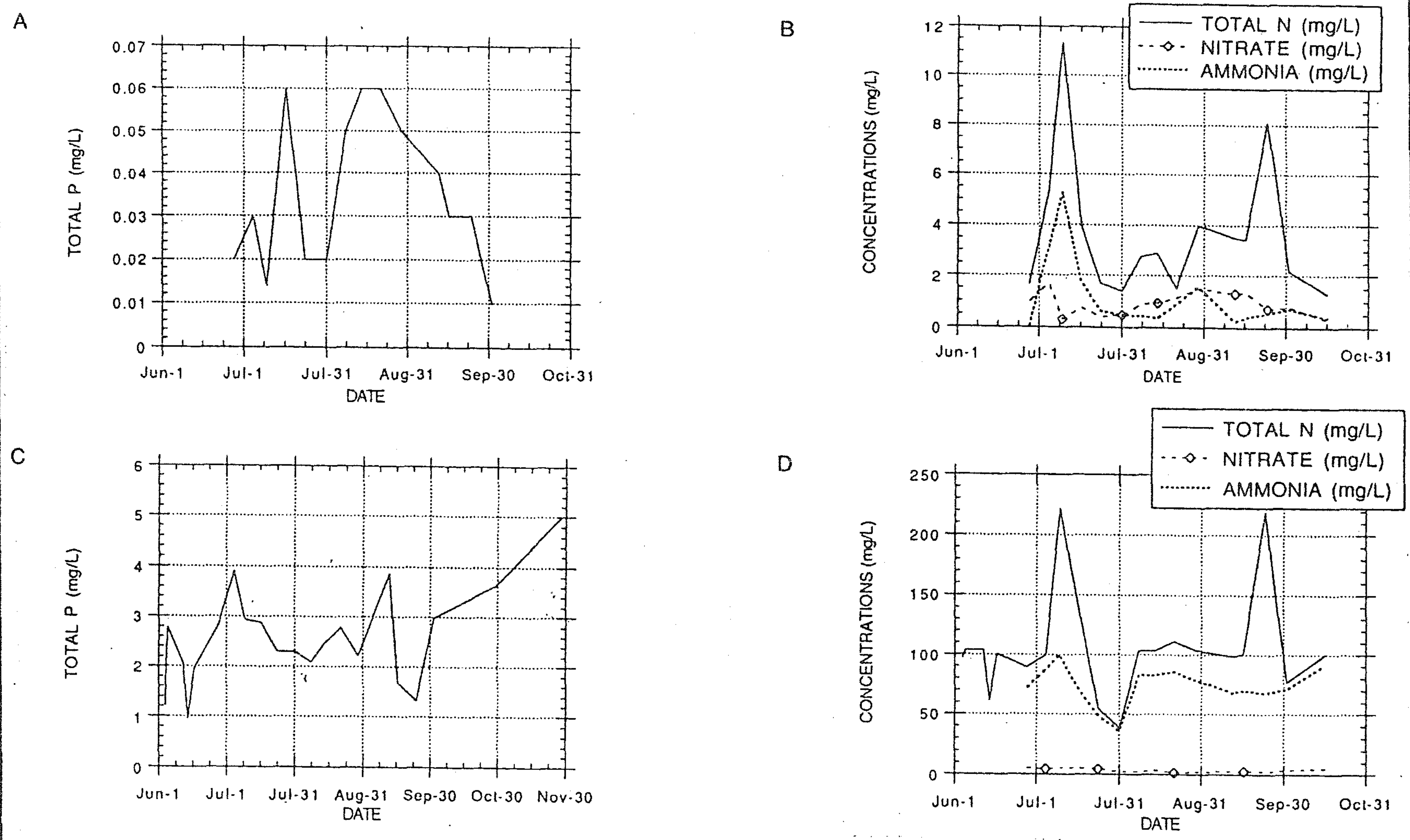


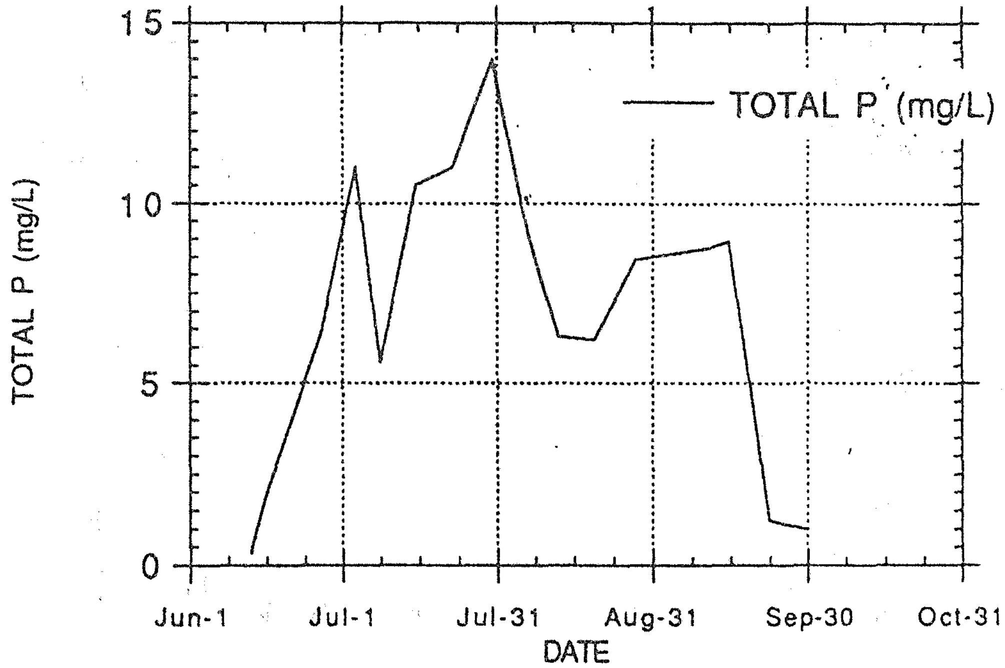
Figure 5. Nutrient concentrations for drainage discharge at the VAL2 site.



A) Total Phosphorous concentration upstream (mg/L) B) Total Nitrogen, Ammonia and Nitrate concentration (mg/L)
C) Total Phosphorous concentration downstream (mg/L)) D) Total Nitrogen, Ammonia and Nitrate concentrations downstream (mg/L)

Figure 6. Nutrient concentrations in drainage upstream (TAA) and down stream (TAB) of the Talloman rendering plant.

A



B

A) Total Phosphorous concentration upstream (mg/L)
B) Total Nitrogen, Ammonia and Nitrate concentration (mg/L)

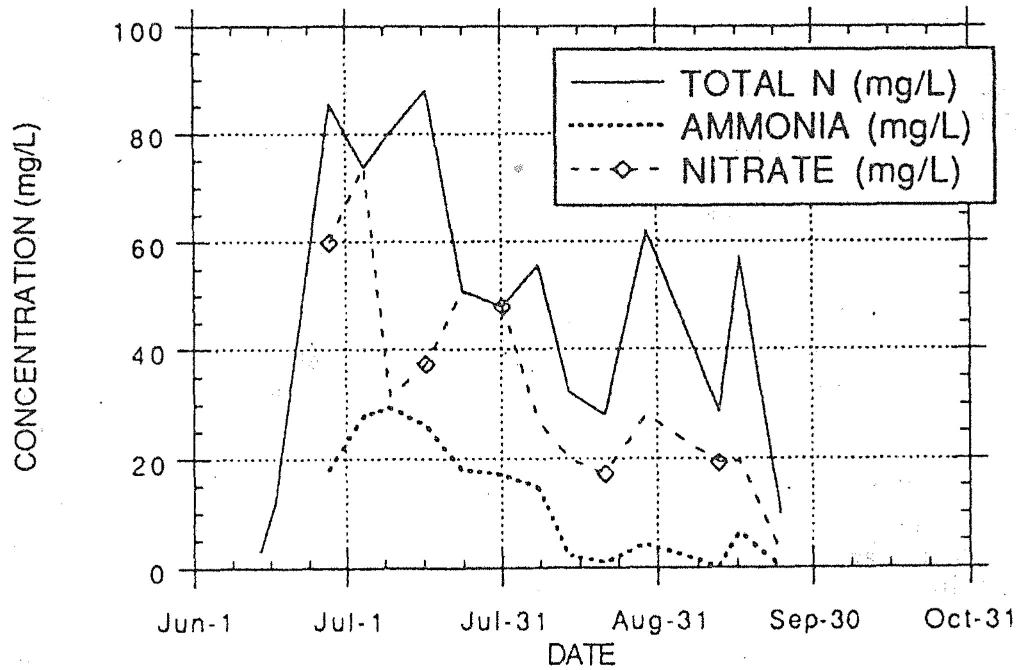


Figure 7.Nutrient concentrations downstream from the Fertal rendering plant (FEB).

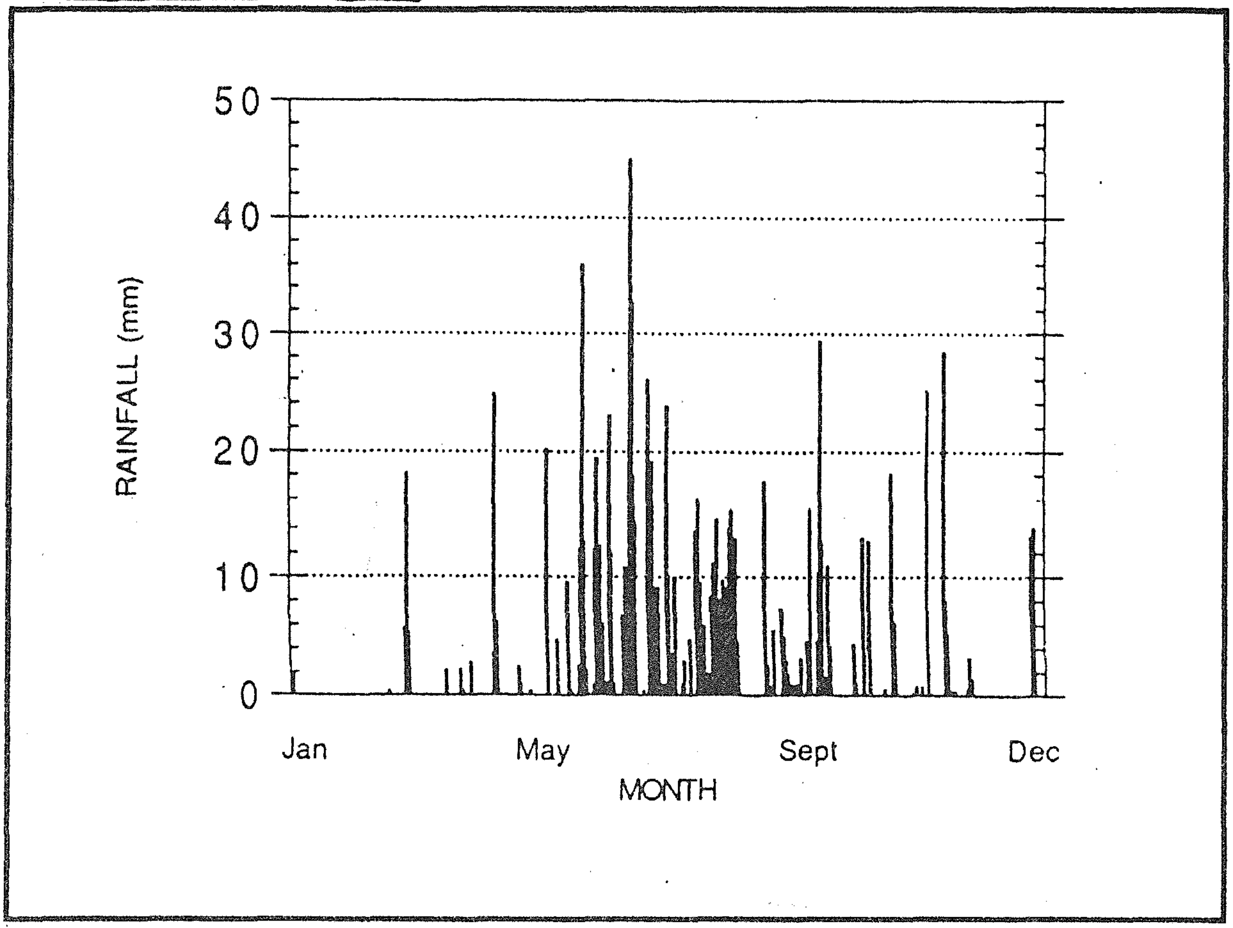


Figure 8. Daily rainfall at Perth Airport (1991).

The source of the high nutrient outputs from the southern catchment appear to be the two rendering works. Monitoring of the drains next to these industries has found very high nutrient concentrations and loads downstream of both industries. The very high concentrations and excessive ammonia or low N:P ratio are consistent with an animal waste source. The quantity of nutrients apparently exported from the site of the northern rendering works is extremely high if the loads from the northern drain of the highway bypass (TAB site) and the flooded paddock (VAL2 site) are combined. However, the results of this monitoring programme can not confirm whether all nutrients in the drains either side of the highway bypass can be attributed to the respective adjacent rendering works. The evidence certainly suggests that the nutrient sources for each of the two drains are separate if the nutrient concentrations and the ratios of the nitrogen fractions are considered. However, it could be argued that contaminated water from one side of the highway may be passing underneath the adjacent drain and highway to enter the opposite drain. Although unlikely this may need further investigation.

The results of this monitoring programme are a best estimate of nutrient export from the catchments to the Hazelmere Lakes using the available resources. They should be viewed as a close approximation to the real numbers. The degree of accuracy could be improved if automated continuous monitoring stations were placed on each site or the number of samples and instantaneous flow meterings increased for each site, but this would require substantially more resources.

The annual nutrient loads and export rates estimated in this investigation are most likely to be an underestimate because the drain monitoring programme began after drain flow had already begun and particularly since the highest nutrient concentrations are often observed in the first flows of the runoff season. Observations indicated that the drains began flowing in mid June but the drain monitoring didn't begin until the first week of July.

The monitoring programme did not consider groundwater flow separately, but drainflow measurements have indirectly included all groundwater inflows to the surface drainage system. Groundwater can either flow directly into a lake or it can enter via drainflow if surface drains intercept the water table (as in this case). The groundwater catchment can be significantly different and larger than the surface water catchment and hence direct groundwater inflow to a lake can be a very significant proportion of total input as found by Bayley et al (1989) for North Lake. However, it is unlikely that groundwater inflows will significantly add to the nutrient load to the southern Hazelmere Lake since the loads discharged from the surface drains are so large. Groundwater inputs to the northern lake may be more significant and certainly need further investigation.

2.3 Assimilative capacity of the Hazelmere Lakes

Introduction

Aquatic ecosystems are very complex and inherently sensitive habitats which have a far ranging influence on natural community structures. This is particularly true for the Swan coastal plain wetlands and those of other parts of WA because of the scarcity of water during the dry months. As a result wetlands often tend to be nodes of high productivity and bio-diversity essential to the survival of wildlife in the region (Seddon, 1972).

In this context the Hazelmere Lakes have been recognised in the System Six Red Book Report (EPA, 1983) as having conservation values in a regional setting which should be preserved. The System Six study identified areas of conservation and recreational value in the greater metropolitan region and made recommendations regarding their protection. The study also recognised that the lakes provided opportunity for human recreation but only if it remained compatible with conservation objectives.

One of the most important parameters requiring management in an aquatic environment where the objective is conservation of flora and fauna, but where there are environmental impacts from surrounding human activities, is general water quality. The state of the water affects both plant and algal growth and determines which animals (if any) can live in the wetland. These factors can in turn affect odour and visual amenity of the wetland. In the Perth metropolitan area the nutrients leached from surrounding catchments appear to be the major factor affecting lake water quality. There are several reasons why this should be so, but investigation of estuarine eutrophication on the coastal plain indicates that it mainly results from the very low nutrient retaining capacity of many of our coastal plain soils, high winter rainfall, shallow watertable, excessive use of fertilisers, construction of an efficient drainage network and the shallow nature of the lakes (generally only 1-2 metres deep) (McAlpine et al, 1989). Shallow lakes provide greater opportunities for algal growth and nutrient recycling and exhibit greater temperature increases during the summer months. The results of the monitoring programme described in the previous chapters of this report indicate that the factors affecting the condition of the Hazelmere Lakes are consistent with other metropolitan lakes. Hence to manage water quality within the lakes it is necessary to manage nutrient export from the catchment such that some maximum level is not exceeded.

The determination of that maximum level should be based on a combination of ecological processes and public expectation for use of the system (ie. beneficial use). Ecosystems are dynamic systems in a constant state of change as they respond to accommodate internal and external alterations in their environment. Therefore the addition of any level of a contaminant to an aquatic ecosystem is likely to cause some change. The amount of change will vary depending on the sensitivity, or buffering capacity, of the system. Therefore the level of input that brings about an unacceptable amount of change based on public expectation, or its beneficial use, must be determined to provide a target for management and this is termed the assimilative capacity. The concept of using assimilative capacity as a management tool for temperate coastal waters of Western Australia has been discussed in some detail by Masini et al (1992).

To accurately determine the assimilative capacity is a very difficult task and would require an enormous amount of work to obtain a complete understanding of the ecosystem in question. This has not been done for the Hazelmere Lakes or any other metropolitan lake and so therefore an estimate must be made based on the general ecological processes of aquatic systems. The approach used here is one developed for northern hemisphere lakes by Vollenweider (Vollenseidèr and Dillon, 1974; Vollenweider, 1975; Vollenweider, 1976) and used with a reasonably high degree of success. In Western Australia Vollenweider's approach has been used to compare the nutrient status of estuaries and appears to correlate well with their observed trophic condition (EPA, 1988; McAlpine, 1989). This demonstrates its robust nature and a potential for use on a broad range of aquatic systems since it is based on a common set of general ecological processes.

There is very little relevant information available from studies on other lakes in the Perth metropolitan area that can be used in the Vollenweider approach to compare with the Hazelmere Lakes and help verify the approach. Most of the metropolitan studies have focused on in situ water quality whereas the data required for the Vollenweider approach is concerned with the water and phosphorus loading into a waterbody. The approach is only applicable to lakes where no element apart from phosphorus is limiting algal growth, which is generally the case for lakes of the Swan Coastal Plain. The soils are naturally infertile with a low phosphorus content, however, much of the vegetation is able to fix nitrogen both in the agricultural and natural environments. Consequently nitrogen is available to be leached to waterbodies downstream and is therefore not generally limiting to algal growth. In addition if nitrogen is in short supply and conditions are suitable, nitrogen fixing algae often thrive and fix nitrogen into the system from the atmosphere.

Other factors such as water turbidity, colour (tanin staining), depth, shading and fringing vegetation are thought to affect the capacity of the lakes to accommodate nutrients. For most lakes with a developed catchment, nutrient input is thought to be the dominant factor in determining trophic state. Therefore in the absence of a better approach for estimating the assimilative capacity of the lakes the Vollenweider model has been used. However, until the model has been calibrated for the metropolitan lake systems or a more accurate approach is developed the estimated assimilative capacity provides a reasonable guide which should be used conservatively until a more accurate estimate can be obtained.

Calculations

The inputs required for the Vollenweider model are total water load and phosphorus load on an a real basis. The main inputs to the lakes come from two sources, surface flows and groundwater flows. The surface inputs are known and have been reported in the previous chapter of this report, however, the groundwater inputs have not yet been quantified and need to be estimated. The study on North Lake in Kardinya by Bayley (1989) measured groundwater inflow to the lake and these results have been extrapolated in an attempt to give a rough estimate of groundwater input to the Hazelmere Lakes.

Groundwater flow patterns through Swan coastal plain lakes has recently been investigated by the CSIRO in the Perth metropolitan area. The pattern of flow and hence volume of groundwater interception was found to depend on several parameters, particularly lake length (in direction of groundwater flow) to acquifer depth ratio, soil resistance (to flow) and lake width (Townley and Turner, 1990). In a simplified model groundwater flows into the coastal plain lakes through the bottom sediments of the upstream half and out again through the downstream half. Half of the area of North Lake is 15ha compared with 4.5ha for each of the Hazelmere Lakes, which means that only 0.333 of the area is available for groundwater inflow in the Hazelmere Lakes compared to the North Lake. In table 4 the North Lake groundwater input has been correspondingly scaled down for the Hazelmere Lakes. This is very much an over simplification of the real situation but in the absence of better numbers it should give a "ball park" estimate.

Table 4. Estimated groundwater inflow to the Hazelmere Lakes using information from North Lake (conversion factor is 0.333).

	Groundwater inflow area (ha)	Groundwater inflow (ML)
North Lake	15.0	210
Northern Hazelmere Lake	4.5	63
Southern Hazelmere Lake	4.5	63

It was not considered appropriate to attempt to estimate groundwater phosphorus inflow to the lakes since the groundwater nutrient concentrations are also unknown and any further extrapolation would multiply the errors in any estimate. A study has been commissioned by the Shire of Swan to attempt to measure groundwater flows and nutrient loads to the lakes and the results will be available in due course. It is unlikely that groundwater nutrient inputs will be significant for the southern lake given the large surface water inputs but for the northern lake groundwater nutrient load may be important. For this report the groundwater nutrient loads have been left out of all calculations which means that the estimate of current trophic status and required reductions to reach the lakes' assimilative capacities are likely to be underestimated. It will not affect the estimate of assimilative capacity itself since groundwater inflows have been estimated.

The estimated total phosphorus and water loading to the lakes have been tabulated in tables 5 and 6. These numbers were then used to plot the trophic state of each lake using the equations developed by Vollenweider (figure 9).

Table 5. Total phosphorus loading and water loading to the northern Hazelmere Lake.

	Area (ha)	Water inflow (Ml/yr)	Phosphorus load (kg/yr)
Groundwater		63	-
Surface water		108	35
Total	9	171	35

Table 6. Total phosphorus loading and water loading to the southern Hazelmere Lake.

	Area (ha)	Water inflow (Ml/yr)	Phosphorus load (kg/yr)
Groundwater		63	-
Surface water		276	837
Total	9	343	837

Both lakes appear to sit in the eutrophic zone of the graph indicating that nutrient input is excessive which explains why the observed condition of the lakes is poor. The position of the southern lake indicates that it is much more eutrophic that the northern lake and may therefore require a much more dramatic programme for its rehabilitation. Once the lakes have been plotted on Vollenweider's graph it is possible to interpolate a target phosphorus loading for the desired level of nutrient enrichment, provided the future water loading is known. Currently there is no evidence to expect water loading to change and so it has been considered to be constant.

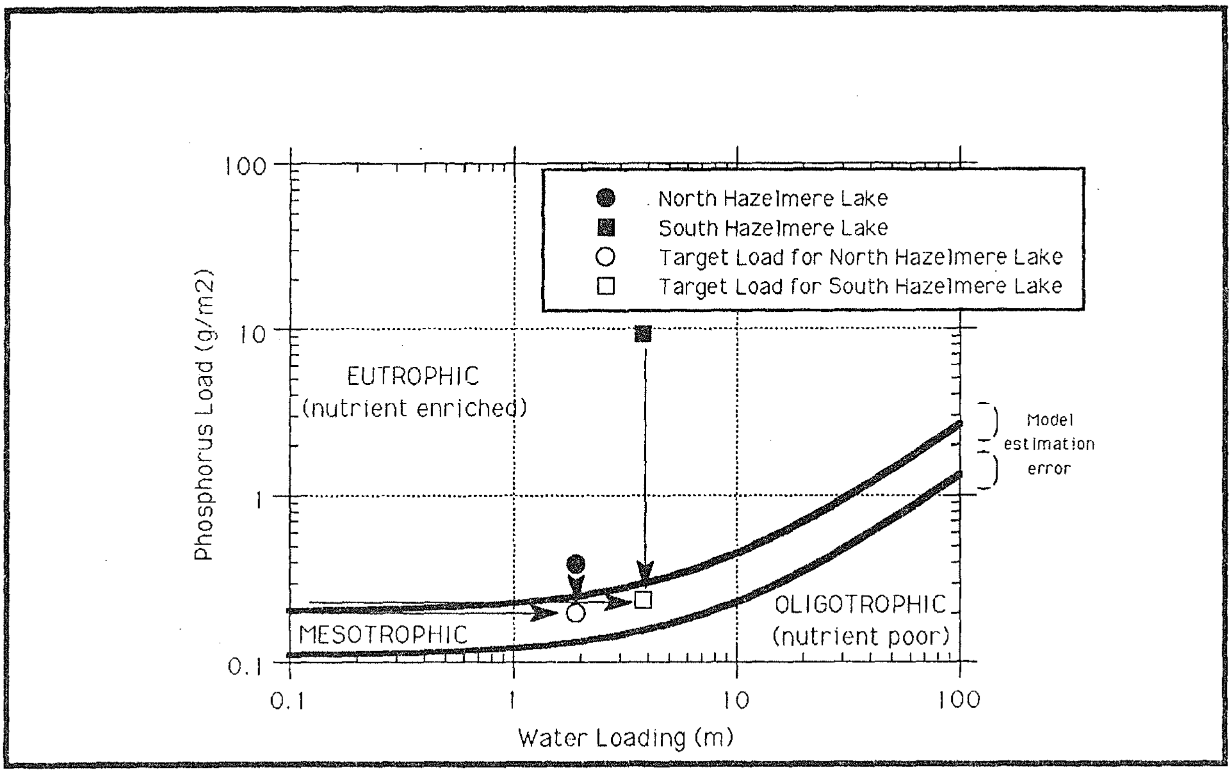


Figure 9. Current trophic status of the Hazelmere Lakes estimated from Vollenweider's phosphorus loading criteria and the estimated target loading required to maintain adequate water quality.

In their original natural state the lakes, like almost all the other coastal plain lakes, would have received very little nutrient load and consequently would have been well within the oligotrophic range. Land clearing, the use of fertilisers on the surrounding land, industrial development and construction of surface drainage channels into the lakes has dramatically altered their trophic state and probably also their general condition including aquatic flora and fauna. The desired trophic state, or level of nutrient enrichment, chosen as the management target for these lakes is in the oligotrophic to mesotrophic range. The level of resources required to return the lakes to a level approaching their original state would be unacceptably high. The oligotrophic/mesotrophic target is a compromise approach that will allow continued land uses within the catchment while ensuring that conservation and recreational values will be preserved. It will mean that the lakes contain a greater level of nutrients than in their natural state and that productivity will therefore be increased. Algal blooms and other symptoms may still occur but at a reduced intensity.

Since the available data is limited and the errors correspondingly large a conservative approach should be taken to calculating the target phosphorus loads for the lakes. Hence the target phosphorus loading rate used to predict the assimilative capacity for the lakes (shown by the arrows in figure 9) is at the lower limit of the model estimation error for the mesotrophic/eutrophic boundary.

The target loads are therefore estimated to be 0.2g/m^2 (18kg) and 0.24g/m^2 (22kg) for the northern and southern lakes respectively. Given that drainage flow, and hence nutrient load, is variable from year to year it is necessary to specify a probability for the assimilative capacity not to be exceeded to allow for extreme events. A one in 10 year (or 10%) exceedance is generally accepted to be reasonable. In this case the monitoring period is insufficient to be able to predict annual flow probabilities for the drain flows. However, there is likely to be a correlation between annual rainfall and annual flow for these drains, although some variability can be expected.

Annual rainfall data has been collected at the nearby Perth airport for many years and probabilities can be calculated. Annual rainfall for 1991 was above average and in the eighth decile. Assuming flow would have been similarly correlated then the 1991 flow may also be in the eighth decile. Therefore given the slope of the Vollenweider curve at these low water loadings the increase resulting from a one in 10 year flow is unlikely to substantially change the target load. Hence the assimilative capacity for the northern and southern lakes respectively is a phosphorus load of less than 18 kg and 22 kg in nine years out of 10 (or in 90% of years) to ensure that long-term water quality within the lakes remains good and the wetlands are managed in a healthy and resilient condition. This equates to a 49% and 97% reduction in load for the northern and southern lakes respectively. Assuming that drain flows remain unaltered then phosphorus concentration in drainage water will need to be reduced to approximately 0.1mg/l and 0.07mg/l respectively depending on the water and phosphorus contribution from groundwater.

Discussion

The phosphorus loading rates for the Hazelmere Lakes can be compared both numerically (table 7) and graphically (figure 10) to other metropolitan lakes where data are available. The southern lake easily receives more phosphorus (and probably nitrogen) than any of the other systems and this load is putting the lake under threat of total collapse. The loading rate to the northern lake is also high and needs to be managed to maintain a healthy wetland and preserve its conservation and recreational values. Poor water quality in the northern lake is exacerbated by the shallow depth and lack of fringing vegetation, which is probably the reason why its position on Vollenweider's graph does not exactly correspond to the observed water quality.

Table 7. Total phosphorus loading and water loading for the Perth metropolitan lakes with available data.

	Area (ha)	Water inflow (ML/yr)	Phosphorus load (kg/yr)	Data source
Hazelmere (northern lake)	9	171	35	this report
Hazelmere (southern lake)	9	343	837	this report
North Lake	29.9	720	354	Bayley et al
Lake Claremont	15.7	75	13.2	Lantzke et al
Mary Carroll Park Lake	14	259	170	Rodda et al
Lake Joondalup	432	1670	369	Congdon

As with the Hazelmere Lakes the water quality in North Lake and the Mary Carroll Park wetlands is very poor with both systems containing major blue-green algal blooms. Blue-green algal blooms release objectionable odours into the atmosphere and as they decompose they can create conditions suitable for bacteria to thrive. Deoxygenation of lake sediments caused by decomposing organic matter, such as algal blooms, and warm water temperatures as lake levels drop is known to trigger outbreaks of the bacteria *clostridium botulinum*. This bacteria is responsible for botulism deaths among waterbirds. Waterbird deaths resulting from botulism have been reported in both North Lake and Mary Carrol Park, and it is likely that if current conditions continue in the Hazelmere Lakes they also may suffer from botulism outbreaks.

Lake Joondalup and Lake Claremont have some water quality problems related to excess nutrients but not as severe as for the other lakes. Lake Claremont is probably the most affected of the two lakes but both generally have increased algal concentrations for much of the summer months when water levels are low.

The estimated trophic state of the six metropolitan lakes using the Vollenweider approach appears to approximate their observed condition at perhaps an under estimation if anything. The result gives some indication that the approach may be worth investigating further as a tool for predicting the assimilative capacity of metropolitan lakes for nutrients and that the estimate for the Hazelmere Lakes is probably reasonably close to the mark. However, the approach should only be used as a guide since the model has not been calibrated to these lake systems and because of the errors or uncertainties contained both within the model and in the water loading data. The model also needs to be refined further to take into account the other factors that can affect the tolerance of a lake to increasing nutrient load such as water colour, vegetation and depth.

Nevertheless the nutrient loads to both lakes, particularly the southern lake, are so excessive that further refining of the assimilative capacity is unlikely to significantly change the amount that the nutrient loads need to be reduced. The reductions need to be dramatic if the lakes are to be managed as a worthwhile resource to the region and their conservation and recreational values preserved.

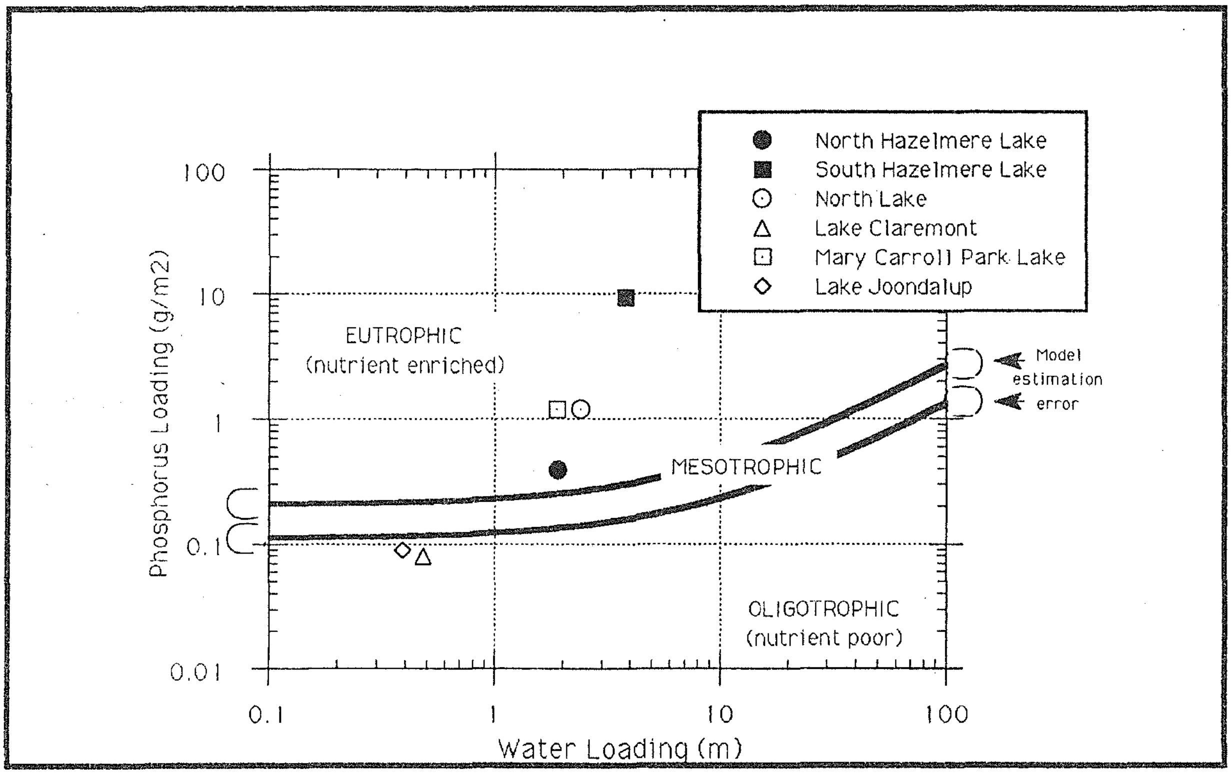


Figure 10. Trophic status of the Perth metropolitan lakes with available data, estimated from Vollenweider's phosphorus loading criteria.

3. General discussion and conclusions

The results of this programme indicate that the Hazelmere Lakes are severely over-enriched with nutrients and that this has caused excessive algal growth leading to blooms of blue-green algae and substantially reduced water quality. The source of the nutrients appears to be landuse activities in the catchment which lies to the east of the lakes. Drainage monitoring indicates that the major sources for the extreme nutrient loads entering the southern lake appear to the two animal waste rendering plants located about 1km east-south-east of the lakes. The results also indicate that the ammonia concentrations entering the southern lake are sufficiently elevated to affect the aquatic fauna at least in the vicinity of the drain. Nutrient loads entering the northern lake via surface drainage are approximately one to two orders of magnitude less than for the southern lake and within the range typical for broadacre agriculture on coastal plain soils. However, they are still considered to be excessive for the maintenance and preservation of aquatic ecosystems.

The monitoring programme has only considered surface water inputs to the Hazelmere Lakes because of limited resources and information. Groundwater quality and inflow to the Hazelmere Lakes has not been investigated in any detail and is therefore largely unknown. As with the surface drainage groundwater quality and flow can be expected to have substantially changed from the original situation as a result of changes in landuse, drainage construction and topography within the catchment. A reasonable estimate of the groundwater component is essential for a full understanding of the condition of the lakes and the steps required for their management.

The water table in the catchment to both lakes is generally shallow and the soils are mainly quartz sands with very little capacity to retain nutrients. Under these conditions significant nutrient loads from fertiliser use and waste disposal may be associated with groundwater flow. Generally groundwater nutrient loads to wetlands are likely to be less significant than surface water nutrient loads where an extensive drainage system is associated with the wetland. This is likely to be the situation for the southern Hazelmere Lake, but for the northern lake groundwater contributions may be very significant.

The capacity for the two lakes to assimilate phosphorus has been assessed with maximum target loads estimated to be 18 and 22kg/yr of phosphorus in nine years out of 10 for the northern and southern lakes respectively. Groundwater and surface water inputs need to be accounted for in achieving these target loads. Nutrient inputs to both lakes exceeded their respective assimilative capacities and it was found that substantial reductions would be required if they were to be managed as healthy, resilient ecosystem in perpetuity.

If the assimilative capacities for the lakes are to be achieved then probably several integrated strategies would be required rather than just one mechanism. Certainly waste management programmes for the animal waste rendering plants should be reviewed. Experience from other similar studies of estuaries has shown that fertiliser use in broad acre agriculture can be reduced with the introduction of appropriate management techniques such as soil testing and timing of application (EPA, 1988). Surface runoff and drainage almost always contains significant nutrient loads, particularly where land has been developed and utilised. Consequently the prevention or reduction of surface drainage into the lakes would have immediate benefits. Emergent wetland vegetation planted along drainage lines and particularly in artificial ponds (wet detention basins) along drainage lines has been found to provide a filtration function reducing the concentrations of several contaminants (Chambers, 1984; AEC,1988). Similarly retention/infiltration basins placed along the drainage lines can reduce drainage nutrient losses (McAuliffe and Evangelisti, 1991). Both types of basins need to be appropriately designed and sized according to input flow rates and nutrient loads. A significant buffer of natural vegetation surrounding a wetland can also act as a filter for groundwater taking up some of the nutrients. The vegetation also provides shade to reduce algal growth and midge populations, food and shelter for the aquatic animals and compounds released with the breakdown of dead leaves and other associated litter appears to inhibit algal growth either by colouring the water and reducing light transmittance or by some other process.

Achieving the assimilative capacities of the Hazelmere Lakes also has consequences for landuse planning in the area. Changes in landuse within the catchments will need to be carefully assessed and managed to ensure that the lake assimilative capacities are not exceeded.

The sediments of the lakes were also found to be enriched with nutrients. Nutrient content in the basin sediments of the southern lake far exceeded anything reported elsewhere for Swan coastal plain lakes (Davis and Rolls, 1991). When conditions are suitable nutrients can readily be recycled from the sediments to the water column with subsequent utilisation by algae (Lukatelich, 1985) and in extreme cases blooms can result. Such conditions have been observed in both of the Hazelmere Lakes and this historical source of nutrients is most likely a major contributor to the poor water quality and algal blooms experienced by both lakes.

The estimated assimilative capacity for each of the lakes should not be considered to be absolute but rather a close estimate based on the available information at the time. As our knowledge base increases and our understanding of the processes and inter-relationships in aquatic ecosystems improves so the estimated assimilative capacity can be refined and the errors reduced. The estimated assimilative capacity has obvious consequences for land users in the catchment since it provides a clear environmental objective within which the cumulative phosphorus export from all activities must be managed. Further refining of the assimilative capacity for the Hazelmere Lakes, particularly the southern lake, is unlikely to make much difference to the amount that the phosphorus loads need to be reduced because the current inputs are so high.

There are several land owners within the catchments of the Hazelmere Lakes all of whom contribute some proportion of the total nutrient load to the lakes and all of whom have a right to a portion of the estimated assimilative capacity. How this target assimilative capacity can be apportioned back among the land users equitably is an important issue that must be addressed as part of an overall management programme for the lakes.

Such a management programme would need to cover the full range of issues affecting the lake environment, including planning for future landuse within the catchment so that the conservation and recreational attributes of the lakes are preserved. Development and implementation of the programme needs to include input from all involved and interested groups, particularly from the community. The Shire of Swan would appear to be the appropriate agency to coordinate such a programme given their role in planning and management for the local community and their familiarity with the lakes and the issues.

The lakes and the catchment are largely privately owned and therefore any action or management that may be required to rehabilitate and maintain these ecosystems will need the support and commitment of the land owners. This again emphasises the need for mechanisms that ensure the community is able to contribute to the process and may well help in addressing the equity issue when it comes to achieving the necessary reductions in nutrient loss rates from the catchment.

The most effective means of developing a management plan that will be acceptable to the land holders is obviously for them to have a major role in developing it. This should also engender a sense of ownership for the wetlands and peer pressure may result in a very effective checking and policing mechanism for ensuring that objectives are achieved and the wetlands maintained in a condition that will benefit both people and the local environment into the future.

The conclusions drawn from consideration of the results of this investigation are summarised below for ease of reference.

1. **Monitoring of water quality in the lakes and of nutrient inputs via surface drainage indicate that both lakes are severely nutrient enrichedand in need of rehabilitative work to protect their values for conservation and to the community.**

2. **It would be appropriate for the Shire of Swan to coordinate planning and management within the lakes and their catchments to achieve rehabilitation of the lakes and to maintain their conservation and recreational values. This may best be achieved by the development of a management plan.**

3. **A Catchment Group should be formed consisting of the local landholders, representatives of interested community groups and the Shire of Swan. Other Government agencies could be involved as the need arises.**

4. **The Shire of Swan would be the most appropriate agency to initiate and service the group.**

5. **The Catchment Group could have a major role in assisting with the development of a management plan and its implementation. It could also**

ensure that land use activities within the lake catchments are consistent with the agreed conservation and recreational objectives for the lakes.

6. To achieve the objective of reducing the nutrient loads to the lakes until the assimilative capacity is achieved, management mechanisms such as those listed below should be investigated for inclusion and implementation as part of the management plan. Such mechanisms may include:
   - No further drain construction within the catchments.
   - Reduce or stop surface flows entering the lakes (eg. filling in or diversion of drainage, use as an irrigant, planting rapidly transpiring trees at strategic locations).
   - Introduce appropriate management to prevent excessive animal stocking rates and fertiliser use and to reduce or prevent leaching of fertilisers.
   - Appropriate management of current waste disposal, and rehabilitation of old waste disposal sites, by the animal waste rendering works to achieve a level of off-site discharge consistent with target nutrient load for the lakes.
   - Construct shallow artificial wetlands with emergent vegetation, including paperbarks, strategically along remaining drainage lines.
7. The feasibility of removing the excessive nutrient store in the sediments of both lakes should be investigated if build up of organic material and nutrient recycling continues to cause algal blooms and poor water quality;
8. Grazing should be excluded from the lake fringes and adjacent areas and a revegetation programme implemented using locally native species.
9. The contribution of groundwater to the lakes should be investigated to complete the information base on inputs and our understanding of the processes contributing to the condition of the lakes.

4. References

EC (1988). Water pollution control guide for urban runoff quality management. Australian Environment Council Report No. 23.

Bayley, P, Deeley, D, Humphries, R, Bott, G (1989). Nutrient loading and eutrophication of North Lake Western Australia. Environmental Protection Authority Technical Series No. 33.

Chambers, J M (1984). The potential of natural and artificial wetlands for phosphorus removal in the Harvey catchment. Environmental Protection Authority Bulletin No. 202.

Congdon, R A (1986). Nutrient loading and phytoplankton blooms in Lake Joondalup, Wanneroo, Western Australia. Environmental Protection Authority Technical Series No. 6.

Davis, J A, and Rolls, S W (1987). A baseline biological monitoring programme for the urban wetlands of the Swan Coastal Plain WA. EPA Bulletin 265, Perth WA.

Davis, J A, Rolls, S W, Wrigley, T J (1991). A survey of the environment quality of wetlands on the Gnangara Mound, WA, Water Authority of WA, Perth.

EPA, (1981). Water quality criteria for marine and estuarine waters of Western Australia. Environmental Protection Authority Bulletin 209.

EPA, (1983). The Darling System — System 6 (Red Book), Part II: Recommendations for specific localities. Environmental Protection Authority Report 13.

EPA, (1988). Peel Inlet and Harvey Estuary management strategy environmental review and management programme stage 2. Report and Recommendations of the Environmental Protection Authority, EPA Bulletin 363.

EPA, (1990). Albany Harbours environmental study (1988 - 1989) Environmental Protection Authority Bulletin 412.

Groundwater Resource Consultants Pty Ltd (1983). Report on groundwater study at Hazelmere Lakes, Perth WA.

Hewson, B H, McDougal, B K (1990). Sampling Techniques for the Determination of Total Phosphorus & Nitrogen in Water (EPA unpublished).

Hillman, K, Lukatelich, R J, Bastyan, G, McComb, A J (1991). Water quality and seagrass biomass, productivity and epiphyte load in Princess Royal Harbour, Oyster Harbour and King George Sound. Environmental Protection Authority Technical Series No. 39.

Humphries, B, Bott, G (1988). Intensive Animal Industries on the Swan Coastal Plain, and their Associated Pollution Problems. Proceedings of The Swan Coastal Plain in Crisis - agriculture and the environment.Australian Institute of Agricultural Science Occasional Publication No. 10.

Lantzke, I R, Gabriel, P W, Haynes, B T (1989). Lake Claremont Research Report (1987-88) for the Town of Claremont.

Lukatelich, R J (1985). Macroalgal growth, phytoplankton biomass, zooplankton populations and the role of the sediments; present trends and possible effects of the proposed Dawesville Channel, Proceeding from the Symposium Peel-Harvey Estuarine System Study: Management of the Estuary. Environmental Protection Authority Bulletin 195.

Lukatelich, R A, Schofield, N J, McComb, A J (1986). The nutrient status of Wilson Inlet (1984 - 1985). Environmental Protection Authority Technical Series No. 9.

McAlpine, K W, Spice, J F, Humphries, R (1989). The environmental condition of the Vasse-Wonnerup wetland system and a discussion of management options. Environmental Protection Authority Technical Series No. 31.

McAuliffe, T F, and Evangeliste, M R (1991). State of the art innovations in stormwater quality control basins. Local Government Engineers Association of WA, Eighth State Conference, Perth 1991, Technical Papers Vol. 2.

Masini, R J, Simpson, C J, Kirkman, H, Ward, T, Crossland, C (1992). The concept of 'assimilative capacity' as a management tool in temperate coastal waters of Western Australia. Environmental Protection Authority Technical Series 48.

Newsome, D, and Ladd, P G (1991). Hazelmere Lakes - biological survey and management recommendations, Perth WA.

Page, P (1991). Macro-invertebrates, Phytoplankton and nutrients in two wetland lakes in Hazelmere, WA. Student project, Murdoch University.

Rodda, J, Deeley, D (1990). Nutrient pollution of Mary Carroll Park wetlands, Gosnells (City of Gosnells publication).

Schofield, N J, Bettenay, E, McAlpine, K W, Height, M I, Hurle, D H, Ritchie, G S P, and Birch, P B (1985). Water and phosphorus transport processes in permeable grey sands at Talbot's site near Harvey, Western Australia. Environmental Protection Authority Bulletin 209.

Seddon, G (1972). Sense of Place. University of Western Australia Press.

Townley, L R, and Turner, J V (1990). Flow of groundwater through shallow lakes and wetlands (submitted to Land and Water Research News, Water Authority of WA).

USEPA, (1986). Quality criteria for water.

Vollenweider, R A, Dillon, P J (1974). The application of the phosphorus loading concept to eutrophication research. National Research Council Canada, NRC Associate Committee on Scientific Criteria for Environmental Quality, NRCC, No 13690.

Vollenweider, R A (1975). Input-Output Models, with special reference to the phosphorus loading concept in limnology. Schweiz, z. Hydrol. 37: 53 - 83.

Vollenweider, R A (1976). Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist., Ital., Idrobiol., 33: 53 - 83.

Walsh, D (1991). Eutrophication of Hazelmere Lakes Investigation of Nutrient Inputs From Stormwater Run-Off (Shire of Swan publication).

Wrigley, T J, Chambers, J M, and McComb, A J (1988). Nutrient and gilvin levels in waters of coastal-plain wetlands in an agricultural area of Western Australia. Australian Journal of Freshwater Research, Vol 39: 685 - 694.