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IMPROVING NUTRIENT MANAGEMENT AT LAKE JOONDALUP, WESTERN AUSTRALIA, THROUGH IDENTIFICATION OF KEY SOURCES AND CURRENT TRAJECTORIES

By

Michelle Cumbers

A thesis submitted in partial fulfilment of the requirements for the award of Bachelor of Science Honours at the School of Natural Sciences, Edith Cowan University, Joondalup

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The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

Eutrophication has become a considerable issue for managers of water bodies across Australia. Rapid urbanisation in the south-west of Western Australia is causing the eutrophication of many wetlands within the region. Lake Joondalup is a eutrophic, urban lake, located approximately 20km north of Perth city. It comprises part of the Yellagonga Regional Park, having a high conservation value.

The aim of this study was to provide managers of Lake Joondalup with information on the relative importance of different nutrient sources into the lake, thus enabling the development of appropriate management strategies. Additionally, a historical examination of available water quality data was conducted to determine the lake's current trajectory in relation to nutrients.

The long-term trends occurring in Lake Joondalup were inferred with the use of information collected between 1973–2001 for total phosphorus and nitrogen concentrations. Relative importance of stormwater, groundwater and surface flow from adjoining swamps was investigated through sampling that occurred between May and August of 2004. A nutrient budget was then extrapolated based on the recent sampling and the use of literature. This budget was compared to a nutrient budget constructed in the mid 1980s to determine changes.

Long-term trends suggest that significant variation has occurred over the years, with nutrient concentrations increasing in the main section of the lake and decreasing in the southern section. This was particularly prevalent for total phosphorus. However, whilst the two sections of the lake seem to be acting differently, the concentrations in the two regions are now quite similar, with both being equally polluted. This is in contrast to the 1980s, when only the southern section showed significant levels of pollution. Surface flow from Beenyup Swamp was considered the major contributor of nutrients to the Lake, as has been identified in several prior studies. Contrary to previous beliefs stormwater was not found to have a significant effect on the nutrient status of Lake Joondalup, while the complexity of groundwater movement made quantification of sub-surface impacts difficult. Nonetheless this study indicates that

an old landfill site east of the Lake appears to contaminate groundwater entering the lake, yet on aggregate a net loss of nutrients from the lake was identified through groundwater flow.

It is recommended that the most appropriate management strategy for Lake Joondalup is to reduce nutrient contributions through surface flows from Beenyup Swamp. Considering the importance of Beenyup Swamp to the hydrology of Lake Joondalup it would be undesirable to restrict the flow from this source. Harvesting of macrophytes may be beneficial, though a study to better understand the sources of nutrients to the swamp is required. In addition, an investigation of the relative importance of groundwater is desirable to determine the net impact of this parameter. Thus, it was concluded that whilst effects of groundwater need further investigation, reductions in nutrient input from Beenyup Swamp should be the priority and would ultimately help to ensure the conservation of Lake Joondalup.

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Michelle Cumbers

12 November 2004

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1 INTRODUCTION

1.1 Eutrophication

Eutrophication is a significant threat to inland wetlands across the world, as much today as it was when first recognised hundreds of years ago. Eutrophication is an increase in nutrients, generally phosphorus in freshwater bodies and nitrogen in marine water bodies, which promote increased algal and plant biomass (Harper 1992; Mason 2002; Mitsch & Gosselink 2000; Smith 1998; Wetzel 2001). The consequences of eutrophication can include algal blooms, plagues of midges, wildlife deaths, alterations to the ecosystem structure and function, loss of aesthetic values and noxious odours (Harper 1992; Humphries, Bott, Deeley & McAlpine 1989; McComb & Lake 1990). Whilst this process occurs naturally, human actions can significantly increase the rate at which it occurs and Australia is not immune (Beeton 1971; Harper 1992; Water and Rivers Commission of Western Australia 2001).

Eutrophication is a process, whereby a water body progresses from an original state of oligotrophy (low nutrient) towards eutrophy (high nutrient) (Beeton 1971; Harper 1992; Water and Rivers Commission of Western Australia 2001). There are many ways of determining a wetland's state of eutrophication (Table 1.1), and depending on the characteristics it may be assigned to multiple classes, although this will still provide an indication of the state and function of the wetland and the organisms present (Harper 1992).

Table 1.1 Characteristics of the common classifications for a wetland. Nutrients and chlorophyll a concentrations are annual averages (Mason 2002; Rast, Smith & Thornton 1989).

Characteristic	Oligotrophic	Mesotrophic	Eutrophic
Total phosphorus (µg/L)	8.0	26.7	84.4
Total nitrogen (µg/L)	661	753	1875
Chlorophyll a (µg/L)	1.7	4.7	14.43
Algal types	Desmid plankton, Chrysophycean plankton	Diatom plankton, Dinoflagellate plankton	Diatom plankton, Dinoflagellate plankton, Cyanobacterial plankton

Nutrients can arise from rainfall, surface flow, groundwater, stormwater or nitrogen fixation (Harper 1992; Stacey, Burris & Evans 1992). In shallow lakes these nutrients are initially absorbed by aquatic plants and algae (Figure 1.1). All organisms require certain nutrients to grow and reproduce. These nutrients can be classified as either micronutrients (trace) or macronutrients (required in large quantities). Nitrogen and phosphorus are some of the most important of the macronutrients for primary producers (McComb & Lake 1990) and the soluble forms of NO_3 (nitrate) and PO_4 (phosphate) are particularly important (Harper 1992). On the addition of nutrients to a lake, the macrophytes and algae can assimilate the nutrients and increase their biomass. Depending on when this nutrient input occurs, it may alter the seasonal occurrence of the algae (Harper 1992).

Increases in algal biomass can result in increased zooplankton populations often followed by increased fish density. Submerged macrophytes may be out-competed by planktonic algae because they will reduce available light (Harper 1992). Eutrophication can result in the stable state of submerged macrophytes being smothered by epiphytic algae. This can then lead to dominance by benthic algae, which can quickly shift to increased phytoplankton (including cyanobacteria or blue-green algae) abundances (Beklioglu & Moss 1996; Blindow, Andersson, Hargeby & Johansson 1993; Scheffer, Carpenter, Foley, Folke & Walker 2001). High densities of zooplanktivorous fish may also increase the quantity of algae since their predation reduces zooplankton abundance, therefore reducing algal grazing (Harper 1992; Mason 2002).

High abundances of algae and other species will decrease the available oxygen through respiration, which can cause further changes in species diversity (Wood 1975). Furthermore, as algal populations die and decay they reduce oxygen in the water as bacteria and fungi at the sediment surface consume oxygen to break down the organic matter (Mason 2002; McComb & Lake 1990). These anaerobic conditions impact on the sediment-dwelling fauna causing a change to community composition, for example increasing the abundance of oligochaete worms and chironomid midge larvae (Harper 1992; Mason 2002; McComb & Lake 1990; Wood 1975).

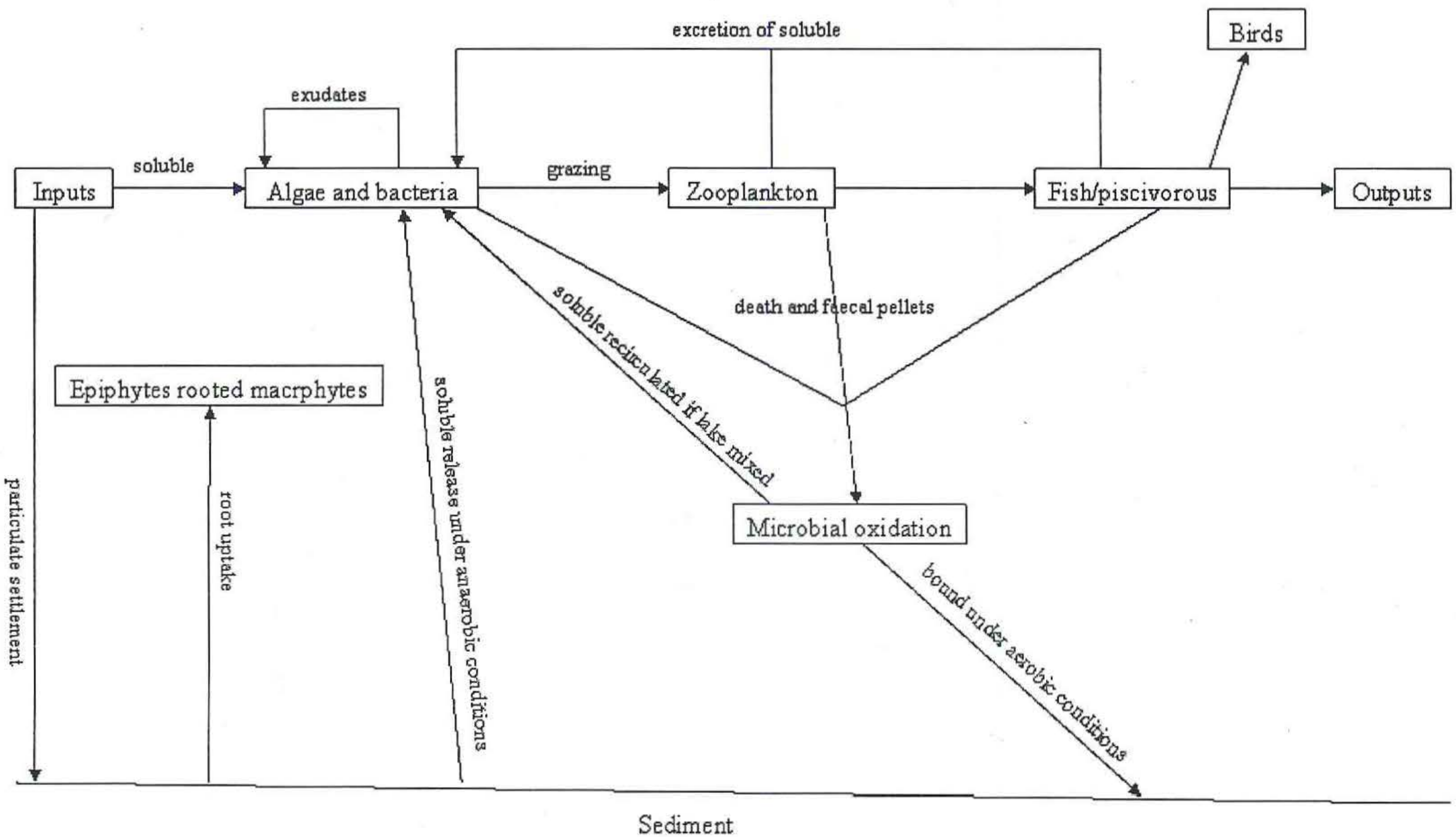


Figure 1.1 Cycling of nutrients within a water body (Harper 1992).

Nutrients accumulated in the sediment, particularly phosphorus, can be released back into the water column under anoxic conditions providing a ready supply of nutrients for algal blooms (Harper 1992; Mason 2002; McComb & Lake 1990; Wood 1975). Wind resuspension of sediment can also release nutrients into the water column (Harper 1992). Denitrification by bacteria reduces nitrate to gaseous nitrogen, which is then lost to the atmosphere (James, Mark & Single 2002). Nutrients can also be lost from the lake through groundwater or surface flow out of the water body.

1.2 Causes of Eutrophication

In Australia, urbanisation is an increasing cause of eutrophication, particularly since 1950 following the rapid growth of Australia's population post World War II (Davis, Rosich, Bradley, Growns, Schmidt & Cheal 1993; Gosselink & Maltby 1990; Lees 1999; McComb & Lake 1988; Pinder & Witherick 1990). The Swan Coastal Plain in south-west Western Australia has also become increasingly urbanised during this time. In 2001, the Perth metropolitan area comprised over 70% of the State's population supporting approximately 1.4 million people (Edwards 2001). Over 70% of the original Swan Coastal Plain wetlands have been lost (Halse 1989) and many of the remaining wetlands are experiencing eutrophication associated with urbanisation (Davis & Froend 1999; Davis, Rolls & Wrigley 1991). Davis *et al.* (1993) found that approximately one third of the 41 wetlands studied on the Plain were extremely nutrient enriched.

Typically urbanisation initially involves the clearing of vegetation. This in itself can mobilise nutrients, as the runoff and groundwater characteristics vary dramatically as a result of this change in the hydrology of the catchment (Bolger & Stevens 1999; Halse 1989; James *et al.* 2002; McComb & Lake 1988; Wong, Breen & Lloyd 1999). The volume and rate of runoff increases in relation to increases in the proportion of the catchment covered in hard (impervious) surfaces. Three-fold increases in the volume of runoff and seven-fold increases in the rate of runoff are not uncommon when converting agricultural surfaces to urbanised areas so for a natural catchment the increases would be higher still (Lawrence & Breen, 1998 cited BSD Consultants, 2003, p. 6). In a developed catchment, runoff can be as much as

90% of the rainfall compared with the original 10% from an undeveloped catchment (Environment Communications Information Technology and the Arts Legislation Committee 2002). An increased runoff rate facilitates the mobilisation of contaminants including sediment and general litter that can impact the water quality of the receiving water body (Humphries & Davis 1988; Leopold 1971; Livingston 1999; Reinelt & Taylor 2001; Wilding 1999; Wong *et al.* 1999). Stormwater can also have an impact on a water body should the stormwater contaminants leach through the soil into the groundwater that supplies water to the water body (Environment Communications Information Technology and the Arts Legislation Committee 2002).

Following urban establishment, groundwater levels initially increase as there is limited vegetation transpiring the groundwater, however the levels may then decrease due to abstraction (Azous & Cooke 2001; Breen 1989; Halse 1989; Leopold 1971; Reinelt & Taylor 2001). In Perth, groundwater currently supplies approximately 40% of the public water supply an increase on the 30% supplied in the early nineteen-nineties (Western Australian Planning Commission & Water and Rivers Commission 1999; Western Australian Water Resources Council 1989). On the Swan Coastal Plain there are two major sources of shallow unconfined groundwater, namely the Gnangara and Jandakot Mounds (Figure 1.2). Together they supply approximately 70% of Perth's total water use, with the majority coming from the Gnangara Mound (Western Australian Planning Commission & Water and Rivers Commission 1999). This abstraction of groundwater can impact flow-through lakes on the Swan Coastal Plain that rely on this water resource (Western Australian Planning Commission & Water and Rivers Commission 1999).

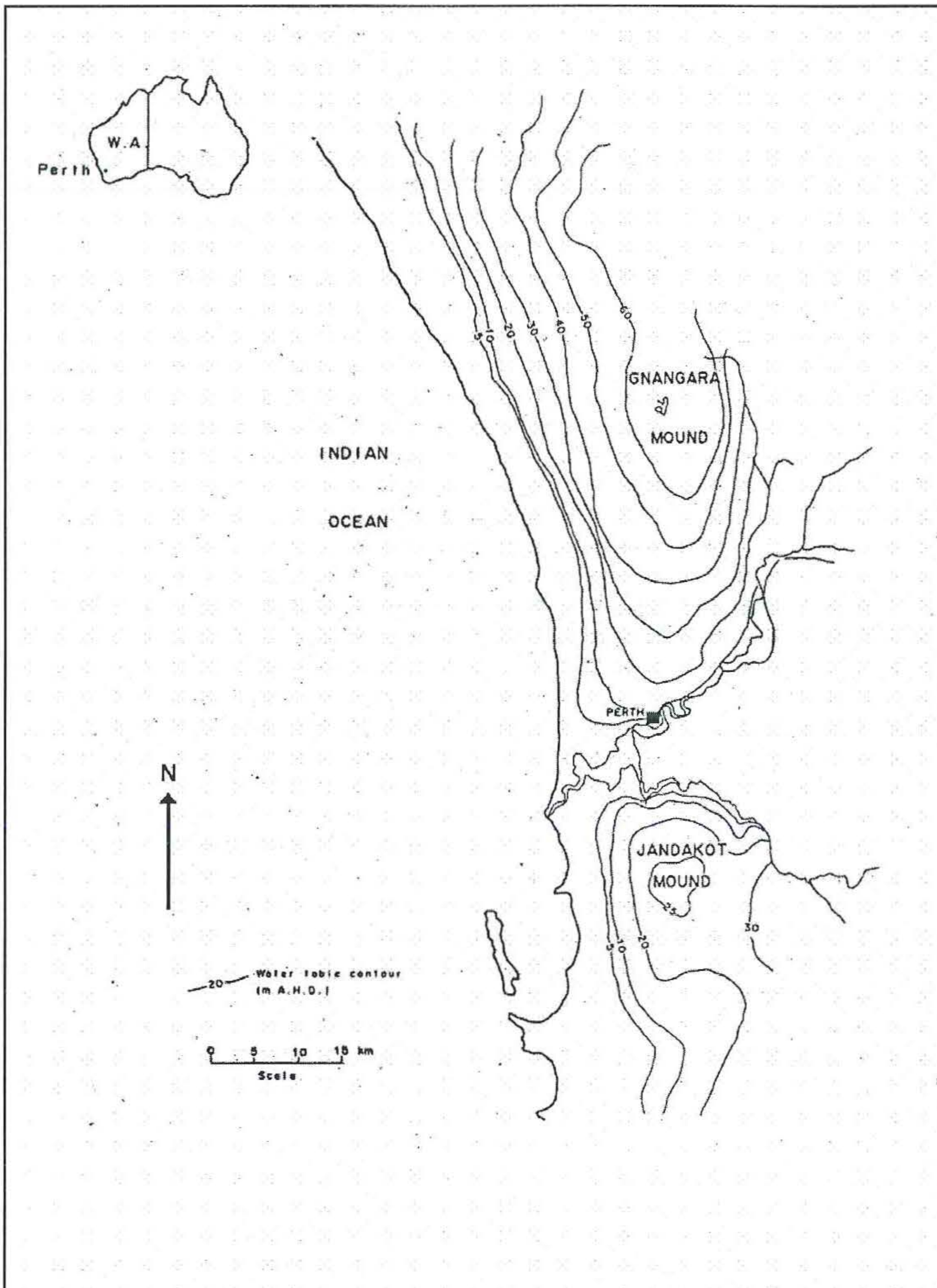


Figure 1.2 Location of the Gnangara and Jandakot Mounds, also showing the Perth metropolitan region (Balla & Davis 1993).

Associated with urban areas is the need for disposal sites and sewage systems. Septic tanks and overflows from sewage pumping stations have been implicated in the release of nutrients into rivers and groundwater on the Swan Coastal Plain (Appleyard 1995; Barber, Otto & Bates 1996; Bolger & Stevens 1999). Landfills are known to detrimentally impact lakes through groundwater contamination (Cox 1996; Martinick McNulty Pty Ltd 1998b; Pierce 1997). Fertilising of gardens and lawns is another considerable source of contamination for the groundwater (Bolger & Stevens 1999; Sharma, Herne, Byrne & Kin 1996). However, the impact of these events is dependent on the soil type of the region, with different soil types ranging in their abilities to bind and retain nutrients in the soil prohibiting them from contaminating the groundwater (Beeton 1971; Bolger & Stevens 1999; Gerritse, Barber & Adeney 1990; Lees 1999; Mason 2002). The processes occurring in the soil may also be important in determining the impact of a contaminant as in some areas denitrification is known to occur in the groundwater, which reduces the contamination from nitrate and ammonia (Bolger & Stevens 1999; Gerritse *et al.* 1990). However, this process requires a certain quantity of organic matter and a specific range of redox potential and pH (Gerritse *et al.* 1990). Groundwater and its pollution can contribute and accumulate in lake systems, which ultimately impacts the flora and fauna inhabiting the receiving water body (Leopold 1971; Wilding 1999; Wong *et al.* 1999).

Wetlands are important as they support a great deal of the fauna on the Swan Coastal Plain, as well as the migrating avifauna from inland areas and the northern hemisphere (Davis *et al.* 1993). The ecological values of wetlands are recognised with a concerted effort required to protect, conserve and appropriately manage wetland structure and function, and the life they support (Breen 1989; Davis *et al.* 1993; Gosselink & Maltby 1990; Horner 2001; Lake 1989; Maitland & Morgan 2001; McComb & Lake 1990). In order to manage a wetland appropriately it is important to differentiate natural eutrophication from cultural eutrophication (accelerated by human influence) (Harper 1992). Eutrophication of urban water bodies is a significant issue for managers (Maitland & Morgan 2001). Knowledge gained from research has identified numerous potential techniques for rehabilitation.

1.3 Lake Rehabilitation

In order to rehabilitate a wetland affected by eutrophication, a nutrient budget is particularly useful, as it identifies all the sources of nutrients to a water body and outlines their fates – whether they are lost from the system or stored within the system (Breen 1989; Davis *et al.* 1993). The initial phase in constructing a nutrient budget is to determine the water balance of the system, which accounts for the change in the stored water volume of the water body by the rates of inputs and outputs of water (Wetzel 2001). Following this, the different components can be monitored and sampled to determine the concentrations of nutrients that can then, in conjunction with water volume, be converted to the loads of nutrients (kg/year). Even though there are soluble and particulate forms of nutrients, within a lake, most budgets are based on the totals of nitrogen and phosphorus as eventually the majority of their forms become available for assimilation (James *et al.* 2002).

In Perth, nutrient budgets have been created for North Lake and Lake Monger (Bayley, Deeley, Humphries & Bott 1989; Martinick McNulty Pty Ltd 1998a). Both urban and agricultural areas surround North Lake, with the prime contributor of nutrients to this lake found to be a drain originating from Murdoch University Veterinary Farm. Thus management largely involved treating the water coming from this drain (Bayley *et al.* 1989). Lake Monger is completely surrounded by urban development and the main inputs of nutrients were identified as coming from stormwater and groundwater, which flowed through an old landfill site (Davis & Rolls 1987; Ltd 1998; Martinick McNulty Pty Ltd 1998a). Constructed wetlands near stormwater drain outfalls have now been established in an attempt to reduce nutrients in the stormwater before it reaches Lake Monger.

A complicated nutrient budget allows key contributors of nutrients to be identified and management to evaluate options for their control. There are a plethora of options available for rehabilitating a eutrophic wetland. These options can be divided into those that are external to the lake and those within the lake (Mason 2002). Generally, the mechanisms that occur outside the lake are long-term approaches to rehabilitation directly addressing and reducing the sources of nutrients, while the internal mechanisms are largely short-term. In some cases a combination of external and internal rehabilitation techniques would be utilised, however it all depends on the source of the nutrients (Harper 1992).

The most prominent external approach should be changes in land management within the catchment, for example catchment management, as it addresses the problem on a broad scale. Catchment management involves all stakeholders within the water body's catchment deciding on appropriate objectives for its health and adopting management strategies to achieve those objectives (Chalmers & Gray 2004; Lees 1999; Livingston 1999; Mason 2002; McComb & Lake 1990). For example, management could encourage native gardens, decreased use of groundwater, adoption of slow release fertilisers, phosphorus free detergents or other aspects of "Urban Water Sensitive Design" to reduce impervious areas (Hodgkin & Hamilton 1993; JDA Consultant Hydrologists 2003; Wong *et al.* 1999).

Other external options include water diversion and nutrient removal by treatment prior to this water entering the lake. Nonetheless, water diversion may impact on the hydrology of the system or simply transfer the problem to another water body. Constructed wetlands are becoming increasingly popular as a means of water treatment prior to discharge into a lake. They reduce nutrients by slowing the rate of flow and allowing sedimentation of nutrients, whilst simultaneously encouraging biological assimilation of the nutrients (Russell, Hunter & Sainty 1999).

The internal mechanisms of rehabilitation all aim to remove or inactivate nutrients once they have entered the water body (Table 1.2). Most rehabilitation methods are focused on phosphorus as this macronutrient is normally limiting in freshwater systems. Phosphorus is also more readily leached from the soil, progressing in the groundwater to the wetland (Harper 1992).

Table 1.2 Describing the different rehabilitation techniques for a eutrophic, phosphorus-limited, shallow lake (Cooke, Welch, Peterson & Newroth 1993; Elliott & Sorrell 2002; Harper 1992; Maitland & Morgan 2001; Wetzel 2001).

Technique	Description
Phosphorus precipitation and inactivation	The addition of salts (e.g. iron) that phosphorus binds to, precipitating out of the water column and inactivating in the sediment.
Lake flushing and hypolimnetic withdrawal	The concentration of nutrients is diluted by the addition of low nutrient water, the additional water also increases the flow rate so more nutrients leave the system. This could occur following the abstraction of nutrient-rich hypolimnetic water.
Sediment oxidation	Under anoxic conditions, iron loses its capacity to bind phosphorus. This ensures the sediment is oxygenated inhibiting phosphorus release into the water column.
Aeration and circulation	Ensures nutrients and oxygen are well mixed throughout the water column to reduce phosphorus release from the sediments.
Sediment removal or covering	The internal loading of phosphorus from the sediments is a complex situation to which the possible solutions may be to cover the sediment with plastic or remove the nutrient-rich sediment.
Lake level draw down	Primarily used to control macrophytes by exposing them to extended dry periods. However, this is generally not used in natural systems due to the impacts on the system and other biota.
Harvesting	The algae, macrophytes and sometimes fish, that assimilate the nutrients are removed from the system thus reducing nutrients.
Biomanipulation	Whilst the previous mechanisms have been bottom-up in controlling the nutrients themselves, biomanipulation is a top-down approach that alters one part of the existing food web to facilitate changes in other parts. For example, the addition of zooplankton so additional grazing reduces algae.

The effectiveness of these rehabilitation approaches depends very much on the existing wetland structures and functions. Sometimes several approaches will have to be adopted in succession or all at once to achieve the desired outcome for the water body. It is important to have an adaptive approach that addresses the changing conditions of the wetland. The recovery period will depend on the period of time the wetland has been eutrophic as this affects the resilience of the system (Wetzel 2001).

1.4 Aims

Urbanisation is causing eutrophication in many of the remaining lakes situated on the Swan Coastal Plain. Lake Joondalup is a large eutrophic lake that has been detrimentally impacted by past and present land uses, particularly recent urbanisation. The lake has been classed as eutrophic for decades, yet it is not known whether its condition is continuing to decline (Davis *et al.* 1991). The lake has high conservation values as part of the Yellagonga Regional Park (Dooley, Bowra, Cluning & Thompson 2003). Whilst a nutrient budget was constructed between 1979-1980 by Congdon (1986), there have been land use changes in the last two decades that may have altered its relevance today.

Residential development of formally agricultural land has increased the volume of stormwater entering the lake since Congdon's (1986) budget. There has been a strong perception in Western Australia that the "first flush" of a stormwater system is the crucial event leading to nutrient transport to lakes, though this has not been verified for Lake Joondalup. The operation of market gardens surrounding the lake in previous years and the continued occurrence of rural activities east of Lake Joondalup have provided consistent contributions of nutrients to groundwater, which over the year may be more important as a nutrient source to the lake. These contributions were not quantified by Congdon (1986). Surface flow from adjoining swamps were also considered a significant source by Congdon (1986). It is important to investigate the relative importance of these sources to ensure management is appropriately focused and effective. In particular a strong commitment on the part of the two local cities, City of Wanneroo and City of Joondalup, to treat stormwater inputs has yet to be tested as being of practical benefit to the lake.

The aim of this study is to provide managers of Lake Joondalup with the relative importance of different nutrient sources entering the lake. Consequentially this will enable them to develop appropriate management strategies. In a historical examination of available water quality data the lake's current trajectory in relation to nutrients will be assessed. Specifically this will include:

- collating existing water quality data (from 1973–2004) and examining long-term changes in the water and nutrient status of the wetland;
- updating Congdon's studies of 1979, 1985 and 1986 to reflect current land uses surrounding the lake, particularly focussing on stormwater and other surface runoff and groundwater
- recommending strategies to improve water quality within the lake.

2 METHODS

2.1 Study Site

Lake Joondalup is a seasonally dry lake situated on the Swan Coastal Plain approximately 20 km north of the Perth CBD, Western Australia (Kinnear & Garnett 1999) (Figure 2.1). It is a large (450 ha), linear (approximately 8 km long and a maximum of 1.2 km wide) and shallow (maximum depth <2 m) lake (Congdon & McComb 1976; Kinnear & Garnett 1999). The lake is part of Yellagonga Regional Park, which also includes Beenyup Swamp, Walluburnup Swamp and Lake Goollelal (Kinnear & Garnett 1999). Lake Joondalup is bisected by Ocean Reef Road into a northern and southern section, linked by a culvert under the road. The southern section of the lake is connected to Beenyup Swamp that is connected to Walluburnup Swamp. There is no surface connection between Lake Joondalup and Lake Goollelal, however Lake Goollelal is 10m higher than Lake Joondalup so connection via groundwater is possible. Yellagonga Regional Park is situated in an interdunal swale of the Spearwood Dune System and is part of a chain of wetlands running parallel to the coast (Dooley *et al.* 2003).

The Spearwood Dune System is of intermediate age, situated between the Bassendean Dunes to the east and the Quindalup Dune system west on the coast. The Spearwood dunes consist largely of consolidated, wind blown, calcareous material (Dooley *et al.* 2003). There are three soil types found at Lake Joondalup they are the Spearwood Sands, Karrakatta Sand and Beonaddy Sand (Figure 2.2). The Spearwood Sands soil is characterised by a dark brown sandy surface that progresses into yellow brown and brown sand. The Karrakatta Sand (Yellow Phase) profile comprises a grey brown sandy surface, which passes into bright yellow sand and Beonnaddy Sand consists of a dark grey surface sand that becomes lighter with depth (Dooley *et al.* 2003).

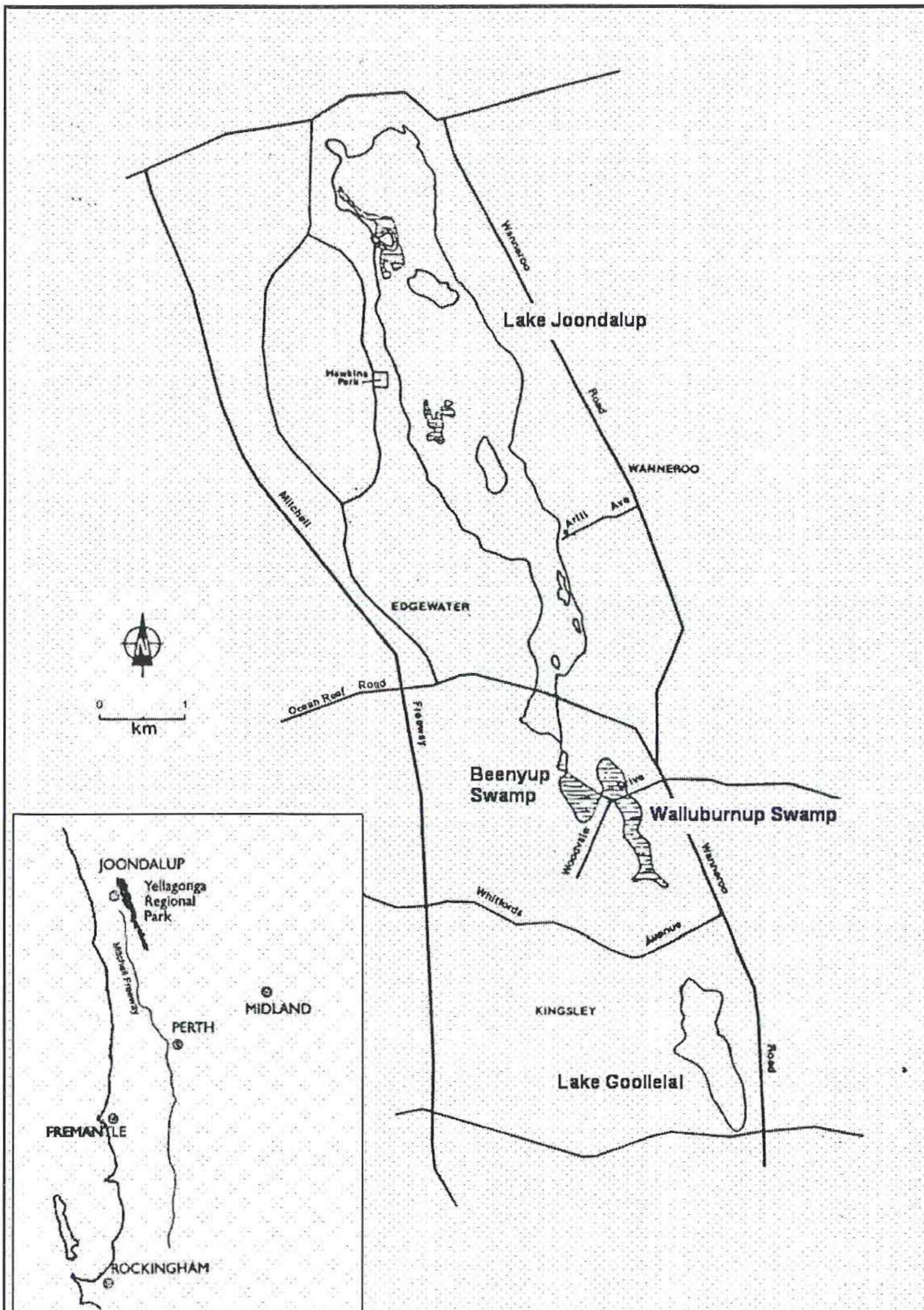


Figure 2.1 Location of Yellagonga Regional Park and its associated wetlands (Congdon 1986; Dooley *et al.* 2003).

Figure 2.2 Soil types of Lake Joondalup (Ove Arup & Partners 1994).

Lake Joondalup experiences a Mediterranean climate, with cool, wet winters and hot, dry summers. The water levels of the lake vary in sympathy with groundwater levels and rainfall, as the lake is a surface expression of the groundwater (Hamann 1992). The Gnangara Mound supplies groundwater to the lake and a large number of private bores (Western Australian Planning Commission & Water and Rivers Commission 1999). Perth has for the last decade experienced below average rainfall and this has increased demands on the Mound as a source of water. Lake Joondalup relies on the Mound for much of its water and has been drier in the last few years as a result.

The Department of Conservation and Land Management and the Cities of Joondalup and Wanneroo jointly manage Yellagonga Regional Park. Jurisdiction of both Cities is split down the middle of the lake (Dooley *et al.* 2003). Lake Joondalup has been recognised for its conservation and recreation values particularly with respect to its diverse wildlife (Dooley *et al.* 2003; Kinnear, Garnett, Bekle & Upton 1997). The vegetation is also important as it is said to be unusual for the chain of wetlands that extend from Yanchep to Lake Goollelal (Semenuik, 1997 cited in Dooley *et al.* 2003). Vegetation communities surrounding Lake Joondalup can generally be divided into tree stands and reeds (Figure 2.3). Apart from the conservation and recreation values, other values of Lake Joondalup include research, as well as European and Aboriginal cultural heritage.

Land use changes and development have seen a gradual decline in the water quality and biodiversity in the lake. Apart from being classed as eutrophic for two decades and possibly being impacted by groundwater extraction, the lake is experiencing an increase in algal blooms, often comprising the more harmful cyanobacteria (Kinnear & Garnett 1999). Midge plagues are also common and require control with the pesticide Abate (Lund, Brown & Lee 2000). Management of these wetlands progresses following the guidelines established by the Yellagonga Regional Park Management Plan (Dooley *et al.* 2003), in conjunction with monitoring and rehabilitation carried out by the Yellagonga Catchment Group and the Department of Conservation and Land Management. The City of Wanneroo is endeavouring to improve the lake by upgrading stormwater outfalls to constructed wetlands and swales, therefore it is important to verify that stormwater is a significant source of nutrients to the lake.

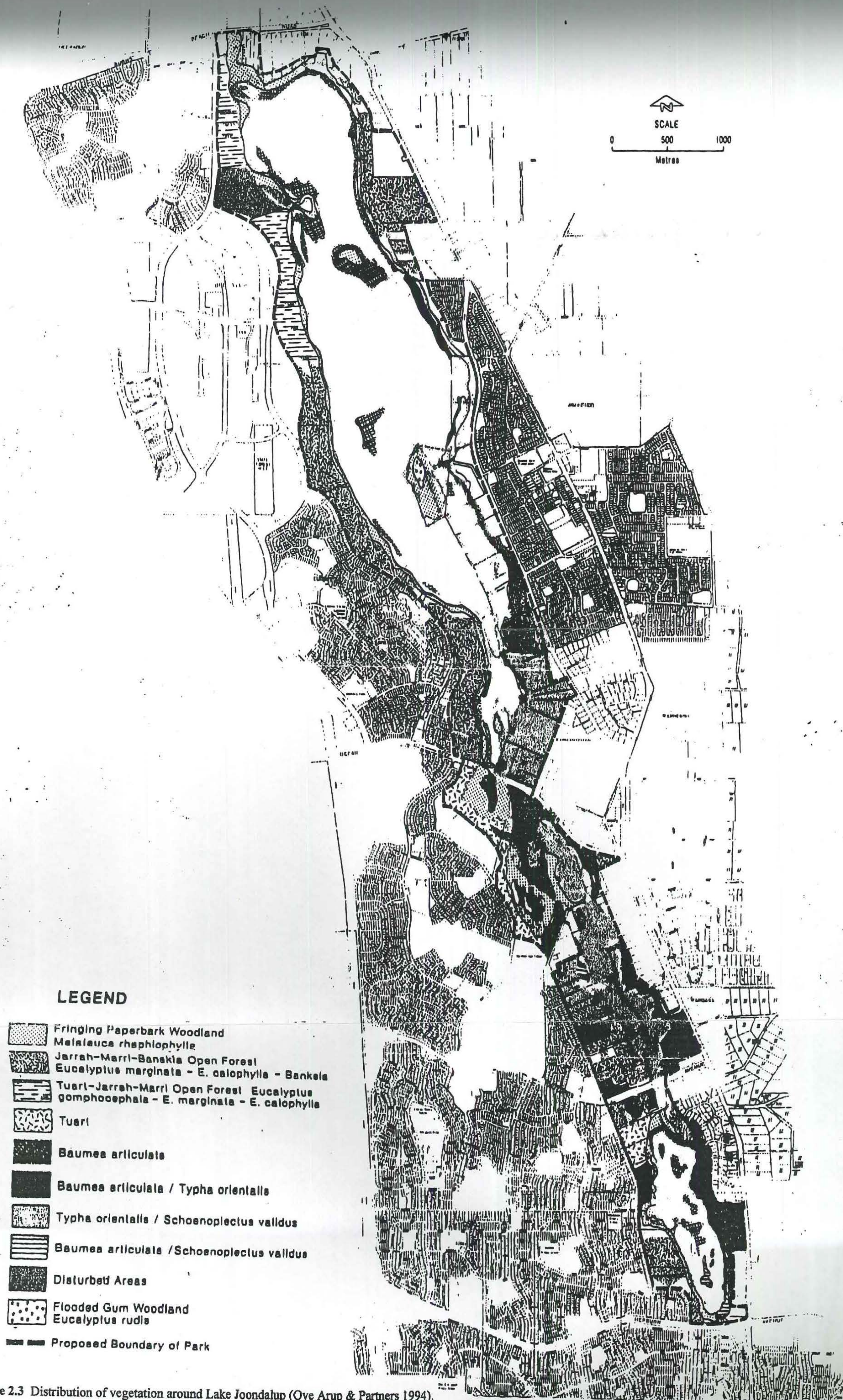


Figure 2.3 Distribution of vegetation around Lake Joondalup (Ove Arup & Partners 1994).

2.2 Long term trends

Lake Joondalup has been the focus of a number of scientific and other monitoring programs. The determination of long-term trends in water quality involved collating all of the available water quality data, specifically that pertaining to total phosphorus and total nitrogen concentrations in the water column of the lake. Total phosphorus and nitrogen concentrations were focused on as they were the most common parameter measured and are useful for budgeting purposes.

Many studies have separated Lake Joondalup into north, central and south sections (Figure 2.4). Collated data was therefore split between these sections depending on where the sampling occurred. Whilst limitations in the different studies were identified, particularly relating to replication and representativeness, all data were included to maximise the limited dataset. Table 2.1 indicates the sources of information utilised, outlining a brief description of the purpose of the data collection and the associated limitations. The long-term trajectories were determined by linear regressions of concentrations and time. An F-value was determined for this regression line to determine its suitability of fit. It should be acknowledged that the data used in this analysis was not transformed to accommodate the changes in water level and the possible effects of evapo-concentration between the time periods, even though evapo-concentration is known to occur at Lake Joondalup.

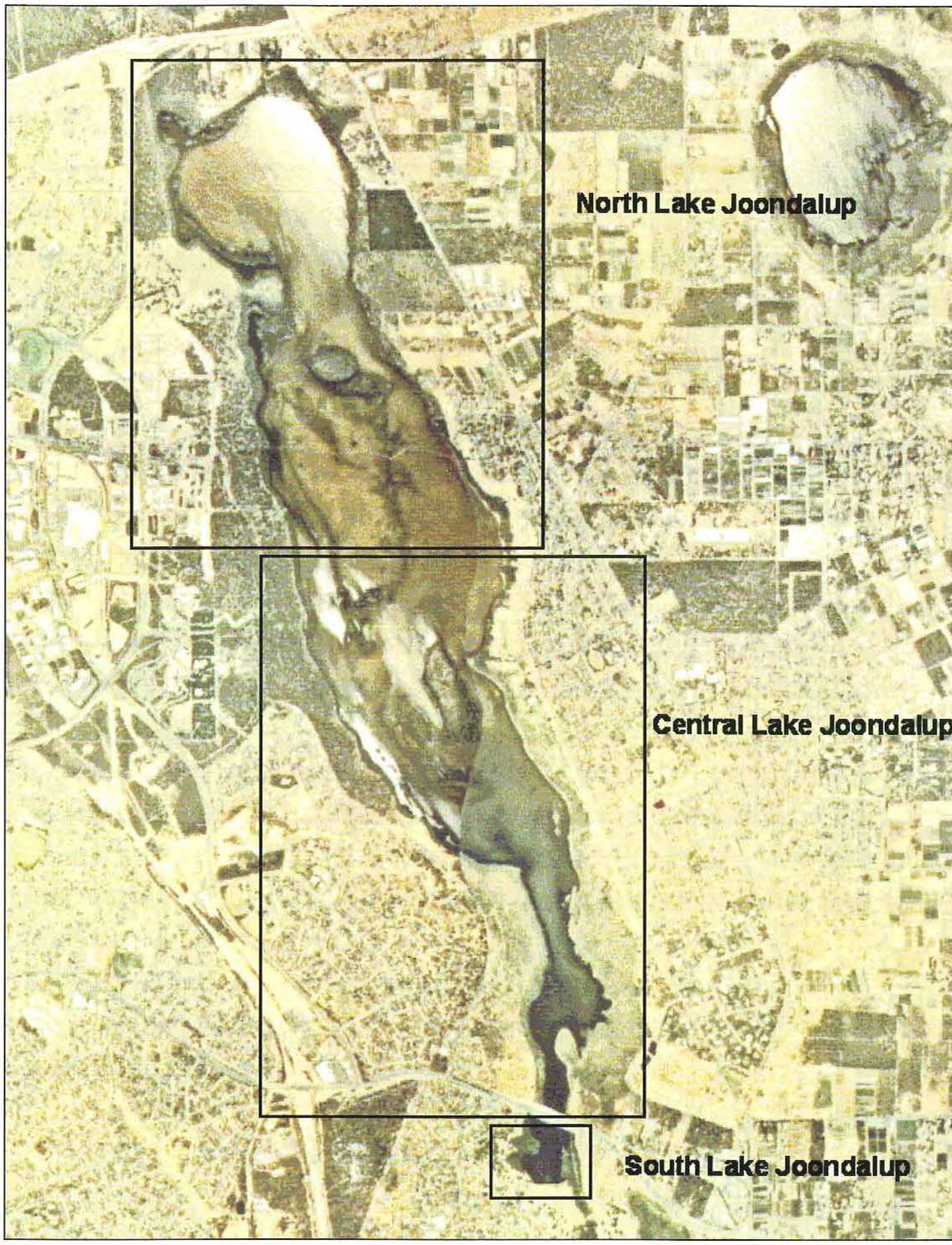


Figure 2.4 The various sections of Lake Joondalup referred to in the literature (Kinnear *et al.* 1997).

Table 2.1 Indication of limitations for all data used within the literature review.

Source	Date of Study	Description	Limitations
Congdon (1973)	1973	Six sites sampled between February – October.	No samples in the south section of the lake.
Gordon & Finlayson (1981)	1975	Sampling occurred between February 1975 – January 1976. Nine sites were sampled and a bulk sample (3 replicates) was analysed for nutrients.	Although a bulk sample was taken, the samples were from various sections of the lake so were deemed representative.
Congdon (1986)	1978-1980	Extensive study of all the sections of the lake over a two and a half year period. Water quality was sampled as well as some other parameters to determine a nutrient budget.	All data seemed to be representative of the whole area of the lake (north, central and south) with consistent times of sampling.
Davis & Rolls (1987)	1985-1986	Sampled water quality and invertebrates over approximately a 12 month period.	Only two sites that were supposed to represent the lake though both were near the shore. Concentrations were approximated by reading off the graphs provided in the publication.
Davis, Rolls & Wrigley (1991)	1987	One sampling occasion in early December 1987, sampled water quality, sediment and invertebrates.	Not sure where the samples were taken from and how many sites were sampled.
Anon. (n.d.)	1989	Loose sheets of information	Unknown where the samples were taken from and the methods used to determine the recorded concentrations.
Kinnear *et al.* (1997)	1992-1993	Sampled water quality for 15 months, with sampling occurring on a fortnightly basis.	On some occasions only one sample was taken to be representative of the section of the lake and sometimes the standard error associated with the average of these samples was greater than the mean.
Lund, Brown and Lee (2000)	1999	Sampled between 21/7/99 – 10/9/99 on grid covering the main section of the lake. Nutrient total and soluble forms were analysed.	Only one sampling occasion, although due to the expanse of the grid was considered a representative study.
Lund (2002 unpublished)	2000	Sampling occurred monthly in the central lake section with samples analysed for all nutrients.	Only one sample taken in the centre of the lake so unlikely to be representative.
Lamb (2001)	2001	Sampled three sites weekly for total phosphorus and fortnightly for nitrogen. Two sites in northern section and one in central. Measured between 5 April - 13 September 2001.	All sites were on the shoreline so may not be very representative. Values estimated from a graph within the publication.
Lund (2002 unpublished)	2002	Sampling occurred monthly in the central lake section with samples analysed for all nutrients.	Only one sample taken in the centre of the lake and is assumed to represent the whole lake.

Classification of the data was used to examine differences between north, central and south sections of the lake. This was important, as there were some studies where samples were taken from an unidentified section in the main lake. For the classification only data pertinent to all three sections of the lake could be used and this only occurred between 1978-1980 and 1992-1993. Initially a correlation (Pearson's Product Momentum) was undertaken between each section for both total phosphorus and total nitrogen. Obvious outliers were removed. The PRIMER software package was used to determine if there were significant differences between sections. ANOVA could not be used due to the cyclic nature of the data, with variation not being random but rather due to season. Trend analysis would have been more appropriate however, there was insufficient data for this. PRIMER was used to determine Euclidean distances between the sections for the times available. This data was used to determine UPGMA classifications of the sections and years. Data was reduced to monthly means for each section analysed.

2.3 Sampling

2.3.1 Stormwater

Stormwater can enter Lake Joondalup directly through an outfall pipe (Figure 2.5) or indirectly from a pipe or bubble up grate (Figure 2.6) where the water runs (20–30m) over lawn before entering the lake. This research focused on those pipes and bubble up grates that were believed to contribute water to the lake (Figure 2.7). There are other discharge points surrounding Lake Joondalup but they are unlikely to impact the lake unless the soil is sufficiently saturated to allow runoff and this did not occur during the sampling period. Various other stormwater drainage points (sumps particularly) could potentially have an impact on the lake through groundwater once the contaminants have leached through the soil, though they were not considered. Outfall 7 could discharge directly into the lake (Ove Arup & Partners 1994), however no sampling was undertaken at the outlet as it could not be located by the author or the drainage maintenance officers at the City of Wanneroo.

Figure 2.5 Outfall 5 directly discharging into Lake Joondalup via a channel (Photo source: author).

Figure 2.6 Bubble up grate 2 showing indirect inputs to Lake Joondalup (Photo source: author).

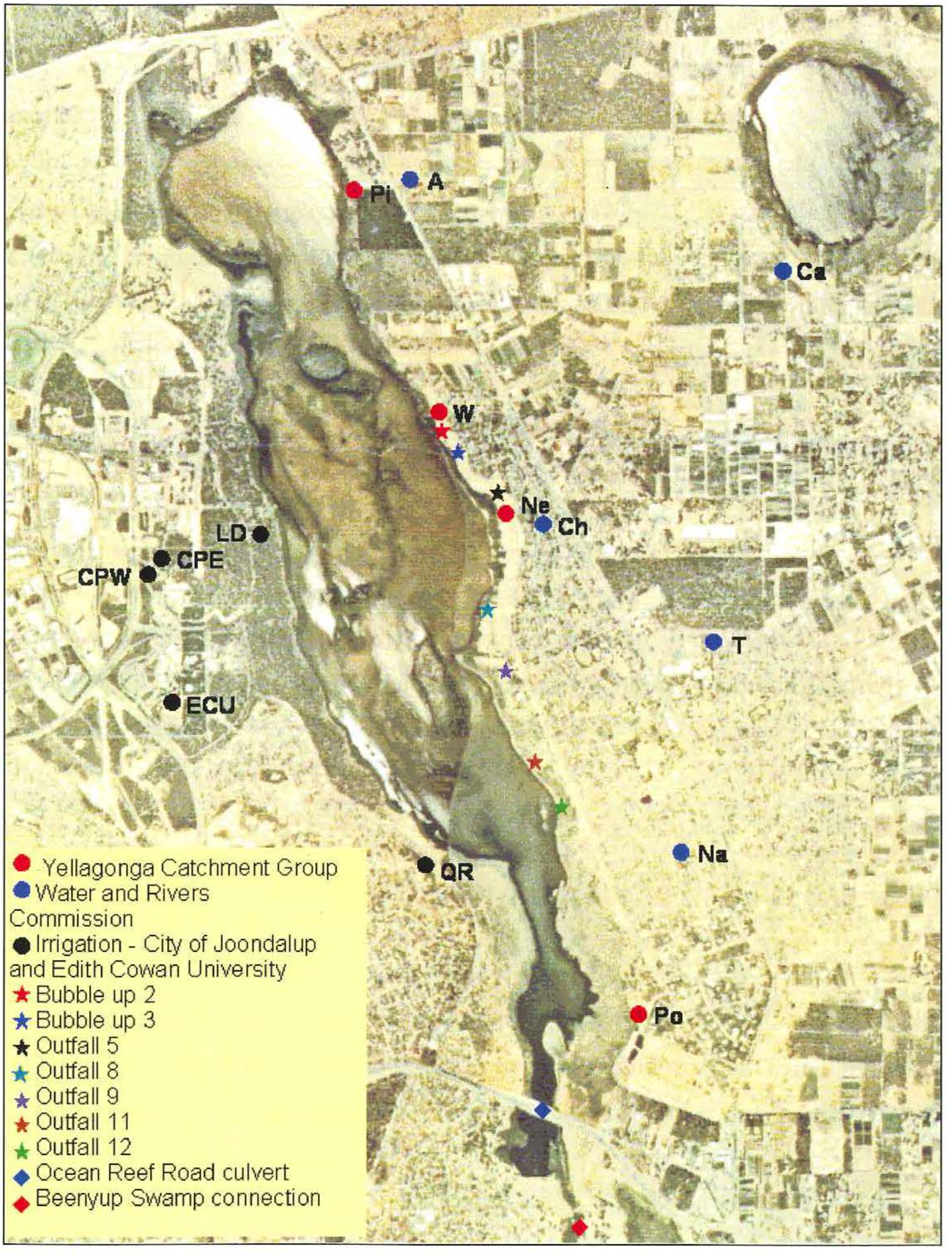


Figure 2.7 Location of all the sampling sites at Lake Joondalup throughout this study (Kinnear *et al.* 1997).

No research attempts have been able to sample stormwater when the first flush has occurred at Lake Joondalup. This study captured the whole of the first storm event at outfall 9 on 7/5/04. Outfall 9 was chosen as it is a largely residential catchment containing two primary schools, whilst also having the largest impervious area

(65 120 m^2) of all the drains since it was combined to also accommodate the flow from outfall 10 (Ove Arup & Partners 1994). Samples (detailed in 2.3.4) were taken between 2-15 minute intervals during the storm event, in response to changes in the hydrograph, to determine the fluxes of nutrients that occurred during the storm. Samples were also undertaken from outfall 9 on 11/5/04, 6/6/04 and 26/8/04, and it was sampled intensely again on 27/8/04 to determine the significance of the first flush compared to the other stormwater contributions throughout the winter months. Samples were taken at 5-7 minute intervals on this occasion.

Samples were also collected at outfalls 5 and 8 on 21/5/04 and 5/8/04 respectively. Samples were taken according to changes in flow at approximately 5-13 minutes intervals. A few samples were taken from outfall 11 on 25/8/04 whilst single samples were collected from outfall 12 (this is a constructed wetland) on 5/7/04 and bubble up grates 2 and 3 on 6/6/04. For the latter four outfalls the sampling was not intense nevertheless it still provided some information pertaining to contributions of nutrients.

When samples were collected from the outfalls, the pipe diameter was noted and the water depth was simultaneously recorded to allow the approximation of stormwater volumes exiting the pipe, using the Manning equation (Table 2.2). This would also be used to determine a runoff coefficient that could be utilised to predict water volumes from other catchments, like the bubble up grates where volume is difficult to quantify as there is no way to reach the pipe without vandalising the grate. Unfortunately, due to the physical structure of the outfalls the determined rates of flow and volumes could not be used, as backflow was an issue that could not be resolved. The outfalls were within a depression, which allowed water to accumulate within the pipe rather than be expelled from it.

Table 2.2 Description of each catchment influencing Lake Joondalup.

Discharge point	GPS coordinate (WGS 84)	Diameter of pipe (m)	Equivalent impervious area (m^2)
2	S 31° 44.310' E 115° 47.388'	N/A	14,500
3	S 31° 44.436' E 115° 47.463'	N/A	11,700
5	S 31° 44.567' E 115° 47.628	0.45	3,520
8	S 31° 44.903' E 115° 47.597'	Two pipes 0.45 (a) and 0.365 (b)	27,360
9	S 31° 45.163' E 115° 47.704'	0.96	65,120
11	S 31° 45.597' E 115° 47.904'	0.63	36,320
12	S 31° 45.700' E 115° 47.918'	N/A	57,920

Volume measurements, for the outfalls and bubble up grates, were obtained by multiplying the impervious area of each catchment by the rainfall of that day as taken from the Perth Airport (Station 9021) from the Bureau of Meteorology. Impervious areas were obtained from Ove Arup and Partners (1994), these values corresponded with another more recent study by BSD Consultants (2003), and were already corrected by a runoff coefficient. Impervious area for both of these studies included the road and its associated road reserve, assuming that runoff from private properties was dealt with on site. Outfall 12 has been upgraded to a constructed wetland since the Ove Arup study. JDA Consultant Hydrologists (2003) have estimated the flow from outfall 12, identifying a base flow due to the interception of the groundwater. This flow is suggested to occur for the majority of the year varying between 2-5 L/s. Based on this a 3 L/s base flow was assumed for the sample period in addition to stormwater. The nutrient concentrations of the base flow were taken to be the same as that of the stormwater. This could underestimate the contribution from this outfall as groundwater is known to have higher nutrient concentrations.

Nutrient concentrations of the samples were used in conjunction with the volume data to determine the loads of total phosphorus and nitrogen entering the lake via stormwater. Some of the nutrient data had to be removed due to the impact of backflow, as the architecture of the discharge points allowed the pooling of water within the pipe. At the point of increasing nutrient concentrations, associated with this pooling and backflow, the data were discarded. The remaining nutrient concentrations were reduced to a single value for each day, whether they were averages of numerous samples from that day or the only sample from that day. From 7 May to 5 August, the average nutrient concentrations of the two consecutive sampling days were applied to the time period between these samples. For sampling from 25 August to 27 August the individual daily average concentrations were used.

2.3.2 Groundwater

Lake Joondalup is a flow-through lake, with groundwater recharging and discharging water to the lake (Townley, Turner, Barr, Trefry, Wright, Gailitis, Harris & Johnston 1993). Bores were monitored to estimate the contribution of nutrients into the lake and the loss of nutrients from the lake through groundwater movement (Table 2.3). Sampling and monitoring of each bore occurred on a monthly basis commencing on 31/5/04 and finishing on 26/8/04. Monthly investigations occurred as the flow rate was not considered significant enough to warrant more frequent investigation.

Table 2.3: Location of bores and sampling dates, also shows the abbreviations used for each bore in Figure 2.7.

Bore	East or west of Lake Joondalup	GPS coordinates (WGS 84)	Sampling dates
Pines (Pi)	East	S 31° 43.538' E 115° 47.059'	31/5/04, 28/6/04, 26/7/04, 22/8/04
Wallawa (W)	East	S 31° 44.224' E 115° 47.336'	
Neville (Ne)	East	S 31° 44.635' E 115° 47.628'	
Poinciana (Po)	East	S 31° 46.285' E 115° 48.142'	
Ashley (A)	East	S 31° 43.508' E 115° 47.284'	28/6/04, 26/7/04, 22/8/04
Capom (Ca)	East	S 31° 44.016' E 115° 48.655'	
Christie Crt (Ch)	East	S 31° 44.675' E 115° 47.749'	
Togno Park (T)	East	S 31° 45.052' E 115° 48.454'	
Nannatee (Na)	East	S 31° 45.736' E 115° 48.304'	
Edith Cowan University (ECU)	West	S 31° 45.215' E 115° 46.342'	1/7/04, 29/7/04, 24/8/04
Quarry Ramble (QR)	West	S 31° 45.791' E 115° 47.349'	2/7/05, 5/8/04, 24/8/04
Central Park West (CPW)	West	S 31° 44.805' E 115° 46.222'	
Central Park East (CPE)	West	S 31° 44.737' E 115° 46.321'	
Lakeside Drive (LD)	West	S 31° 44.679' E 115° 46.607'	

Nine bores were monitored east of the lake and five west of the lake (Figure 2.7). Five of the bores on the east were owned by the Water and Rivers Commission and the remainder were owned by the Yellagonga Catchment Group. The water level was recorded at each Water and Rivers Commission bore using an electronic tape gauge, as in some cases the bore depth was quite large, whereas at the Yellagonga bores a fox whistle on the end of tape measure was used. Comparison between these methods produced <100mm difference. Water samples for nutrient analysis were collected from the Yellagonga Catchment Group bores. The height of the water table measurement was used to determine the quantity of water to be purged (using 250 mL disposable bailers cleaned with phosphorus-free detergent) before a sample could be taken. These bores were directly adjacent to the lake and, therefore, it could be stated confidently that the sampled groundwater would be entering the lake.

Water samples were also collected from irrigation bores on the west of the lake. Samples were taken after the bores had been running for a couple of minutes, which was deemed appropriate purging considering the volumes of water that were pumped out during this time. However, these bores are located some distance from the lake and the concentrations may not be an accurate reflection of what was exiting the lake. The bores located west of the lake were owned by the City of Joondalup or Edith Cowan University. The water level could not be measured at these bores. Therefore the static water level was used as the water table height and this was assumed not to change throughout the year even though it was likely to change through the seasons. It should also be noted that the depth at which a groundwater sample was taken from the western bores was different to the eastern bores and this could impact the water quality of the samples.

The rate of groundwater flow east and west of the lake was determined using Darcy's equation, where velocity (m/day) is equal to the saturated hydraulic conductivity (m/day) multiplied by the hydraulic gradient (Davidson 1995). The hydraulic gradient was determined by dividing the difference in water table elevation between two points by the horizontal distance between these points. All of these measurements are made in the direction of flow, which is approximately west southwest for Lake Joondalup.

By pairing the individual bores on either side of the lake with the lake surface in a west southwest direction the hydraulic gradient could be calculated. The static water level or measured water level heights were used for the bores and interpolated surface water heights were used for the lake on those days that did not correspond with the sampling times of bores. Distance between the bores and the lake was determined using the Perth Street Directory (Universal Press Pty Ltd 2002). The hydraulic gradient was then multiplied by the hydraulic conductivity to determine velocity of flow.

Two different hydraulic conductivities were applied to calculate the flow. A value of 13.33 m/day was determined using Davidson's (1995) formula for calculating this based on a transmissivity of 600 and saturated aquifer thickness of 45 m. The second value was obtained from Townley *et al.* (1993), which had a range of hydraulic conductivities based on core samples of the lake lining of Lake Joondalup taken from three sites, the figure of 0.05 m/day was used as it was considered the most relevant figure within the range of those recorded. Both figures were utilised because the low conductivity of the lake at the three sampled sites from Townley *et al.* (1993) did not necessarily represent what occurred over the rest of the lake surface. In conjunction with these figures and the hydraulic gradient, flow rates could be compared between bores surrounding Lake Joondalup.

The Yellagonga Catchment Group, City of Joondalup and Edith Cowan University bores were used to approximate lake flow volumes and nutrient loads, as water samples were collected from these sites. Volumes were determined by multiplying velocity (m/day) by the aquifer thickness and width. The individual velocities for each bore, as calculated in the previous section, were averaged for the two end bores to obtain a value for that segment. The velocities at those bores closest to the ends of the lake were applied to the areas north and south, thus assuming the same flow. Aquifer width was simply deemed to be the distance between two points and this was calculated based on the GPS coordinates of the bores. Distances north and south of the end bores were estimated using the Perth Street Directory (Universal Press Pty Ltd 2002). Townley (pers. comm., Townley and Associates Pty Ltd) suggested that 200 m be added to the ends of the lake as the top and bottom also draws in water, not just the sides.

Aquifer thickness was somewhat more complicated to determine than aquifer width. According to Townley *et al.* (1993) there are two types of lakes, namely short or long. The type of lake influences the depth of the aquifer (aquifer thickness) from which they draw water (capture zone). To determine the capture zone, the lake length

(length of lake in terms of the groundwater flow direction) was divided by the thickness of the aquifer which is 45 m surrounding Lake Joondalup, and if this value was greater than or equal to four then it was considered a long lake and its capture zone expands the whole width of the aquifer. Based on this Lake Joondalup was considered a long lake and consequentially can be assumed to draw water from the whole 45 m.

There are other variables that impact the capture zone including the anisotropy ratio and hydraulic conductivity of the lake lining (Townley *et al.* 1993). Cores of Lake Joondalup's sediment were found to be quite low with regards to conductivity of the lake lining, which could reduce the capture zone though these influences are complex and may not necessarily change the capture zone (Townley *et al.* 1993). There may also be a confounding layer that restricts groundwater flow to the lake, like clay or peat, although preliminary data for peat suggested that this may not be a major factor for Lake Joondalup. An aquifer thickness of 45m was therefore still deemed appropriate to use to determine flows.

A second value for aquifer thickness was also used as comparison. Denitrification is known to occur in groundwater systems of the Swan Coastal Plain and it was suggested that using an aquifer thickness of 45m would likely overestimate the volume of water contributed by groundwater and the nutrient loads, as nutrients are known to occur predominantly in the top 5m of an aquifer (pers comm., Dr Wen Yu, Department of Environment). Thus a comparative aquifer depth of 5m was used in calculations.

To determine the loads of nutrients contributed by groundwater, only the volumes obtained using the 5 m aquifer thickness were used, although both hydraulic conductivities were used. On the east side of Lake Joondalup, the nutrient concentrations recorded at Pines bore were applied for the distance north of the lake, and Poinciana bore concentrations were applied south. The segments in between were an average of the concentrations of the two bores at each end. For the western side of the lake, the concentration of the Lakeside Drive bore was applied north and Quarry Ramble bore was applied south. For the segments in between, the averages of

Quarry Ramble and ECU, and ECU and Lakeside Drive were used. Each sample within the month was applied to the whole month. For the western bores, samples on the 1/7/04 and 2/7/04 were assumed to be for June, samples on 29/7/04 and 5/8/04 were assumed to be for July and samples on 24/8/04 were assumed to be for August.

2.3.3 Surface water inflow

Surface flow into Lake Joondalup occurs from Beenyup Swamp into the southern section of the lake, and then from the southern section under Ocean Reef Road into the main portion of the lake (Figure 2.8). Sampling at the connection between Beenyup Swamp and south Lake Joondalup (Figure 2.9a and b) commenced 24/5/04 and continued every fortnight until 30/8/04, however this connection was established prior to 24/5/04.

Figure 2.8 Ocean Reef Road culvert site showing the narrow channel that flow occurs through (Photo source: author).

Figure 2.9 Beenyup Swamp site showing **a)** where samples were taken and **b)** the associated objects reducing flow on the outer edges of the channel (Photo source: author).

Samples were taken approximately 50 mm below the surface, which was considered to be representative as stratification was not believed to occur (Upton 1996). The water depth and flow were also measured on each sampling occasion. Flow was measured using an orange and the float method outlined by Gore (1996), as flow was too low to use the available flow meter. The time it took for an orange to flow down stream 1 or 1.5m (depending on the date) was recorded with a stopwatch. The majority of the flow occurred over a cross-section of six metres, this length was divided into two where the depth and flow was recorded in both of these sections and then an average was obtained. For the first two sampling events, only one flow amount was measured. Flow occurring in the 3 m either side of the main channel was considered insignificant due to the shallowness and disruptions of flow caused by dumping of materials. The cross sectional area of flow was obtained by multiplying the depth by the area for the two sections and then summing them.

The flow quantity and quality was also determined for the water flowing from south Lake Joondalup to north Lake Joondalup beneath Ocean Reef Road. Flow started just before 7/6/04 and the water was sampled fortnightly until 30/8/04. Samples were taken approximately 50mm below the surface, and depth was recorded to determine the cross sectional area of flow. Flow was measured using a flow meter (Model C.M.C. 20 Current Meter Counter, Hydrological Services P/L Sydney Australia) at ⅔ the depth of the water column (Martinick McNulty Pty Ltd 1998b). The flow occurred through a constructed culvert therefore the cross section was easy to determine.

The load of nutrients contributed by both of these inflows was determined by multiplying the flow rate by the appropriate time period and nutrient concentrations.

2.3.4 Sampling and nutrient analysis

On every sampling occasion 500 mL of sample was collected in acid-washed containers as specified by the American Public Health Association (1998). The samples were placed on ice until returned to the laboratory where 250 mL of sample was filtered through 0.47 μm glass fibre filter papers (Grade 453, Filtech) for analysis of filterable reactive phosphorus, nitrate/nitrite and ammonium. The other 250 mL was kept for analysis of total nitrogen and phosphorus. Samples were stored in a freezer (-20°C) until analysis.

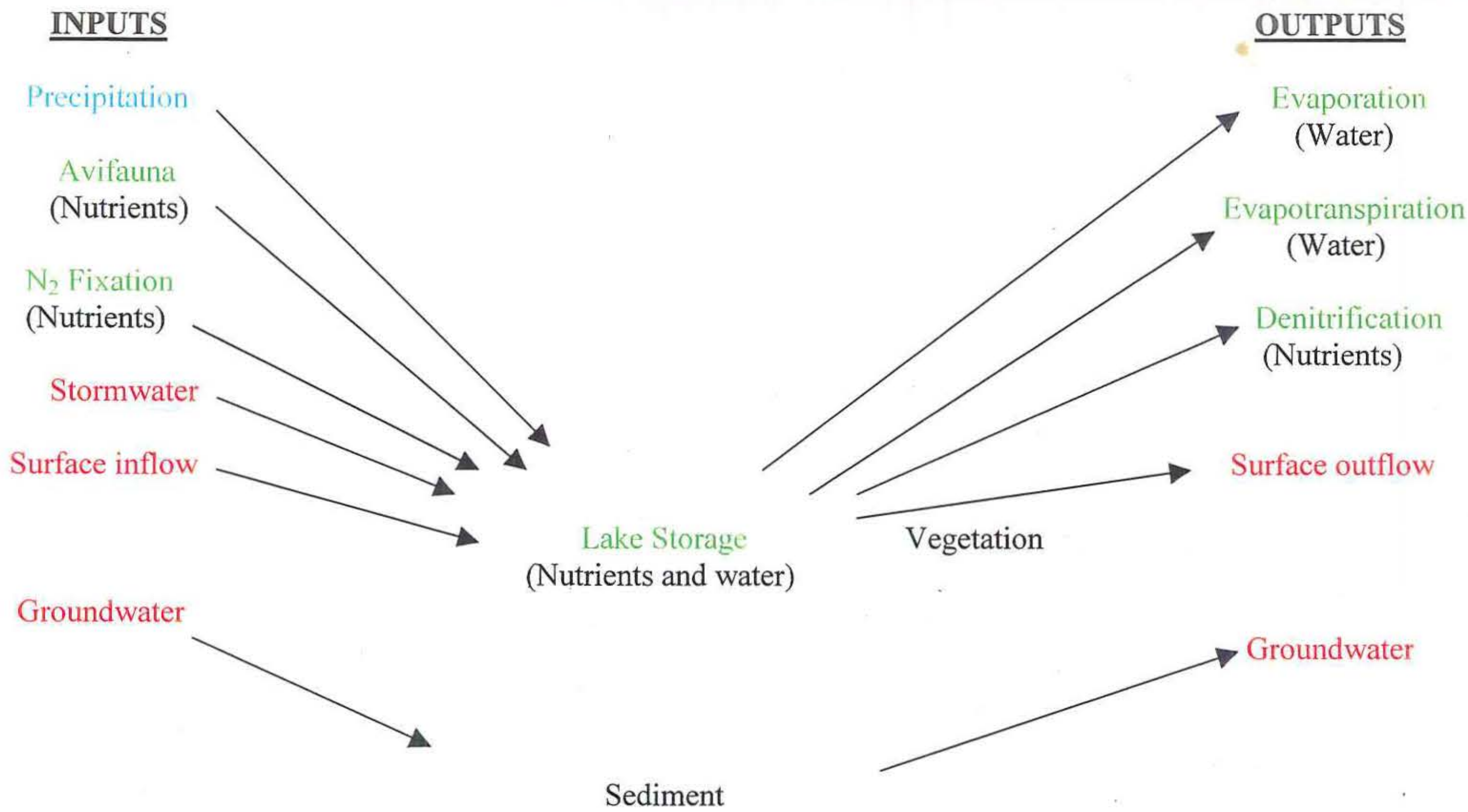
Various physico-chemical parameters were recorded during the sampling period, namely temperature, pH, dissolved oxygen and conductivity, using a multimeter. At the Beenyup Swamp connection and Ocean Reef Road culvert these physico-chemical measurements were taken *in situ*, approximately 5 cm below the water surface. Measurement of groundwater samples and stormwater samples were not taken *in situ* due to risk of damaging equipment, therefore measurements were taken in sample containers.

All samples were analysed on a Skalar autoanalyser. Total phosphorus and nitrogen were analysed following potassium persulfate digestion, and dissolved nutrients were analysed using methods from American Public Health Association (1998) as modified for the Skalar Autoanalyser (Skalar analytical, Manual San Plus Analyser, S.F.A.S.).

2.4 Nutrient budget

Congdon (1979; 1985; 1986) developed a water and nutrient budget for Lake Joondalup. Condgon (1986) determined the major contributor of phosphorus to be surface flow from Beenyup Swamp, whilst the major contributor of nitrogen was atmospheric fallout. However, several factors likely to impact on the budget have changed since this time particularly the stormwater contribution. A number of variables such as transpiration by aquatic plants, waterbird contributions, and accurate groundwater measurements were not measured in the previous budgets by Congdon (1985; 1986).

Through the sampling conducted specifically on stormwater, surface flow and groundwater the budgets Congdon developed were revisited. The parameters included are shown in Figure 2.10. Intensive sampling was conducted between May and August 2004, therefore the budget spanned twelve months from September 2003 – August 2004. Both this study and that by Congdon do not address the cycling of nutrients between the sediment and the water column.



LEGEND

Adequate information obtained from the literature

Information available but it will be re-sampled for verification of accuracy

Inadequate information

Not calculated in this study

NB: Water and nutrient contributions were determined for all the parameters, unless specified otherwise.

Figure 2.10 Conceptual model of the various inputs and outputs of water and nutrients for Lake Joondalup.

2.4.1 Lake water storages

The volume of water in Lake Joondalup was estimated by creating a hypsographic curve (Kalff 2002; Richard n. d.). Using the lake's bathymetric map (Hamann 1992) and assuming no significant changes in the lake's morphology have occurred over the years, an estimation of the surface area occupied by each depth contour produced a graph for the main and southern sections, which was then used to calculate the separate volumes of water at various depths. The surface area was determined using the square grid method whereby the number of whole squares occupied by a contour were counted and converted to the actual area (Kalff 2002; Richard n. d.). For those squares that were not fully covered there were two options, either count all the part squares and divide them by two or only count those squares that were greater than half within the contour. Both of these methods were adopted and the average of the two was used so the area was not overestimated or underestimated (Richard n. d.).

Upon graphing the depth contours against the respective surface areas, a curve was created for the main and south sections. The grid method was used to determine the area between this curve and the respective axis, for each monthly depth (based on staff gauge No. 8281 heights obtained from the Water and Rivers Commission) and approximate volume. Volumes were calculated separately for the main section and southern section of Lake Joondalup, these values were then summed to give a total for the budget.

Data obtained from Kinnear *et al.* (1997) were used to estimate the nutrients within the water column of the lake. Whilst the study was conducted almost a decade ago and the data had inadequacies (limited number of samples taken and large standard errors) it is the most recent study that provides a thorough understanding of nutrient concentrations over a year (January – December 1992) for the relevant sections of the lake. However, in comparison to Lund (2002 data unpublished) sampling in July and August 2002 total phosphorus concentration for this and Kinnear *et al.* (1997) are 70.04 ug/L and 60.90 µg/L and 222.38 µg/L and 116.00 µg/L respectively. Total nitrogen was 3 285.71 µg/L and 4 000 µg/L for Lund (2002 data unpublished) and

1 370 μg/L and 1 400 μg/L for Kinnear (1997). These differences were highlighted to show the water quality changes that had occurred in five years and the need for further extensive sampling of the lake. Although these differences could be due to differences in climate and water volumes and natural seasonal changes. Kinnear *et al.* (1997) partitioned Lake Joondalup into northern, central and southern sections, thus the nutrient concentrations for the main lake were an average of the original northern and central values.

Whilst there was no significant difference between evaporation rates in 1992 and 2003-2004 that could affect nutrient concentrations by evapo-concentration, there was a significant difference between the staff gauge heights between the two study periods. The 17.5 mAHD level was reached during 1992 and this may also impact the concentration of nutrients as there would have been a surface outflow from the lake. Nutrient concentrations were converted to reflect the reduced volumes of water. Volumes for each month were extrapolated from those volumes determined for the September 2003-August 2004 period, using the gradient of the last three points on the volume curve. Nutrient loads were calculated for the two different sections of the lake for each month and then summed for the purpose of the yearly budget.

2.4.2 Precipitation

Congdon (1985) determined that variations in rainfall data obtained from Edgewater, Wanneroo and Perth were not significant. This study used t-tests, specifically paired two sample for means in Excel data analysis, to compare rainfall measurements for September 2003-August 2004 from Wanneroo (Station 9105) and Perth Airport (Station 9021) and again the differences were not significant ($p > 0.05$). Therefore, the precipitation data was obtained from the Bureau of Meteorology for Perth Airport. This coincided with the use of evaporation data from this station and it was considered more accurate than the Wanneroo station more regular measurements of rainfall were recorded.

To determine the volume of rainfall entering Lake Joondalup throughout the extrapolated year, from September 2003-August 2004, the total rainfall for each month was multiplied by the surface area of the lake. The total area of the lake receiving rainfall was determined using the square grid methods (outlined in section 2.8.4) with the receiving area assumed to be the outer contour of 17.67 mAHD based on the bathymetric map obtained from Hamann (1992). A scale was also used to weigh the whole area of the lake. In conjunction with a known area and weight of paper, the surface area could be calculated (Kalff 2002; Richard n. d.). All measurements were averaged to give an approximation of the surface area.

Once the volume of rainfall entering the lake was determined the nutrient loads were calculated. The quantity of nutrients in the rainfall and the contribution from this source was sampled. Samples were collected in 30 cm x 24 cm x 12.5 cm containers that had been acid-washed and placed in an open area, samples being collected within 12 hours of the rainfall. Sampling and nutrient analysis occurred as in section 2.3.4. Table 2.4 outlines the days rainfall was collected and the number of containers used to collect the rainfall. The individual containers were averaged to obtain nutrient concentrations for that day or month. All of the values were then averaged to obtain an approximate value of the nutrient concentrations in rainfall all year round. The nutrient concentrations were then multiplied by the volume of receiving water to determine the nutrient loads from rainfall.

Table 2.4 Sampling days for rainfall and the number of containers used to collect the rain.

Date	No. of containers used
10/6	4
7/7	4
1/8	2
5/8	1
11/8	1
27/8	1

2.4.3 Evapotranspiration

Evapotranspiration incorporates losses of water from the lake surface and that transpired by vegetation. Evaporation values were obtained for Perth Airport (Station 9021) from the Bureau of Meteorology as this is the only station that records evaporation. The monthly values were corrected using the Black and Rosher (1980, cited in Congdon, 1985) pan correction factor to approximate evaporation from the lake surface. The Black and Rosher correction factors were created for the Peel-Harvey Estuary, however it was used because it incorporates a large shallow area and is close to the coast experiencing a similar effect from salt as Lake Joondalup would experience (Congdon 1985). The corrected evaporation values were multiplied by the area of open water, which was determined by subtracting the associated monthly total surface area of the main and south sections (based on hypsographic curves) minus the area of swamp vegetation. Staff gauge heights for September and October 2003 were averages of two values, all other months were only one value. The water level was assumed to be the same between the main and south sections, although this may not have been the case.

Transpiration was not considered by Congdon (1985) when he constructed his water balance. The surface area of *Typha* vegetation, calculated as for the surface area of the lake in section 2.4.1, was multiplied by a coefficient of evapotranspiration by vegetation to evaporation from the open water. The coefficient values for *Typha latifolia* were obtained from Wetzel (2001) and these ranged from 1.41-12.5 but these values were from temperate areas and fens rather than the hot dry climate that Perth experiences, therefore the coefficient was increased to 8 and transpiration was assumed to occur all year round. *Typha latifolia,* is considered morphologically closer to *Typha orientalis* than *Typha domingensis,* as they have a more similar leaf type and would thus have a similar transpiration rate (Sainty & Jacobs 2003). However, there are many factors that affect transpiration rates, not just the plant species but also the site specific factors like soil properties and vegetation density (Lott, Hunt & Randall 2001).

2.4.4 Nitrogen fixation

Nitrogen fixation at Lake Joondalup is known to occur from cyanobacteria in the water column, the sediment, from the rhizosphere and legume nodules in plants as determined by Finlayson & McComb (1978). Of these, fixation by *Anabaena* in the water column was the greatest contributor. Nitrogen fixation was not re-estimated, as it is quite difficult to measure accurately and was deemed insignificant by Congdon (1979), however the estimated value for the year will be included in this updated budget. As such, the value obtained by Congdon (1979) assumed that nitrogen fixation occurred over half the day (12 hours) and the blooms occurred for three months of the year over the whole volume of the lake. This is expected to give an overestimation of the contribution.

2.4.5 Denitrification

Congdon (1979) considered denitrification to be an important loss of nitrogen for Lake Joondalup, however it was beyond the scope of this study to quantify it accurately. Thus, the value estimated by Congdon (1979) was used, even though it is based on Danish lakes where denitrification values were obtained as the residual factor of a nutrient budget and does not account for the seasonal differences that would occur at Lake Joondalup due to the different climate.

2.4.6 Waterbirds

The contribution of nutrients by avifauna was estimated using the same rate used by Congdon (1979) in his studies, and the most recent information of waterbird abundance from Kinnear *et al.* (1997). This rate was developed by Wood (1975) and approximated for a wild duck which produces 0.48 kg N/yr and 0.09 kg P/yr. These figures were divided to give a monthly rate, under the belief that waterbirds contribute even amounts throughout the year. The total number of waterbirds for the whole lake occurring each month between September 1991-August 1992 was then multiplied by the monthly rates of 0.04 kg for nitrogen and 0.0075 kg for phosphorus and these were then summed to give an estimated contribution from waterbirds during this study. This method also assumes that the number of birds at Lake Joondalup has not changed over the last ten years and that the contribution from birds other than waterbirds is not significant.

2.4.7 Surface water outflow

There is a channel to a cave system that allows outflow of water from Lake Joondalup (Hamann 1992; Ove Arup & Partners 1994). In order for this channel to flow, the surface water level of the lake has to exceed 17.5 mAHD. This did not occur during the study period hence surface outflow was not considered in the budget.

2.4.8 Stormwater

Nutrient loads for stormwater from September 2003-August 2004 were estimated based on the nutrient concentrations recorded during the study period. The volume of stormwater entering Lake Joondalup was determined as in section 2.3.1., where the total monthly rainfall was multiplied by the catchment areas of those outfalls entering directly into the lake. The 3 L/s base flow from outfall 12 was also incorporated into the flow of every month, though due to the interception of groundwater it is unlikely that nutrient concentrations are accurate. The average nutrient concentration recorded on 7/5/04 was applied to stormwater discharges between 1 January to April 31, whilst an average of the concentrations recorded in August were applied from 1 September to December 31. This was based on no rainfall being recorded in January so it was assumed that the previous months would still have low concentrations whilst those after would have more. For the months between May-August, the average of the average or individual nutrient concentrations within these months were applied for the whole month.

2.4.9 Groundwater

Due to the complexity of groundwater flow and the fact that the seasonality was not determined during the sampling regime for this study, the volume contributions were estimated as the residual of the inputs and outputs in relation to the lake's surface water storage. Total nutrient loads were not estimated due to large inaccuracies associated with the residual method, specifically not knowing the sinks of nutrients in the sediment and vegetation stores.

2.4.10 Surface water inflow

Beenyup Swamp dries out over summer (Kinnear *et al.* 1997; Upton 1996), hence it was assumed that flow from Beenyup occurred from the beginning of May to the end of December, which was similar for Congdon's (1986) study. Nutrient concentrations and flow rates recorded during the sampling in May-August were averaged for each month and these concentrations were applied for the calculation of loads. From September–December the average August concentrations and flow rates were applied and the concentrations and flow rate from 24 May were applied for May. The flow rates were multiplied by the number of days in each month to determine the volume of water.

3 RESULTS

3.1 Long term trends

Using the average concentrations for two extensive studies from 1978-1980 and 1992-1993 a hierarchical group clustering from total nitrogen and total phosphorus data (Figure 3.1) it can be seen that the water chemistry of south Lake Joondalup is different to the north and central sections an therefore the latter sections can legitimately be grouped into a single section.

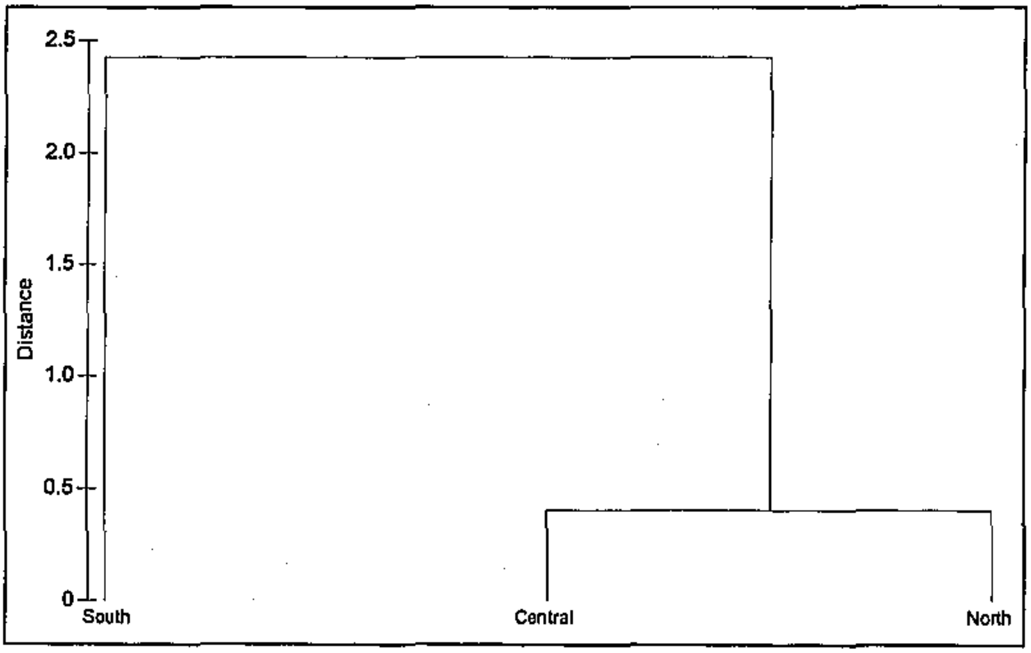


Figure 3.1 Hierarchical agglomerative cluster of sampling sites from complete datasets of total nitrogen and total phosphorus showing the similarity between north, central and south section of Lake Joondalup based on data from extensive studies in these sections during 1978-1980 and 1992-1993. Data log + 1 transformed, Euclidean distance.

This grouping is also supported by the considerably higher correlations for total phosphorus and total nitrogen between the north and central sections (Figure 3.2a and b), compared to the poor correlations for north and south (Figure 3.3a and b) and central and south sections (Figure 3.4a and b).

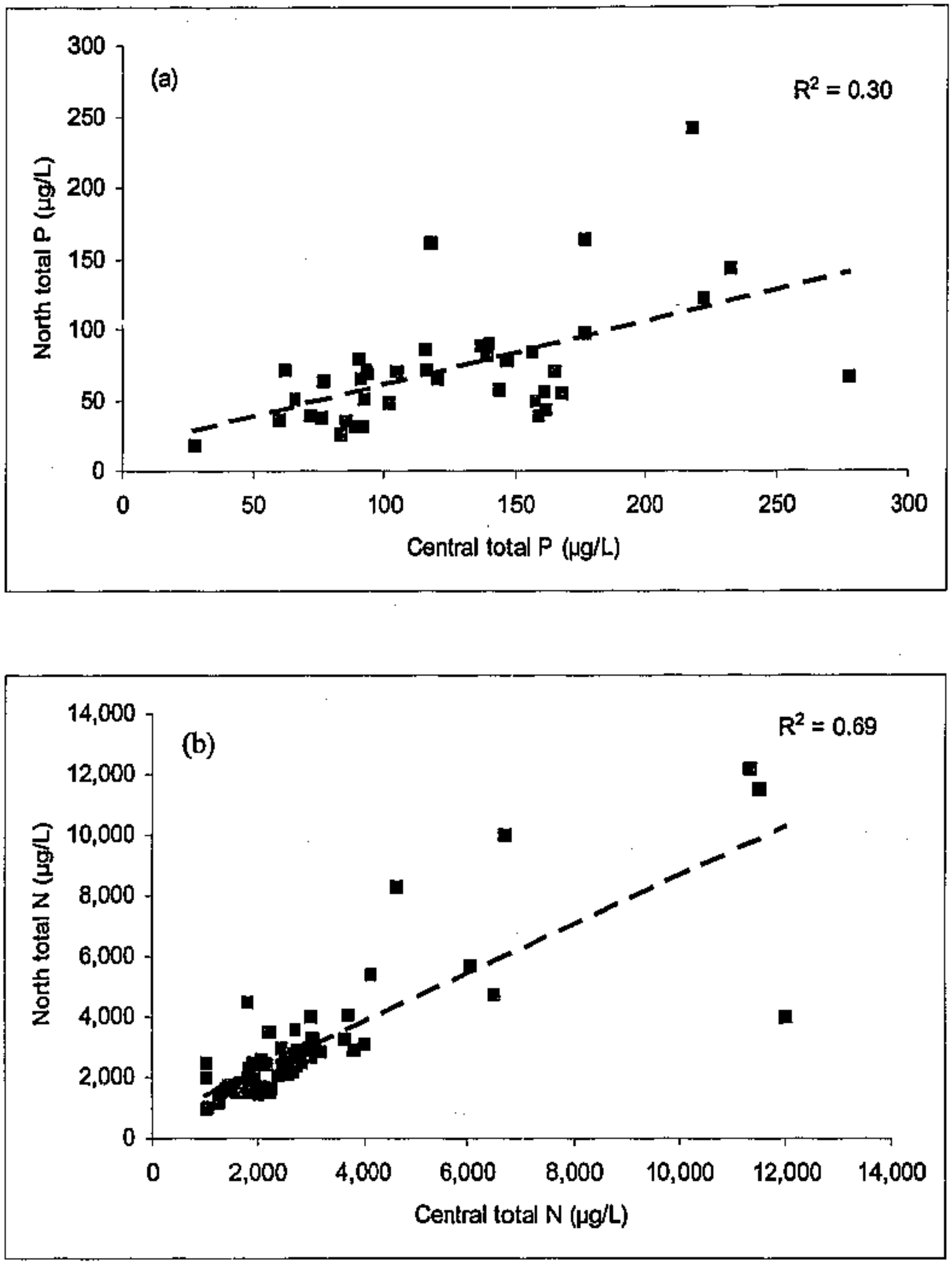


Figure 3.2 Bivariate plot comparing the northern and central sections of Lake Joondalup for a) total phosphorus ($F_{1,67}$ = 62.15, p = 3.90x10^{-11}) and b) total nitrogen ($F_{1,67}$ = 143.99, p = 2.39x10^{-18}) for various months in 1973, 1978-1980, 1985-1986, 1992-1993, 1995 and 2001.

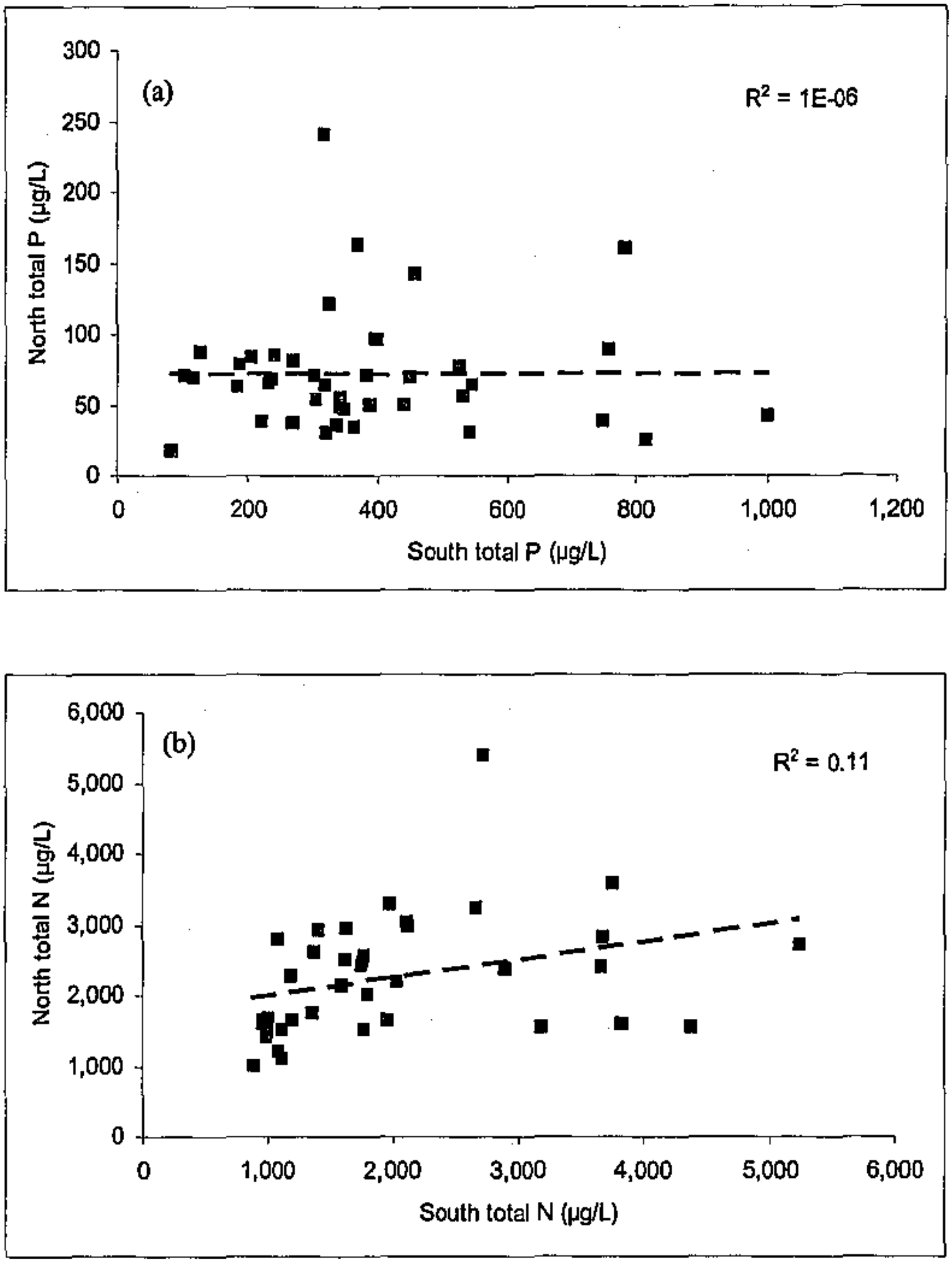


Figure 3.3 Bivariate plot comparing the north and south sections of Lake Joondalup for a) total phosphorus ($F_{1,38} = 5.1 \times 10^{-5}$, $p = 0.99$) and b) total nitrogen ($F_{1,36} = 4.43$, $p = 0.04$) for studies conducted in 1978-1980 and 1992-1993. Total nitrogen excludes two outliers (March and April 1980, north = 12,199.25µg/L and 8,280.25µg/L, south = 5,618.7µg/L and 14,375.13µg/L respectively).

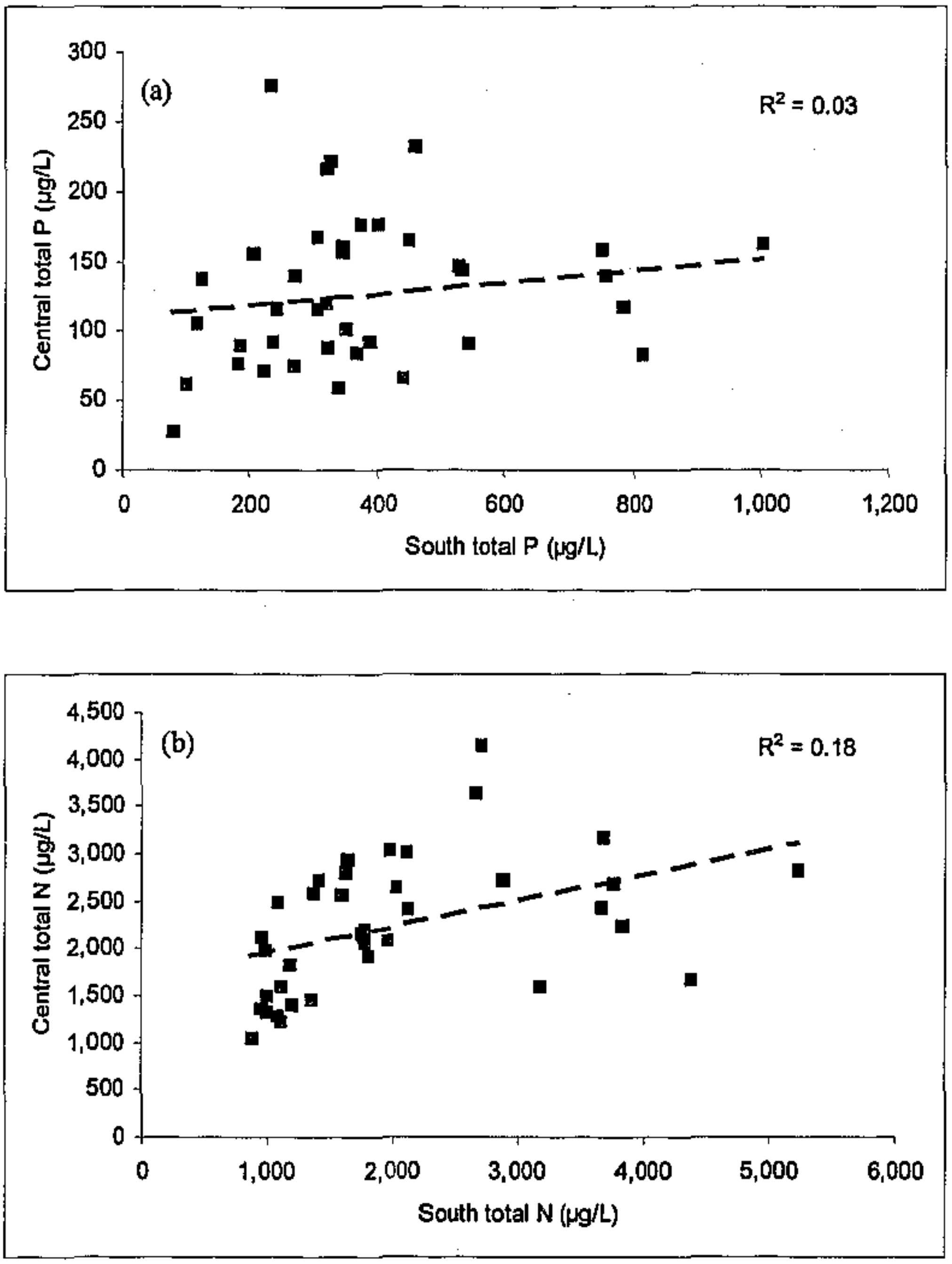


Figure 3.4 Bivariate plot comparing the central and south sections of Lake Joondalup for a) total phosphorus ($F_{1,38}$ = 1.02, p = 0.32) and b) total nitrogen ($F_{1,36}$ = 8.00, p = 0.01) for studies conducted in 1978-1980 and 1992-1993. Total nitrogen excludes two outliers (March and April 1980, central = 11,349.75µg/L and 4,647.88µg/L, south = 5,618.7µg/L and 14,375.13µg/L respectively).

The two extensive studies between 1978-1980 and 1992-1993 were additionally investigated in terms of variations over time (Figure 3.5) indicating that changes have occurred between the two studies, and suggesting changes are occurring relatively quickly with 1978-1979 being more similar than 1992-1993.

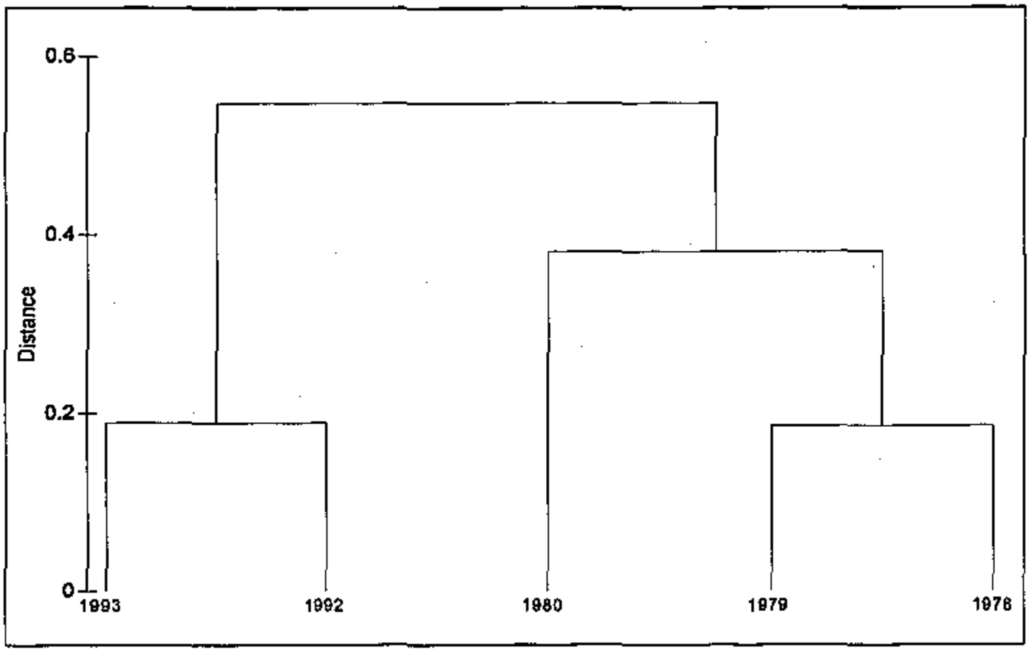
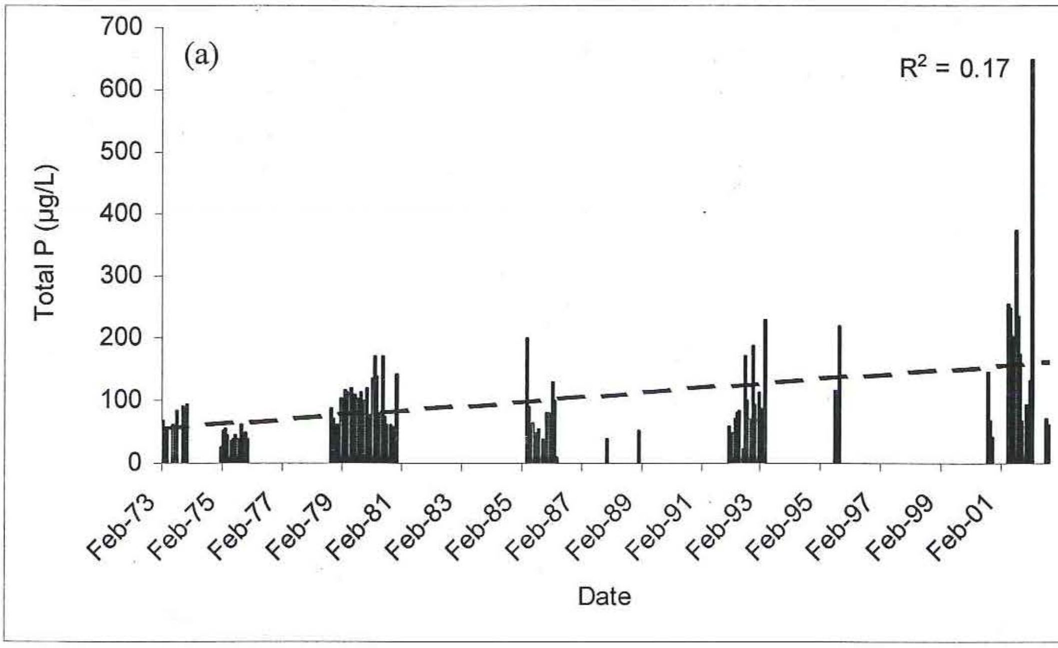


Figure 3.5 Hierarchical agglomerative cluster of sampling years for the main lake from complete datasets of total phosphorus and total nitrogen showing the similarity between the north, central and south sections of Lake Joondalup based on data from extensive studies in these sections during 1978-1980 and 1992-1993. Data log + 1 transformed, Euclidean distance.

Changes in nutrient concentrations over time for the particular sections of Lake Joondalup show that in the main section, nutrients have only slightly increased over approximately 30 years (Figure 3.6a and b). However these changes are considered statistically significant. Concentrations of total phosphorus are more significantly correlated with time than total nitrogen.



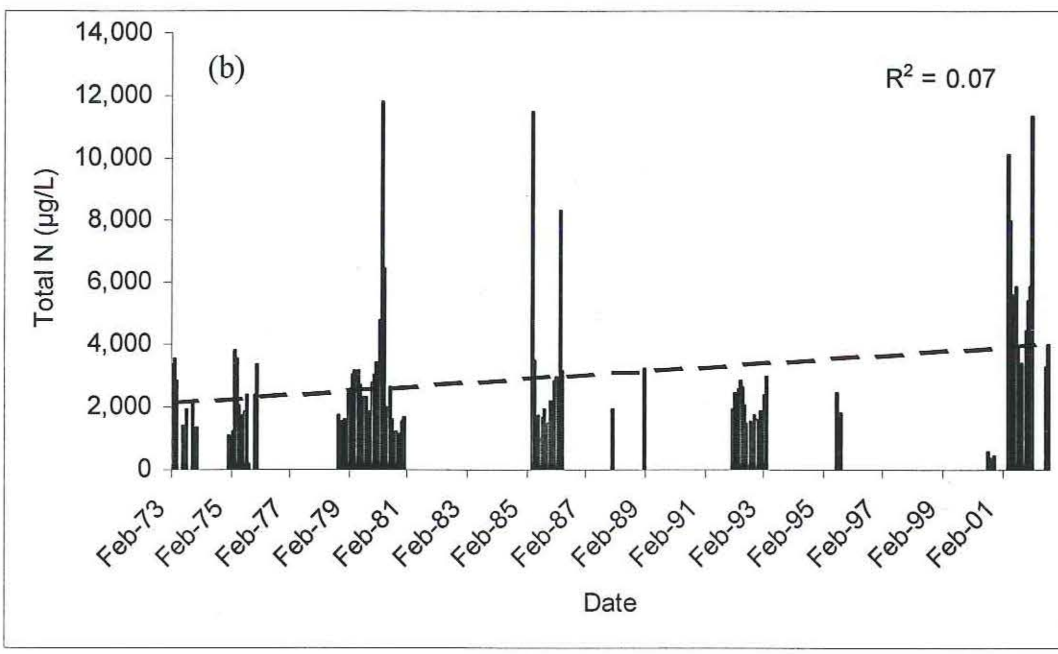


Figure 3.6 Comparison of **a)** average total phosphorus concentrations ($F_{1,93} = 19.52$, $p = 2.69 \times 10^{-5}$) and **b)** average total nitrogen concentrations ($F_{1,93} = 6.60$, $p = 0.01$) in the main section of Lake Joondalup, north of Ocean Reef Road for studies conducted between 1973 and 2001.

In contrast to the main lake, total phosphorus and total nitrogen concentrations have significantly decreased in south Lake Joondalup between the two studies, however again the correlations are weak (Figure 3.7a and b). Though the concentrations have decreased over the time period they are still higher than that occurring in the main section of the lake.

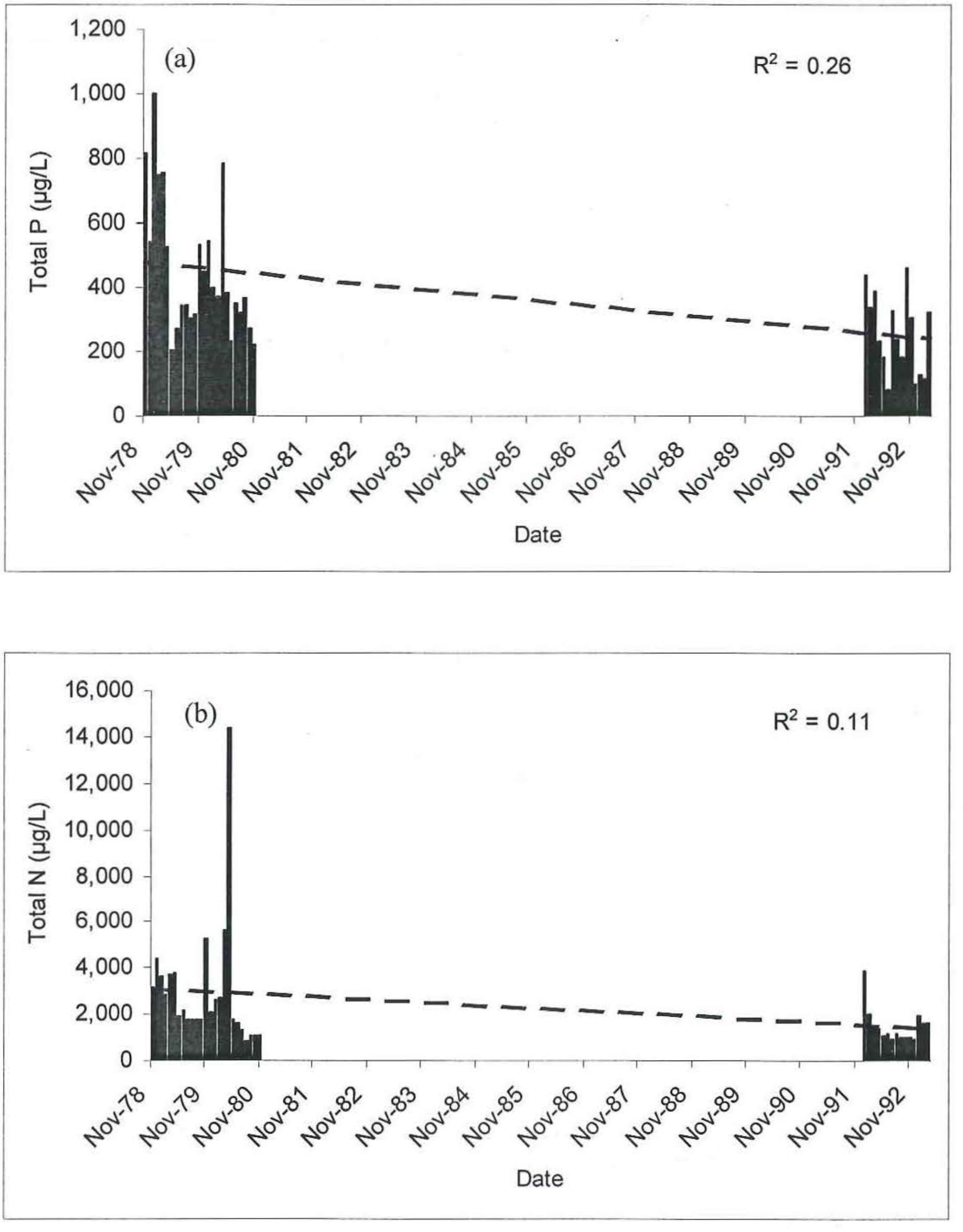


Figure 3.7 Comparison of **a)** average total phosphorus concentrations ($F_{1,38} = 13.30$, $p = 7.92 \times 10^{-4}$) and **b)** average total nitrogen concentrations ($F_{1,38} = 4.68$, $p = 0.04$) for south Lake Joondalup, between 1978-1980 and 1992-1993.

The correlations in the main lake between total phosphorus and time appear to be driven by the north section (Figure 3.8a and b). Average total phosphorus concentrations in the north section were correlated stronger with time than both the main and central sections alone, with the central section having the lowest correlation (Figure 3.9a and b). Despite the fact that these correlations were weak all correlations were considered significant. The main section had a higher correlation between time and total nitrogen than the north and central sections separately. A poor correlation between time and total nitrogen for the north section was not considered significant although for the other two it was. Thus, this would generally suggest that significant changes have occurred over time, albeit only slight.

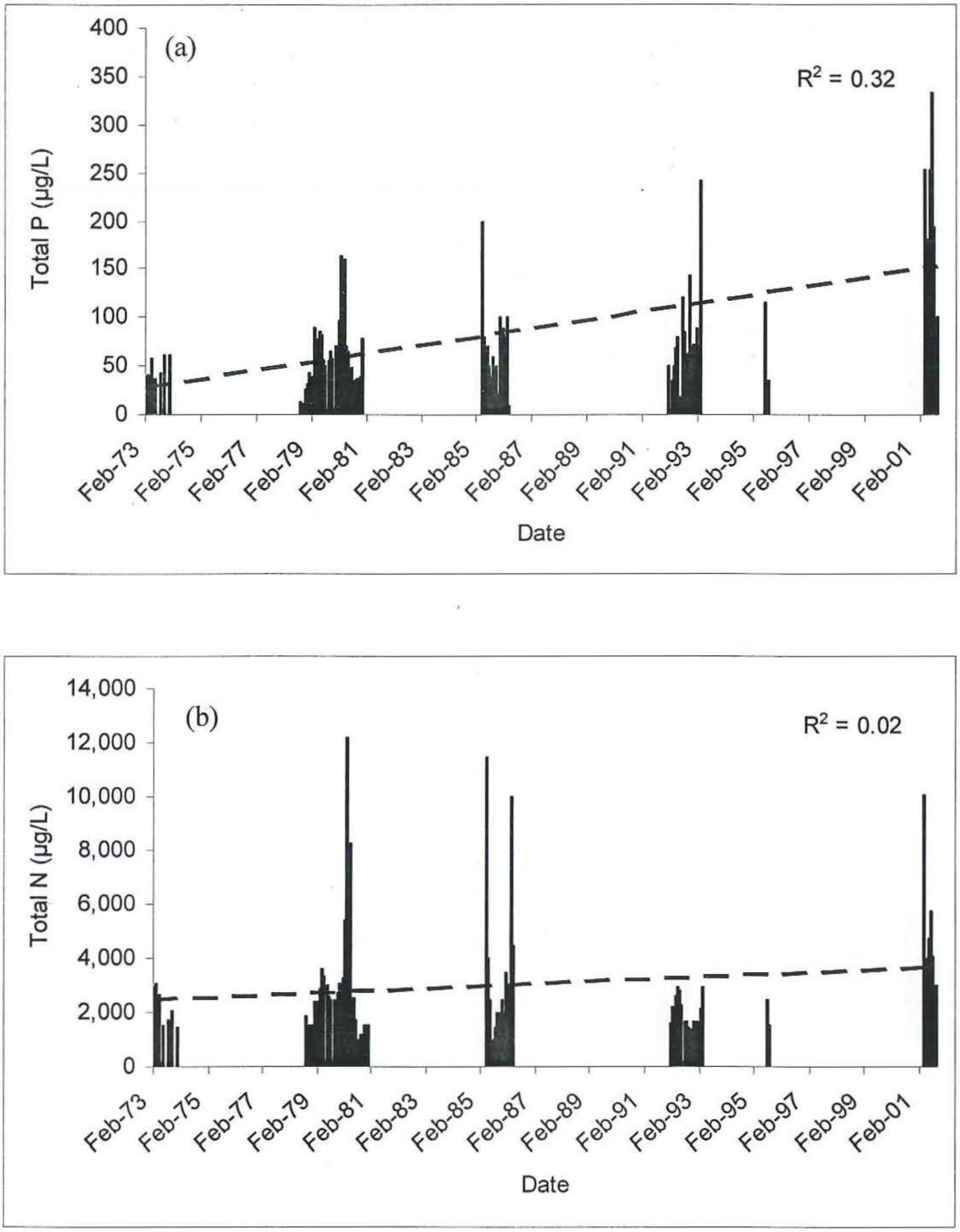


Figure 3.8 Comparison of **a)** average total phosphorus concentrations ($F_{1,69} = 31.72$, $p = 3.57 \times 10^{-7}$) and **b)** average total nitrogen concentrations ($F_{1,69} = 1.47$, $p = 0.23$) for north Lake Joondalup between 1973 and 2001.

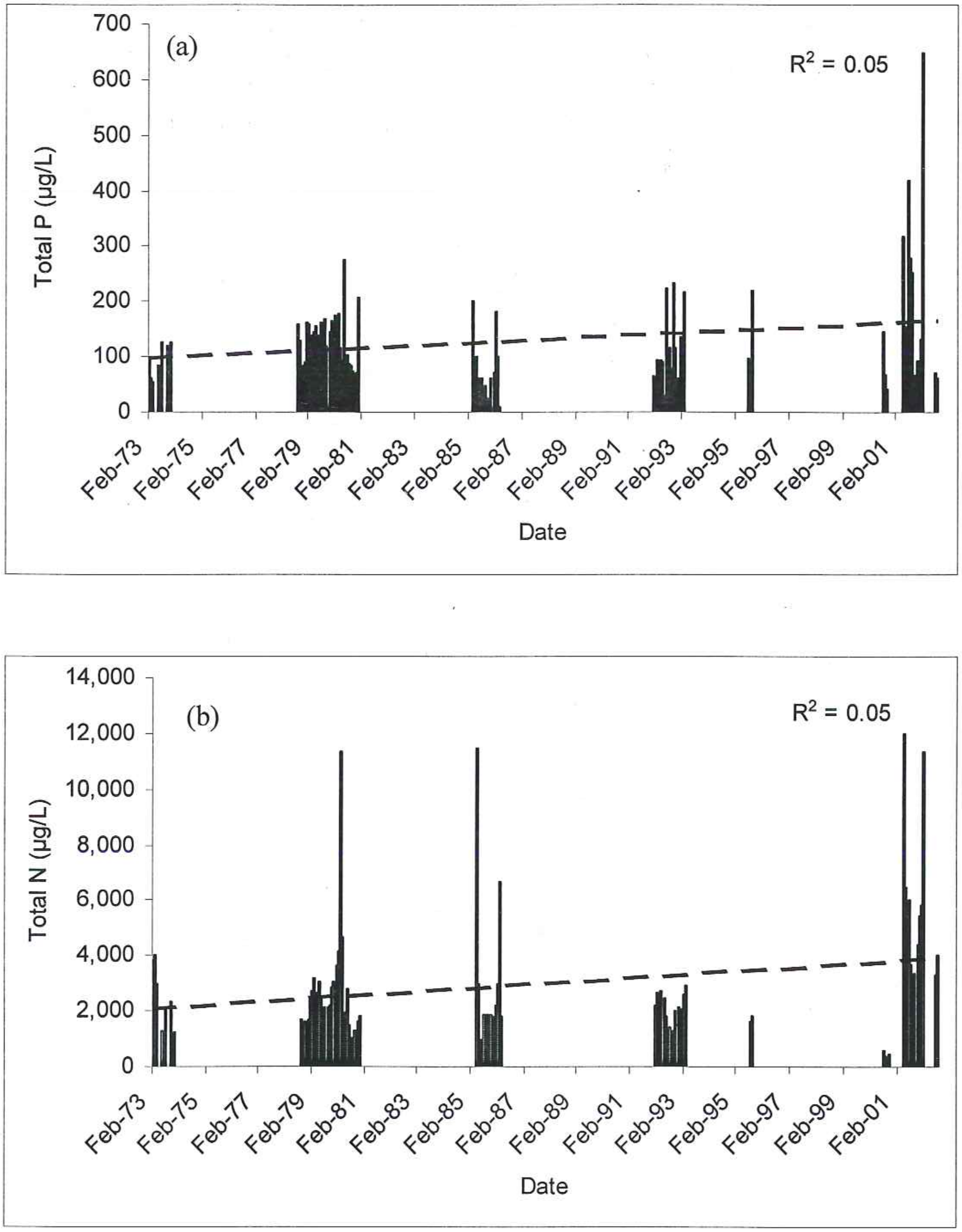


Figure 3.9 Comparison of **a)** average total phosphorus concentrations ($F_{1,78} = 4.16$, $p = 0.04$) and **b)** average total nitrogen concentrations ($F_{1,78} = 4.49$, $p = 0.04$) for central Lake Joondalup between 1973 and 2001.

3.2 Nutrient Budget

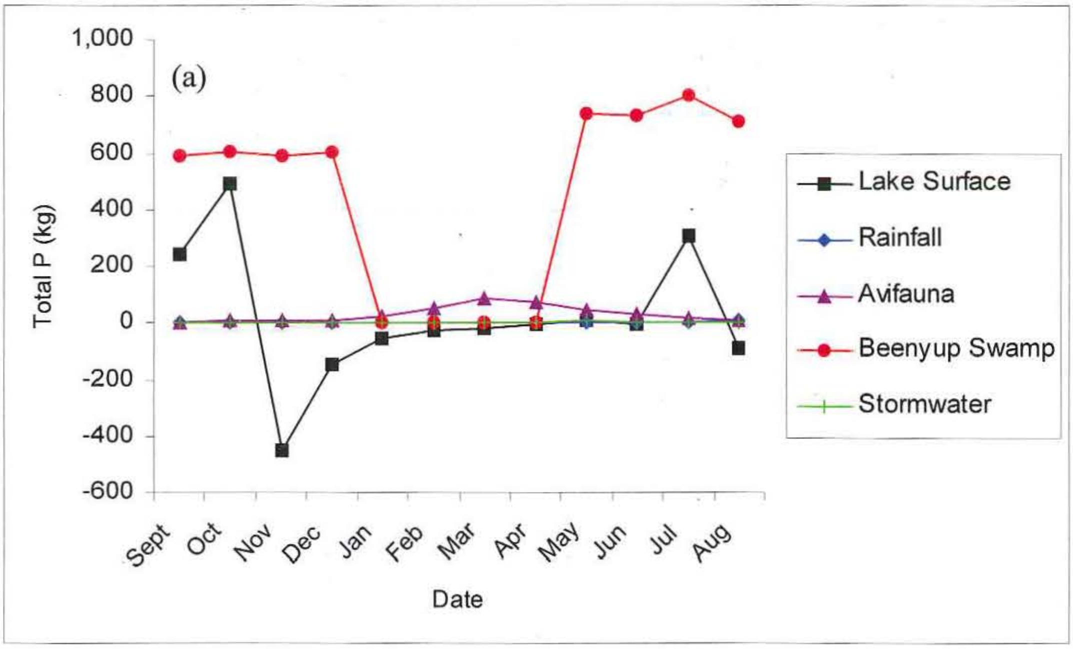
Beenyup Swamp and precipitation contributed the majority of water to Lake Joondalup with evaporation being the greatest loss. Stormwater had the least impact on the lake in terms of volume. Although it contributed a small volume, stormwater contributed larger quantities of phosphorus compared to rainfall, although lower nitrogen quantities, and rainfall had a much greater contribution of water. Denitrification was the only recognised loss of nutrients. It is also obvious that Beenyup Swamp had the greater impact in terms of contributions of both nutrients; however waterbirds also had a considerable impact.

Table 3.1 Net contribution of water, total phosphorus and nitrogen to Lake Joondalup from various sources between September 2003-August 2004 (except groundwater, net from October-August).

Parameter	Water volume (m^3)	Total phosphorus (kg)	Total nitrogen (kg)
Lake Volume	+ 2 362 972	+ 246	+ 3 597
Rainfall	+ 4 267 320	+ 24	+ 471
Evaporation	- 5 160 472		
Transpiration	- 2 847 938		
Beenyup Swamp	+ 5 346 149	+ 5 369	+ 4 325
Stormwater	+ 238 064	+ 40	+ 239
Groundwater	- 2 001 742		
Nitrogen fixation			+ 52
Denitrification			- 1 008
Waterbirds		+ 366	+ 1 950

The relative influence of each of these sources and losses of nutrients over the year shows that Beenyup dominates the influence (

Figure 3.10a and b). The input from waterbirds is the only other noticeable influence on the lake; contributions of nitrogen over the summer months ensure a constant supply of nitrogen for the whole year in Lake Joondalup. The nutrient loads in the lake's surfacewater began to increase after at least one month of contributions from Beenyup Swamp, and loads decreased a couple of months before the Beenyup Swamp flow ceased. Nitrogen loads were much more variable in the lake surface storage than phosphorus.



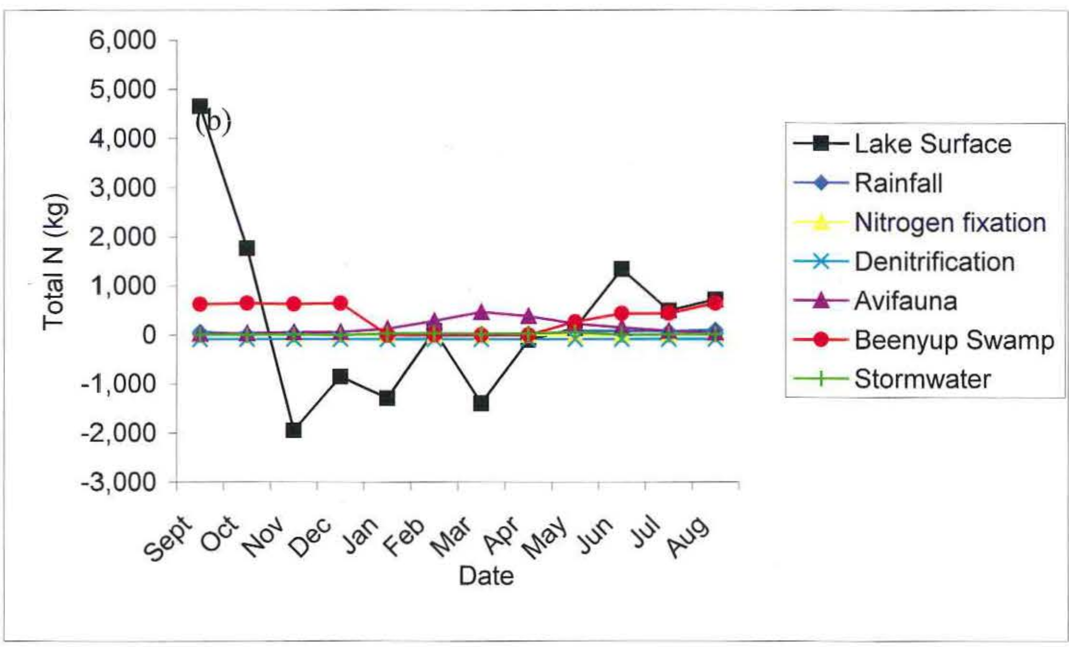


Figure 3.10 Comparison of **a)** phosphorus loads and **b)** nitrogen loads from the various sources between September 2003-August 2004.

A comparison of the recent sampling to the budget constructed by Congdon (1986) indicates that the proportion of nitrogen and phosphorus contributed from Beenyup Swamp to Lake Joondalup has increased, whilst the nutrient contribution from rainfall has markedly decreased although this may be due to the acknowledgement of waterbirds as a source of nutrients to the lake in this study (Table 3.2). The contribution of stormwater in terms of phosphorus has slightly decreased while nitrogen has increased. Although there are differences, the same conclusion can be drawn regarding the relative importance of Beenyup Swamp to Lake Joondalup between the recent study and that of Congdon (1986).

Table 3.2 Comparison of Congdon's budget (1986) with this study – proportions in percentage of inputs for phosphorus and nitrogen.

	Beenyup Swamp	Rainfall	Stormwater	Waterbirds	N_2 Fixation
Phosphorus					
Congdon (1986)	76	26	1		
This study	93	0.1	0.6	6.3	
Nitrogen					
Congdon (1986)	30	69	1		
This study	61	7	3.3	28	0.7

The water level of Lake Joondalup varied according to rainfall and evaporation, being higher during winter when rainfall was high and evaporation rates were low (Figure 3.11). Lake surface water height was greatest in October, decreasing to its lowest in April. Despite the fact this figure appears to show that there was always water in the lake, this was not the case with the majority drying except for small pockets around the edges, which is where the lake staff gauge is located. Small increases in depth can result in large increases in volume for both the north and southern section of Lake Joondalup (Figure 3.12a and b, Figure 3.13a and b).

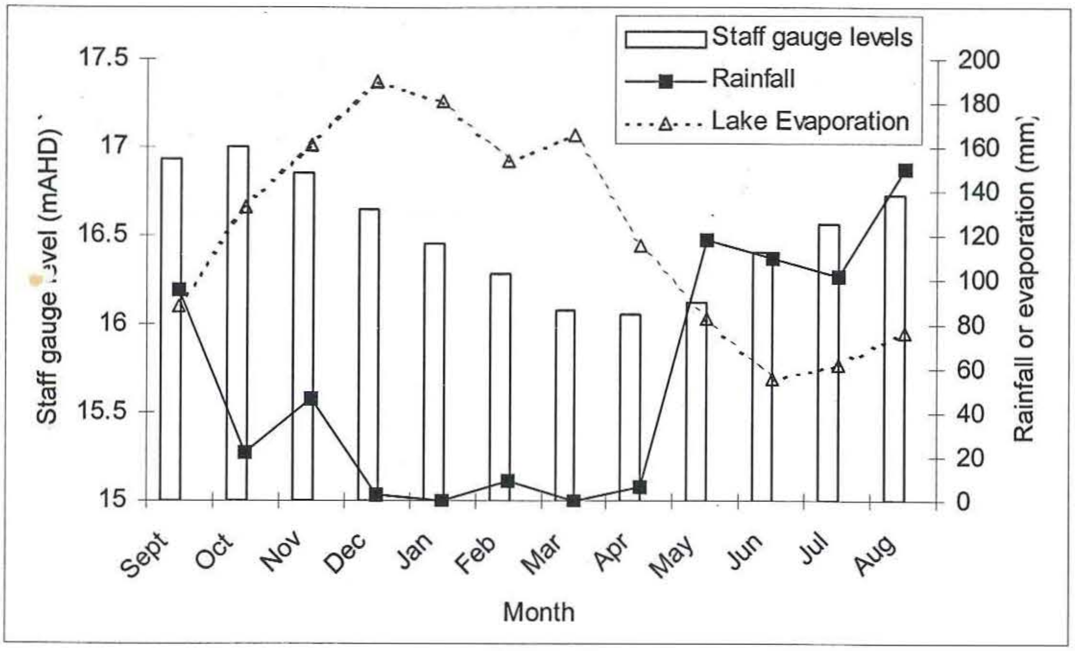
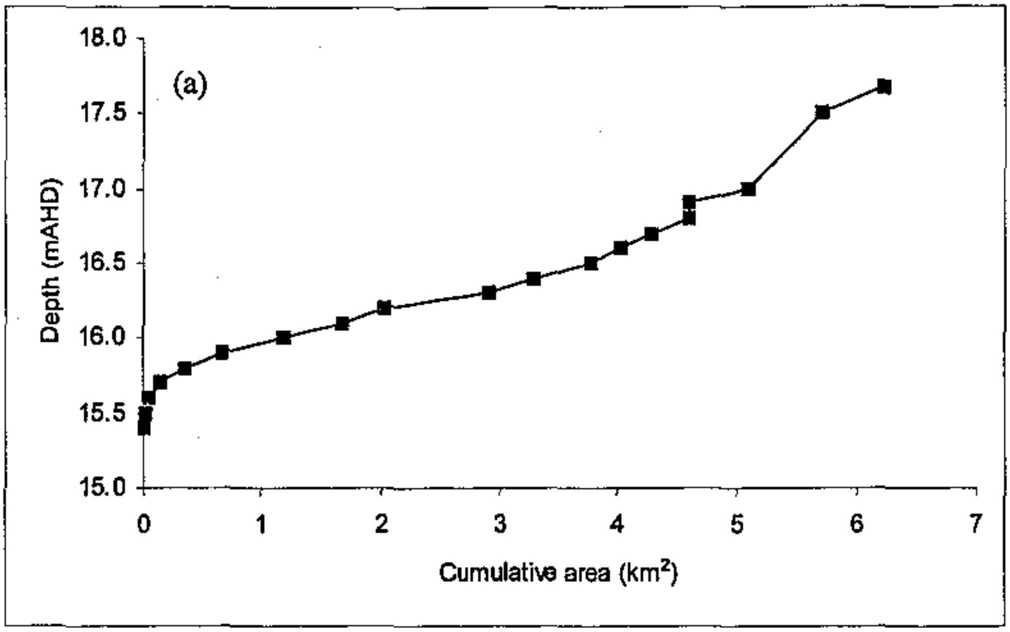


Figure 3.11 Comparison of staff gauge heights (No. 8281) and climate conditions (Perth Airport Station 9021) at Lake Joondalup between September 2003 and August 2004.



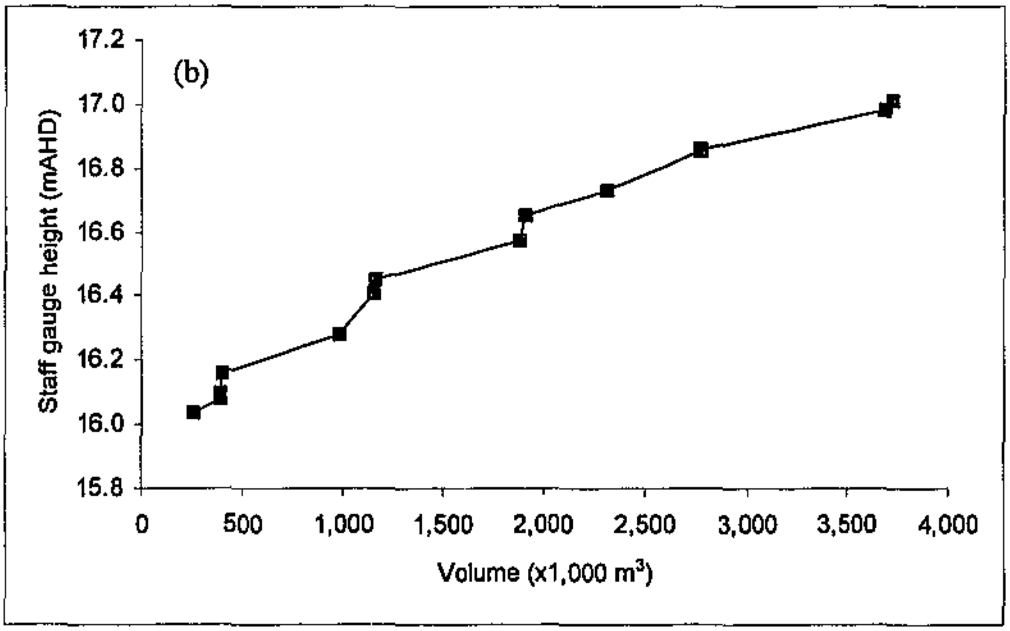


Figure 3.12 The **a)** hypsographic curve and **b)** volume curve for the main section of Lake Joondalup.

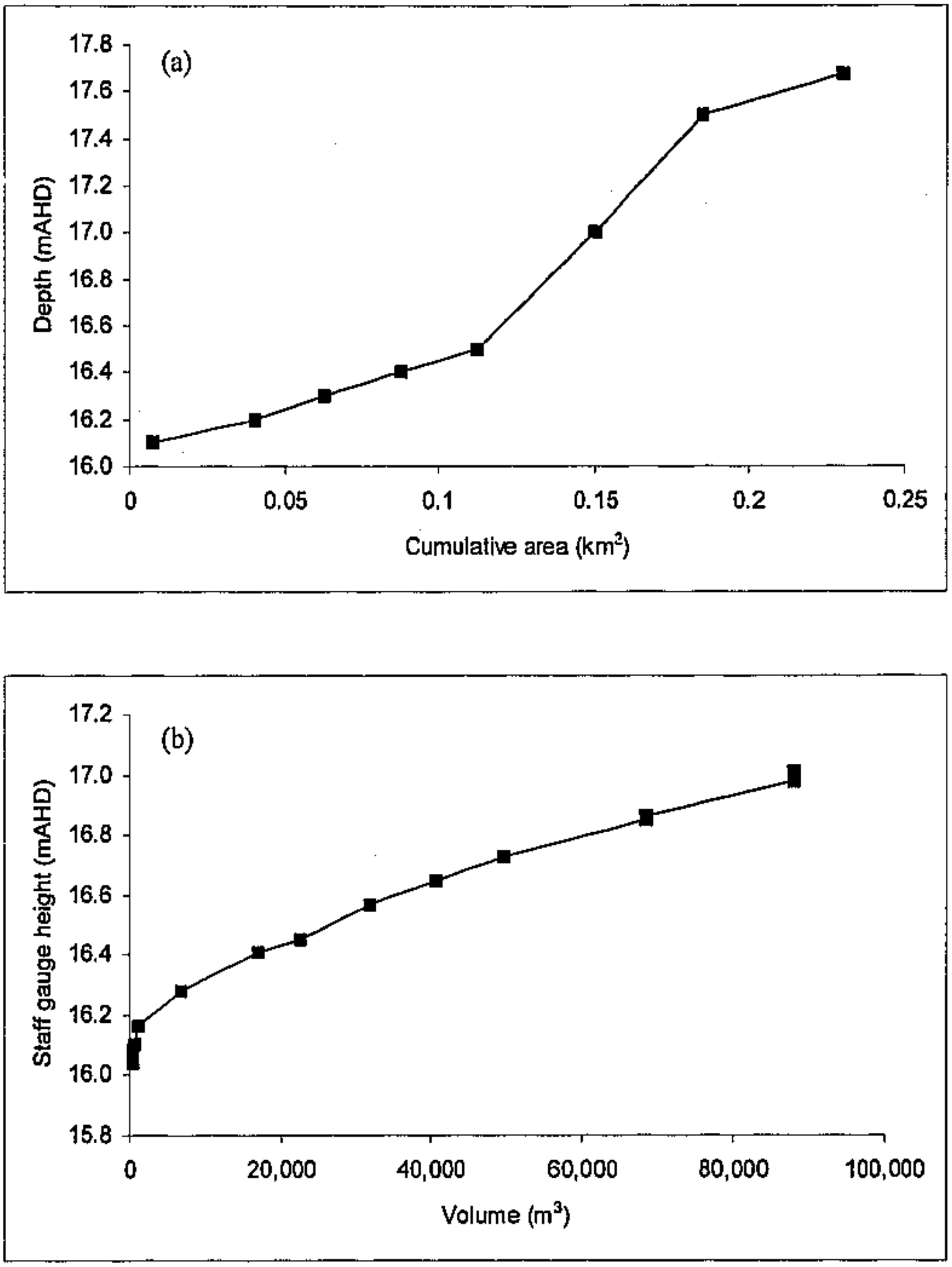


Figure 3.13 The a) hypsographic curve and b) volume curve for the south section of Lake Joondalup.

Nutrient concentrations in rainfall were quite similar for each month. For this reason an average of all the months concentrations were used when calculating nutrient loads from rainfall (Table 3.3).

Table 3.3 Average rainfall and standard error of the total phosphorus and nitrogen mean for collected samples. Four simultaneous samples during June and July, four individual samples during August.

Month	Average total P (µg/L)	Average total N (µg/L)
June	5.19 ± 1.03	106.07 ± 8.42
July	6.61 ± 2.26	103.27 ± 12.71
August	5.37 ± 2.48	122.39 ± 19.08
Average	**5.73 ± 0.44**	**110.57 ± 5.96**

The loadings of total phosphorus and nitrogen from stormwater over the sampling period (Figure 3.14) started to increase from the beginning of the year 2004 with the highest loads of nutrients occurring during May. Following this, the loads of nutrients depended on the volume of rainfall and the average nutrient concentrations. Total nitrogen loads were considerably higher than phosphorus throughout the year.

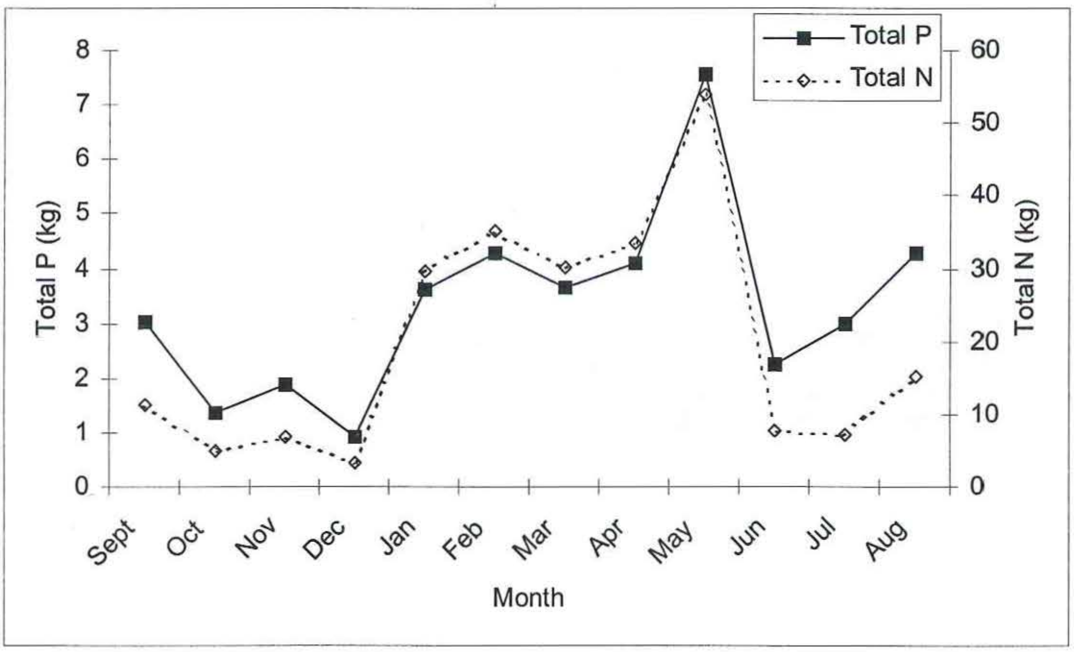


Figure 3.14 Estimated loadings of total phosphorus and nitrogen from stormwater discharge points directly entering Lake Joondalup between September 2003-August 2004.

3.3 Stormwater

Stormwater loadings of total phosphorus and total nitrogen during the sampling period showed an initial high load of both nutrients before a rapid decline, increasing sharply at the start of June and then decreased as winter progressed (Figure 3.15).

Nitrogen loads were noticeably higher than phosphorus loads, even though they both followed the same pattern. The high loads at the start of the sampling period coincided with high concentrations of nutrients and low rainfall (Figure 3.16a and b). There was another peak during June, and this was associated with among the lowest recorded nutrient concentrations and medium rainfall. So both concentrations and rainfall are important for determining loads. It can also be seen in these figures that stormwater was collected on one day when no rain was recorded at the Perth weather station. So while the Wanneroo and Perth station were deemed not significantly different, differences still occur.

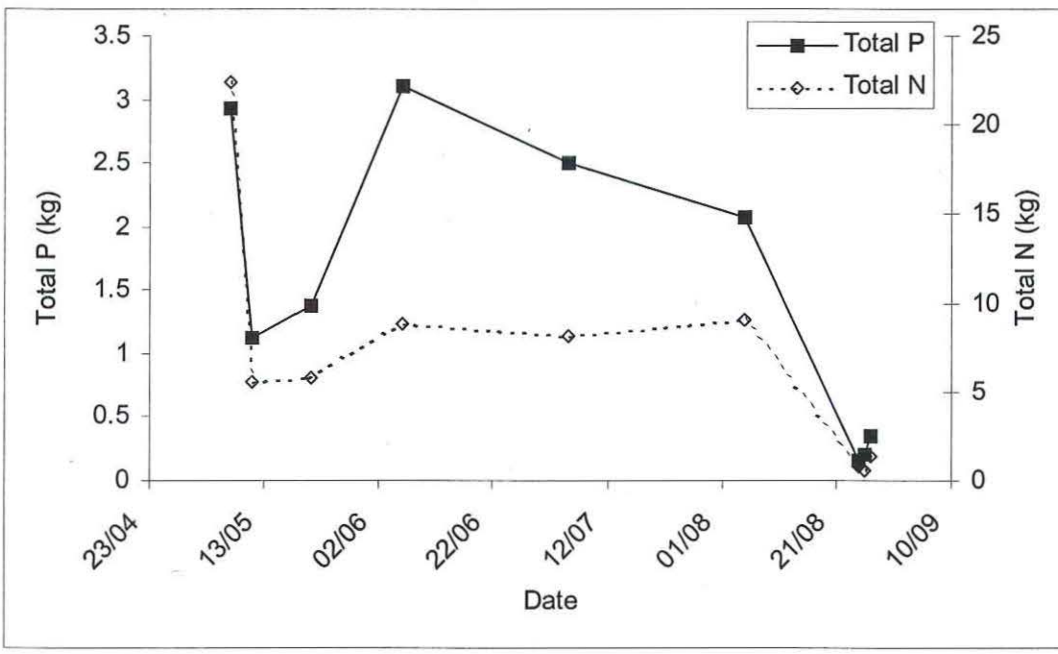
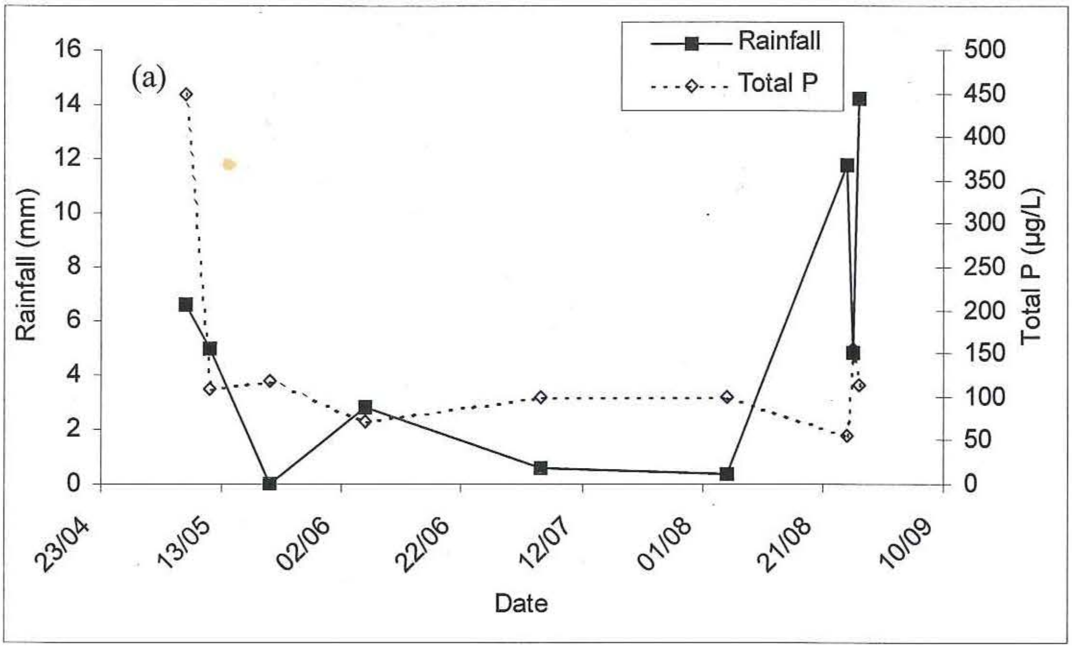


Figure 3.15 Estimated loadings of total phosphorus and total nitrogen from stormwater discharge points directly entering Lake Joondalup during the sampling period.



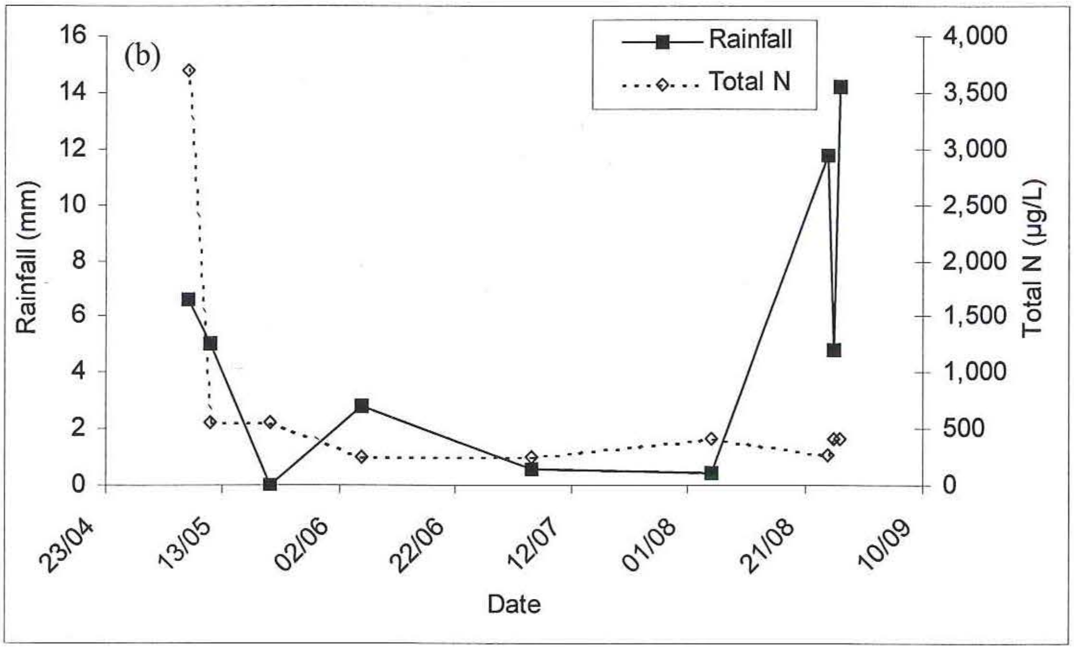


Figure 3.16 Average daily a) total phosphorus and b) total nitrogen concentrations for outfalls and bubble up grates that impacted Lake Joondalup and daily rainfall during the sampling period.

Comparisons of the storm events captured during the study give an insight into the fluxes of nutrients during such events. Outfall 9 was sampled during the first storm event of the year where total phosphorus and nitrogen concentrations were high for the initial ten minutes before both progressively decreased to a plateau (Figure 3.17).

Due to the architecture of the pipe and backflow, nutrient concentrations increased following the sample taken at 8:30am, for this reason all samples taken after this time were not included in any of the calculated loadings. The backflow problems have prevented the hydrograph of each storm event being determined. Although this limits interpretation of nutrients released during the event, concentrations of both N & P were initially high (before 8:00am) indicating a possible first flush. Then between 8:09am and 8:38am concentrations declined to a plateau. As these concentrations did not decline further to concentrations more similar to rainfall it suggests a constant release rate of nutrients from the catchment.

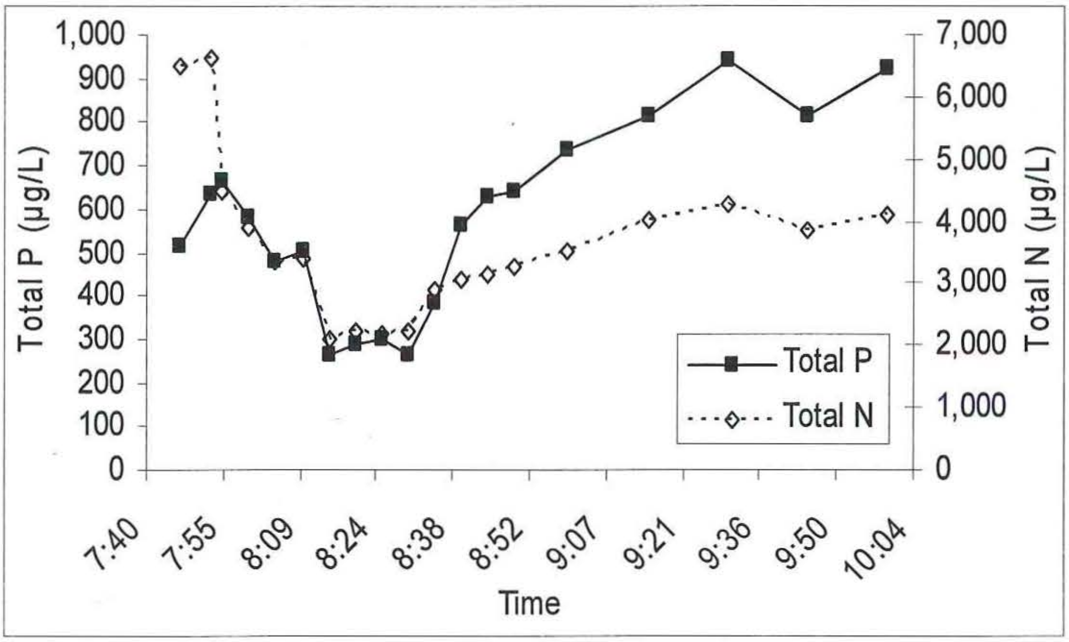


Figure 3.17 Total phosphorus and nitrogen concentrations at various time intervals during the first storm event at Outfall 9 on 7/5/04.

Concentrations of nutrients in samples collected from outfalls 5 (Figure 3.18) and 8 Figure 3.19) showed similar trends to outfall 9 with a steady decline in total phosphorus and nitrogen concentrations in a similar pattern. Outfall 5 was impacted by backflow and thus concentrations recorded after 13:00 were not included in loading calculations. Outfall 5 also experienced a slight increase in nutrient concentrations at 12:30 pm followed by a continued decline. However, in contrast to outfall 9, both outfall 5 and 8 recorded markedly lower nutrient concentrations with outfall 8 recording slightly lower concentrations.

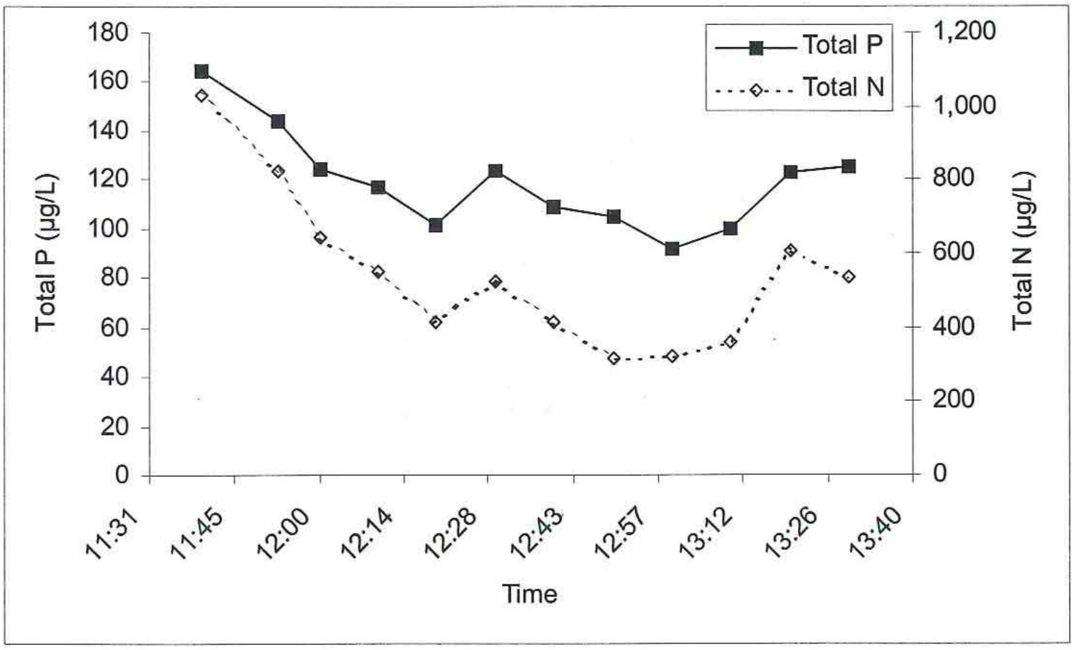


Figure 3.18 Total phosphorus and nitrogen concentrations at various time intervals during a rainfall event at Outfall 5 on 21/5/04.

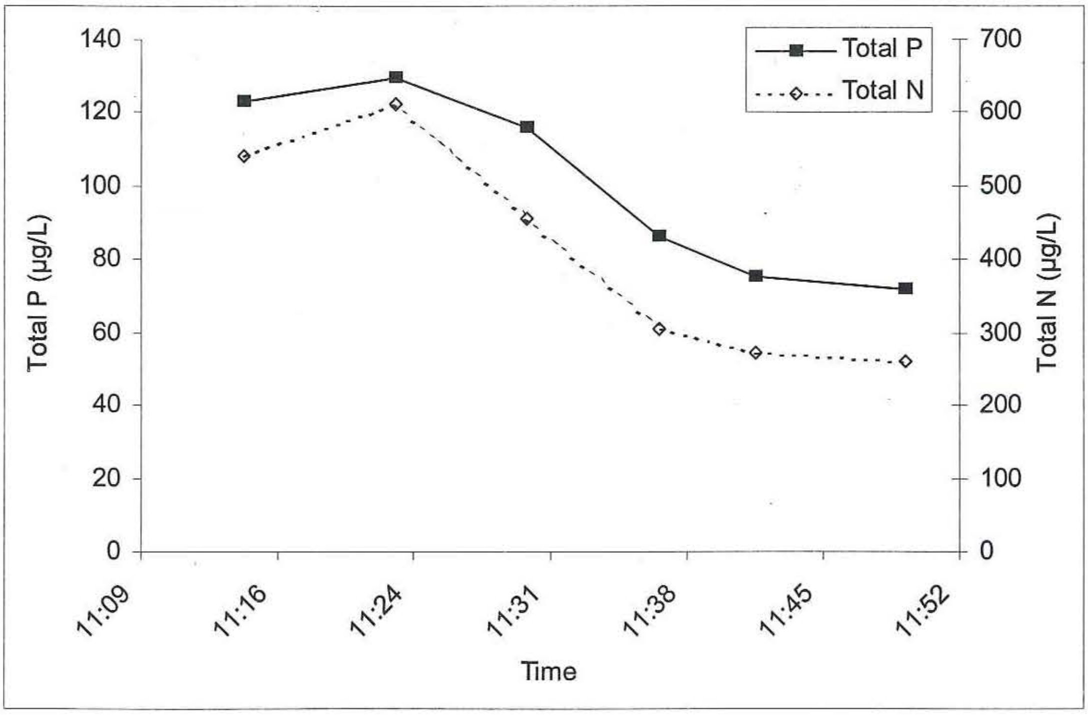


Figure 3.19 Total phosphorus and nitrogen concentrations at various time intervals during a rainfall event at Outfall 8 on 5/8/04.

Outfall 9 was re-sampled at the end of the sampling period and the nutrient concentrations showed high initial concentrations that progressively decline to a plateau after 30 minutes (Figure 3.20). These initial phosphorus and nitrogen concentrations were much less than during the first sampling event, but were also slightly higher than that occurring at outfall 5 and 8. Plateau concentrations of phosphorus were approximately 100 µg/L and were similar between all the outfalls measured. As with nitrogen concentrations which were about 300 µg/L for the outfalls measured. Whilst outfall 9 has backflow problems, the impact of backflow during this sampling event could not be determined and therefore all samples were used in the calculations of loadings.

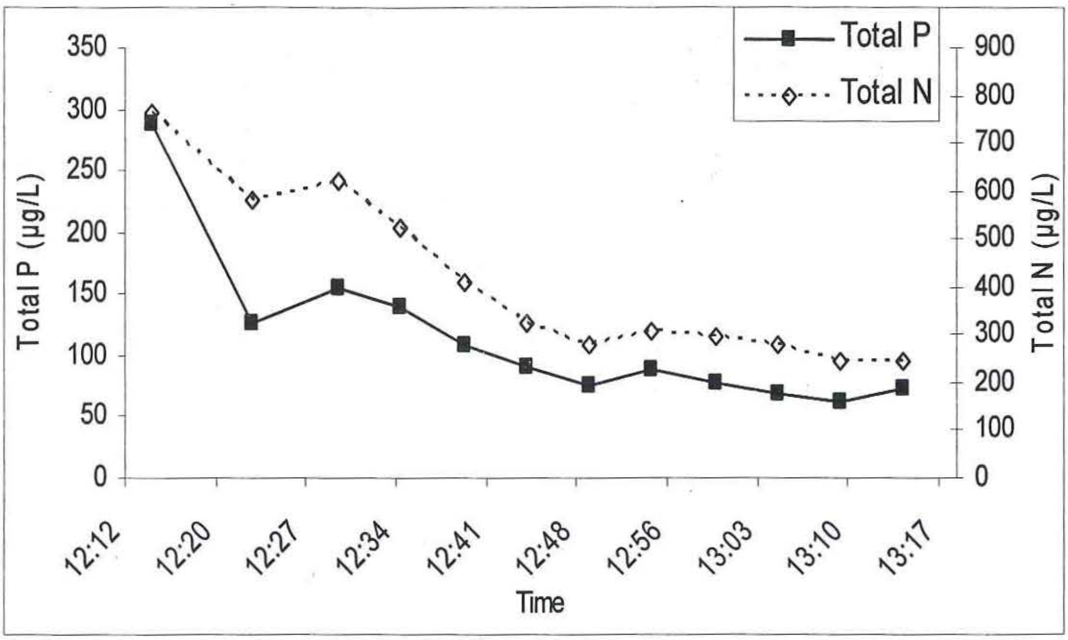


Figure 3.20 Total phosphorus and nitrogen concentrations at various time intervals during a rainfall event at Outfall 9 on 27/8/04.

3.4 Groundwater

Loadings of total phosphorus were much less than total nitrogen in terms of both contributions and losses from groundwater around Lake Joondalup (Figure 3.21, Figure 3.22). Loadings of phosphorus entering Lake Joondalup tended to decrease over the sampling period. Losses were highest during July, these deficits were almost twice what entered the lake. Nitrogen loads tended to decrease over the sampling period for the eastern bores while losses increased for the western bores. The loss of nitrogen was at least three times greater than the contributions throughout the sampling period. Supplementary to that shown by the graphs, the eastern bores were also sampled during May. This month shows a negative loading for all the eastern bores at this time, suggesting water was flowing out of the lake rather than into it at this time. The average loadings of the eastern bores during May when there was a negative flow were –34 kg of phosphorus and –88 kg of nitrogen.

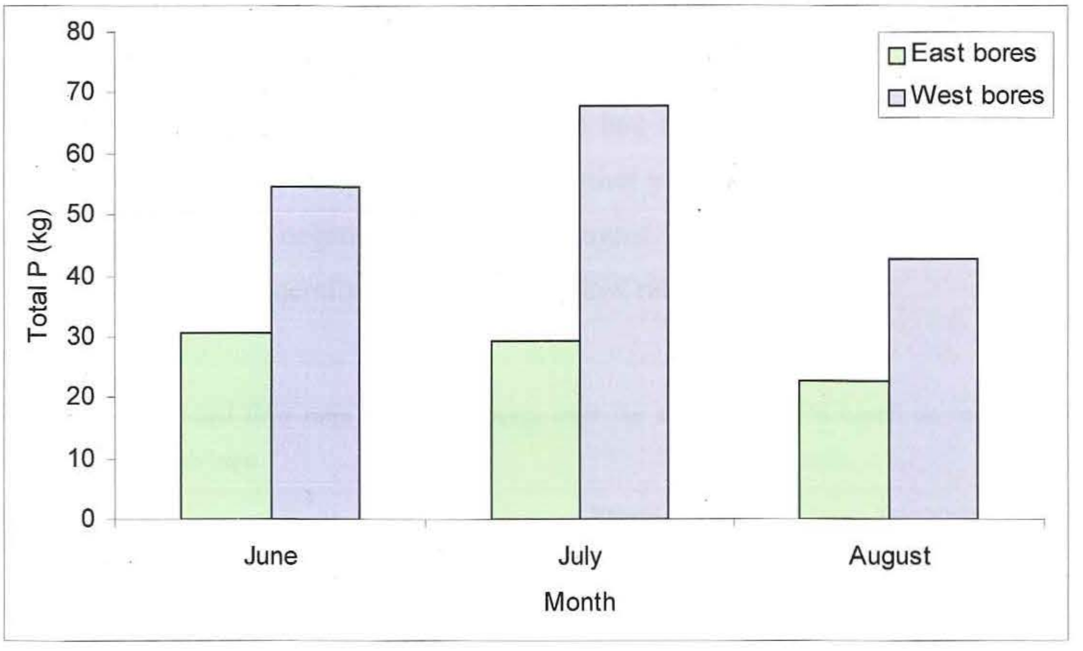


Figure 3.21 Loadings of total phosphorus contributed by the eastern bores and lost through the western bores of Lake Joondalup during the sampling period. For the western bores the sampling date of 2/7 was classed as June, 5/8 as July and 24/8 as August.

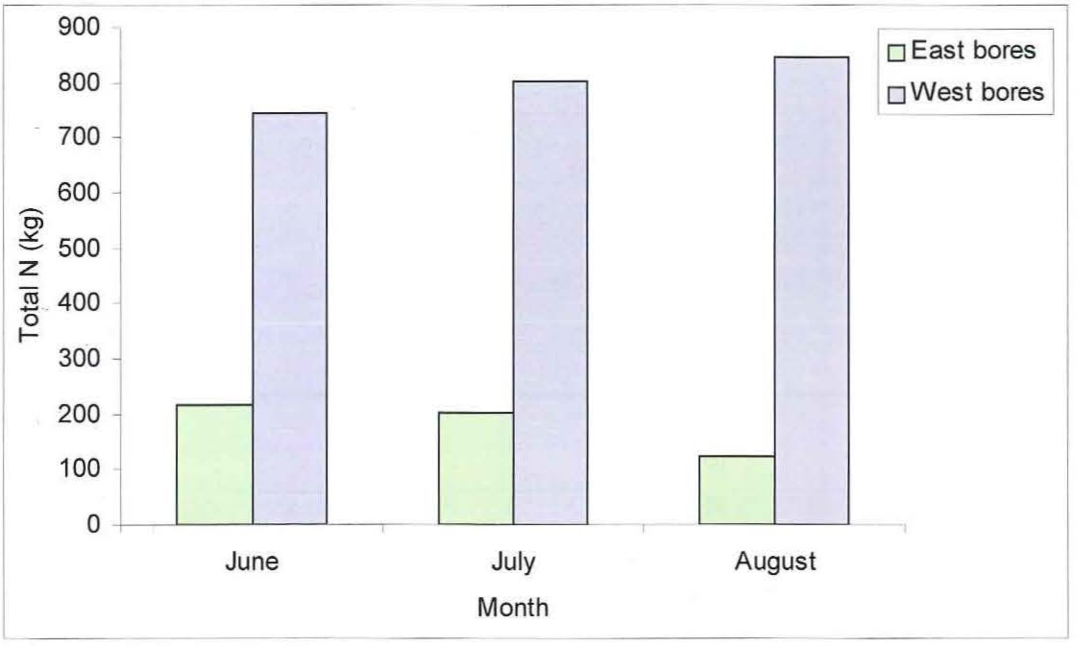


Figure 3.22 Loadings of total nitrogen contributed to Lake Joondalup from the eastern bores and lost through the western bores during the study period. For the western bores, the sampling date of 2/7 was classed as June, 5/8 as July and 24/8 as August.

The hydraulic conductivity has a significant effect on determining the flow rate (Table 3.4). Flow rates were higher for those bores located further east compared to the eastern bores closest to the lake. Neville had the highest negative flow during May, it had the lowest sampling rate for the other sampling months and also was the only bore to record a negative flow during August. The flow rates of the bores west of Lake Joondalup generally had the highest flow rates throughout.

Table 3.4 Individual flow rates for all the bores over the sampling period based on two different hydraulic conductivities.

Bore	Date	Velocity based on hydraulic conductivity of 13.33 m/day	Velocity based on hydraulic conductivity of 0.05 m/day
Pines	31/5/04	-0.025085	-0.000094
	28/6/04	0.132452	0.000497
	26/7/04	0.254845	0.000956
	22/8/04	0.124575	0.000467
Wallawa	31/5/04	-0.173290	-0.000650
	28/6/04	0.206615	0.000775
	26/7/04	0.162182	0.000608
	22/8/04	0.172179	0.000646
Neville	31/5/04	-0.197284	-0.000740
	28/6/04	0.039990	0.000150
	26/7/04	0.039990	0.000150
	22/8/04	-0.001333	-0.000005
Poincicana	31/5/04	-0.053764	-0.000202
	28/6/04	0.132856	0.000498
	26/7/04	0.131523	0.000493
	22/8/04	0.121081	0.000454
Ashley	28/6/04	0.048369	0.000181
	26/7/04	0.041160	0.000154
	22/8/04	0.045512	0.000171
Caporn	28/6/04	0.134823	0.000506
	26/7/04	0.132316	0.000496
	22/8/04	0.134284	0.000504
Christie	28/6/04	0.106276	0.000399
	26/7/04	0.099006	0.000371
	22/8/04	0.099914	0.000375
Togno Park	28/6/04	0.204337	0.000766
	26/7/04	0.202198	0.000758
	22/8/04	0.202696	0.000760

Nannatee Park	28/6/04	0.184089	0.000691
	26/7/04	0.183077	0.000687
	22/8/04	0.182655	0.000685
Lakeside Drive	2/7/04	- 0.340775	- 0.001278
	5/8/04	- 0.349375	- 0.001310
	24/8/04	- 0.353890	- 0.001327
Central Park East	2/7/04	- 0.219056	- 0.000822
	5/8/04	- 0.222611	- 0.000835
	24/8/04	- 0.224477	- 0.000842
Central Park West	2/7/04	- 0.222563	- 0.000835
	5/8/04	- 0.225737	- 0.000847
	24/8/04	- 0.227403	- 0.000853
Edith Cowan University	1/7/04	- 0.153838	- 0.000577
	29/7/04	- 0.156318	- 0.000586
	24/8/04	- 0.158565	- 0.000595
Quarry Ramble	2/7/04	- 0.135680	- 0.000509
	5/8/04	- 0.154723	- 0.000580
	24/8/04	- 0.164721	- 0.000618

It can be seen that hydraulic conductivity and aquifer thickness have a large impact on the estimated volumes and they therefore need to be accurate (Table 3.5 and Table 3.6). Coinciding with higher flow rates, those bores west of Lake Joondalup had greater volumes exiting than was contributed from the east.

Table 3.5 Volumes of water entering Lake Joondalup based on the eastern bores across the various sections of the lake, based on two different hydraulic conductivities and aquifer thickness.

Bore segment	Date	Volume through segment (m^3/day) based on 13.33 m/day velocity and 5 m thick aquifer	Volume through segment (m^3/day) based on 13.33 m/day velocity and 45 m thick aquifer	Volume through segment (m^3/day) based on 0.05 m/day velocity and 5 m thick aquifer	Volume through segment (m^3/day) based on 0.05 m/day velocity and 45 m thick aquifer
North Lake Joondalup – Pines	31/5/04	-115.39	-1 038.50	-0.43	-3.90
	28/6/04	609.28	5 483.50	2.29	20.57
	26/7/04	1172.29	10 550.60	4.40	39.57
	22/8/04	573.04	5 157.40	2.15	19.35
Pines – Wallawa	31/5/04	-666.20	-5 995.77	-2.50	-22.49
	28/6/04	1138.68	10 248.11	4.27	38.44
	26/7/04	1400.49	12 604.42	5.25	47.28
	22/8/04	996.58	8 969.24	3.74	33.64
Wallawa – Neville	31/5/04	-823.90	-7 415.07	-3.09	-27.81
	28/6/04	548.28	4 934.49	2.06	18.51
	26/7/04	449.49	4 045.39	1.69	15.17
	22/8/04	379.84	3 418.58	1.42	12.82
Neville – Poinciana	31/5/04	-1984.02	-17 856.20	-7.44	-66.98
	28/6/04	1365.99	12 293.92	5.12	46.11
	26/7/04	1355.46	12 199.10	5.08	45.76
	22/8/04	946.36	8 517.25	3.55	31.95
Poinciana - South Lake Joondalup	31/5/04	-346.78	-3 121.02	-1.30	-11.71
	28/6/04	856.92	7 712.27	3.21	28.93

	26/7/04	848.32	7 634.89	3.18	28.64
	22/8/04	780.97	7 028.74	2.93	26.36

Table 3.6 Volumes of water leaving Lake Joondalup based on the western bores across the various sections of the lake, based on two different hydraulic conductivities and aquifer thickness.

Bore segment	Date	Volume through segment (m^3/day) based on 13.33 m/day velocity and 5 m thick aquifer	Volume through segment (m^3/day) based on 13.33 m/day velocity and 45 m thick aquifer	Volume through segment (m^3/day) based on 0.05 m/day velocity and 5 m thick aquifer	Volume through segment (m^3/day) based on 0.05 m/day velocity and 45 m thick aquifer
North Lake Joondalup – Lakeside Drive	June	- 5 179.78	- 46 618.02	- 19.43	- 174.86
	July	- 5 310.50	- 47 794.50	- 19.92	- 179.27
	August	- 5 379.13	- 48 412.15	- 20.18	- 181.59
Lakeside Drive – Edith Cowan University	June	- 1 331.53	- 11 983.81	- 4.99	- 44.95
	July	- 1 361.36	- 12 252.26	- 5.11	- 45.96
	August	- 1 379.57	- 12 416.11	- 5.17	- 46.57
Edith Cowan University – Quarry Ramble	June	- 1 383.28	- 12 449.52	- 5.19	- 46.70
	July	- 1 486.11	- 13 375.02	- 5.57	- 50.17
	August	- 1 544.62	- 13 901.57	- 5.79	- 52.14
Quarry Ramble – South Lake Joondalup	June	- 1 526.40	- 13 737.64	- 5.73	- 51.53
	July	- 1 740.64	- 15 665.73	- 6.53	- 58.76
	August	- 1 853.11	- 16 677.97	- 6.95	- 62.56

Average total phosphorus concentrations for bores east of Lake Joondalup were relatively similar throughout the four months of sampling, yet concentrations were quite different among bores (Figure 3.23). The Poinciana and Pines bores had similar, consistent concentrations throughout the study compared to higher and more variable concentrations in the Neville and Wallawa bores. Neville bore exceeded the average monthly concentrations on all occasions.

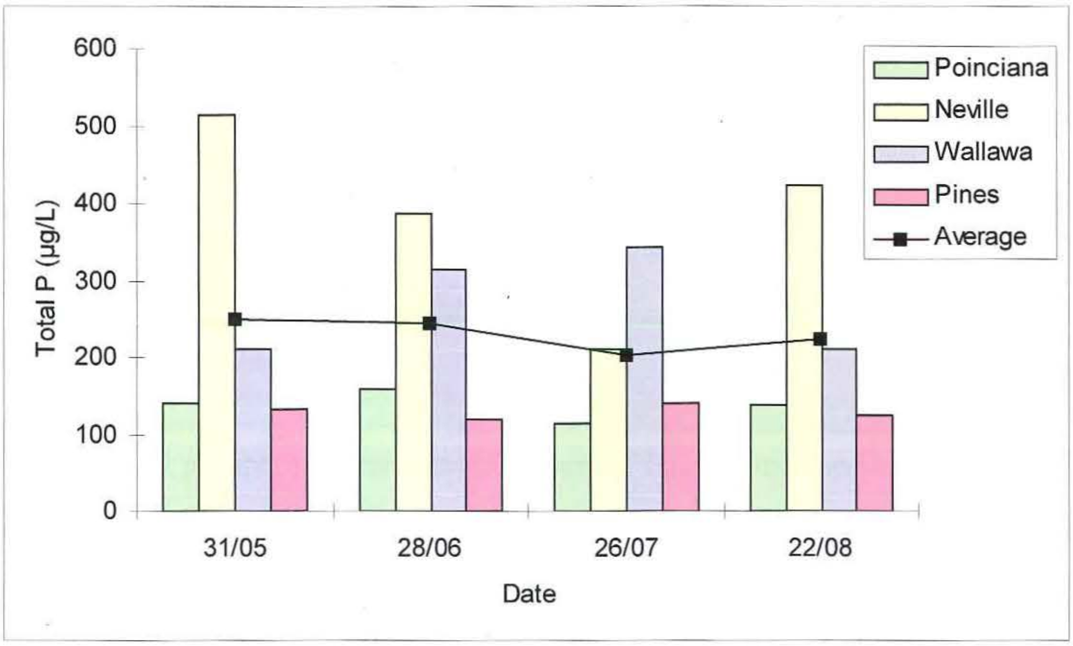


Figure 3.23 Individual and average total phosphorus concentrations during the sampling period for bores located east of Lake Joondalup.

Average and individual total nitrogen concentrations for the eastern bores were generally greater than the total phosphorus concentrations between May and August (Figure 3.24). The average nitrogen concentration increased between May and June, although concentrations for the latter two months were slightly lower. Total nitrogen at Poinciana bore was the only bore recording consistent concentrations across the sampling period. Neville bore concentrations progressively increased over the four months, whereas Wallawa bore and the Pines bore had the highest concentrations in June.

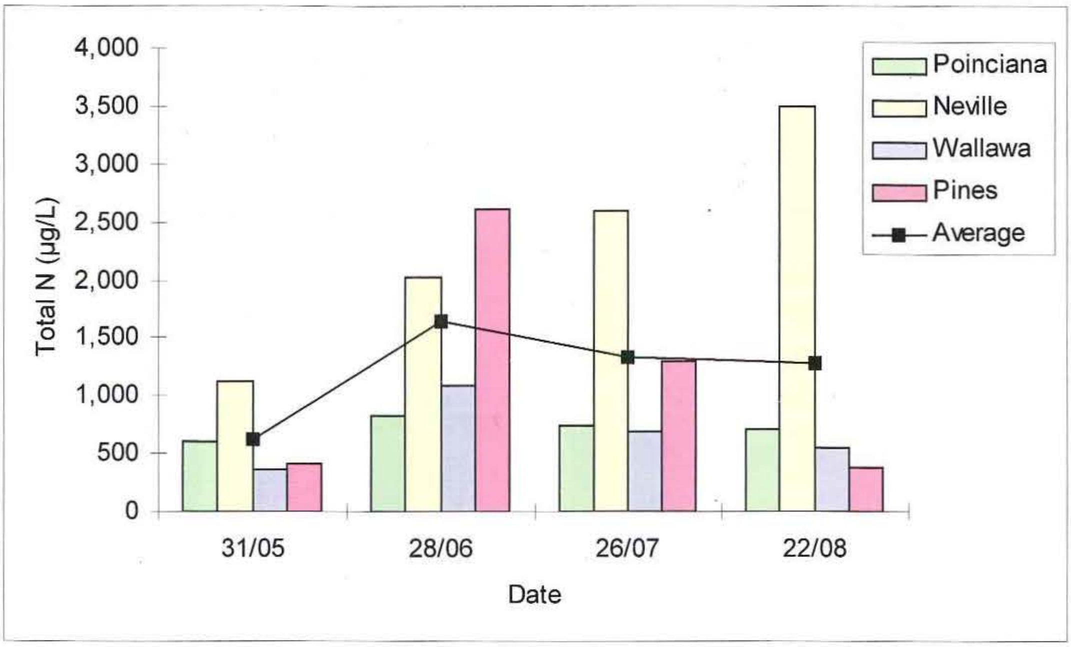


Figure 3.24 Individual and average total nitrogen concentrations during the sampling period for bores located east of Lake Joondalup.

Average total phosphorus concentrations west of Lake Joondalup were quite similar throughout the three months with a slight increase during early August (Figure 3.25). Central Park West was the only bore that recorded consistently high concentrations during the sampling period. Quarry Ramble increased slightly at the beginning of August, the ECU bore also increased during this month. Central Park East showed marked total phosphorus increases in the latter two samples whereas Lakeside Drive was higher during the first sampling occasions and decreased considerably towards the end of August.

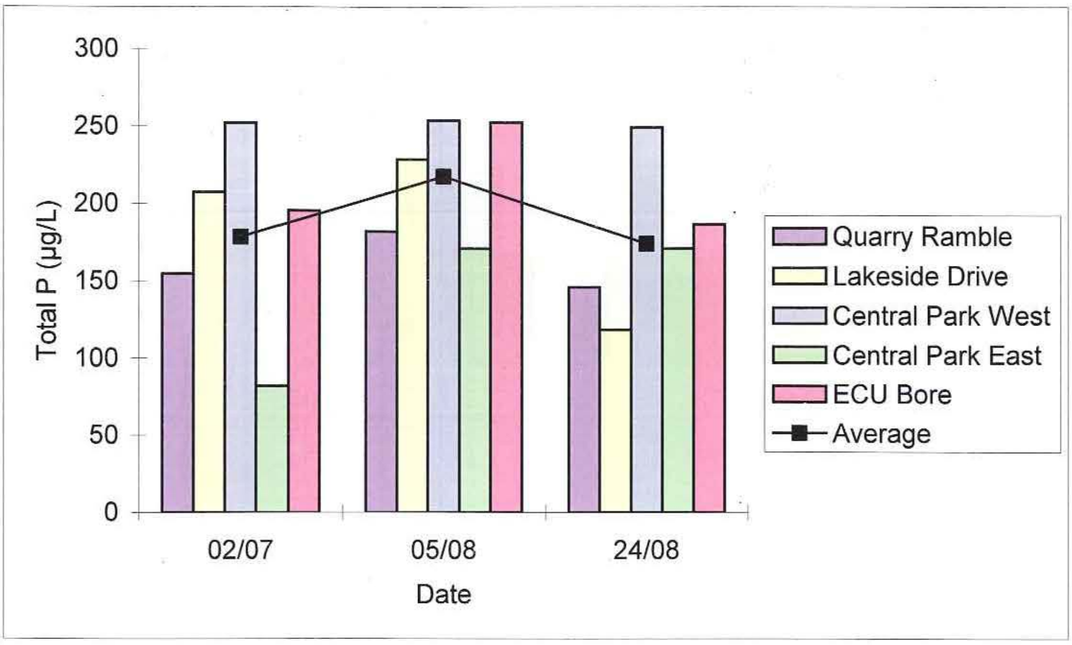


Figure 3.25 Individual and average total phosphorus concentrations during the sampling period for bores located west of Lake Joondalup. The Edith Cowan University (ECU) bore was sampled on 1/7, 29/7 and 24/8.

Average and individual nitrogen concentrations west of Lake Joondalup were considerably higher than their respective phosphorus concentrations (Figure 3.26). The average nitrogen concentration also slightly increased each sampling time. All bores had consistent concentrations during the three months, with Lakeside Drive recording the highest concentrations and Quarry Ramble the lowest. Central Park East and Central Park West had similar concentrations and the Edith Cowan University bore consistently recorded the second lowest concentrations.

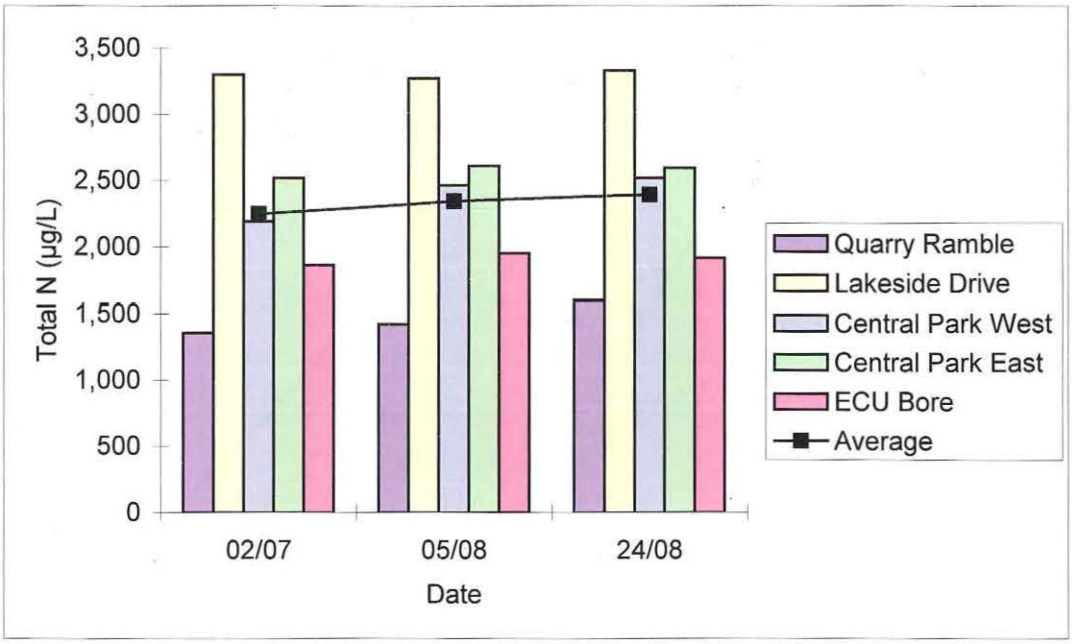


Figure 3.26 Individual and average total nitrogen concentrations during the sampling period for bores located west of Lake Joondalup. The Edith Cowan University (ECU) bore was sampled on 1/7, 29/7 and 24/8.

3.5 Surface water inflow

Beenyup Swamp generally contributed the highest loads of both phosphorus and nitrogen (Figure 3.27a and b) over the sampling period. Only once were the loads higher at Ocean Reef culvert for total nitrogen (at the end of June). The loads generally had the same inconsistent pattern, with nitrogen being noticeably more variable than phosphorus loads.

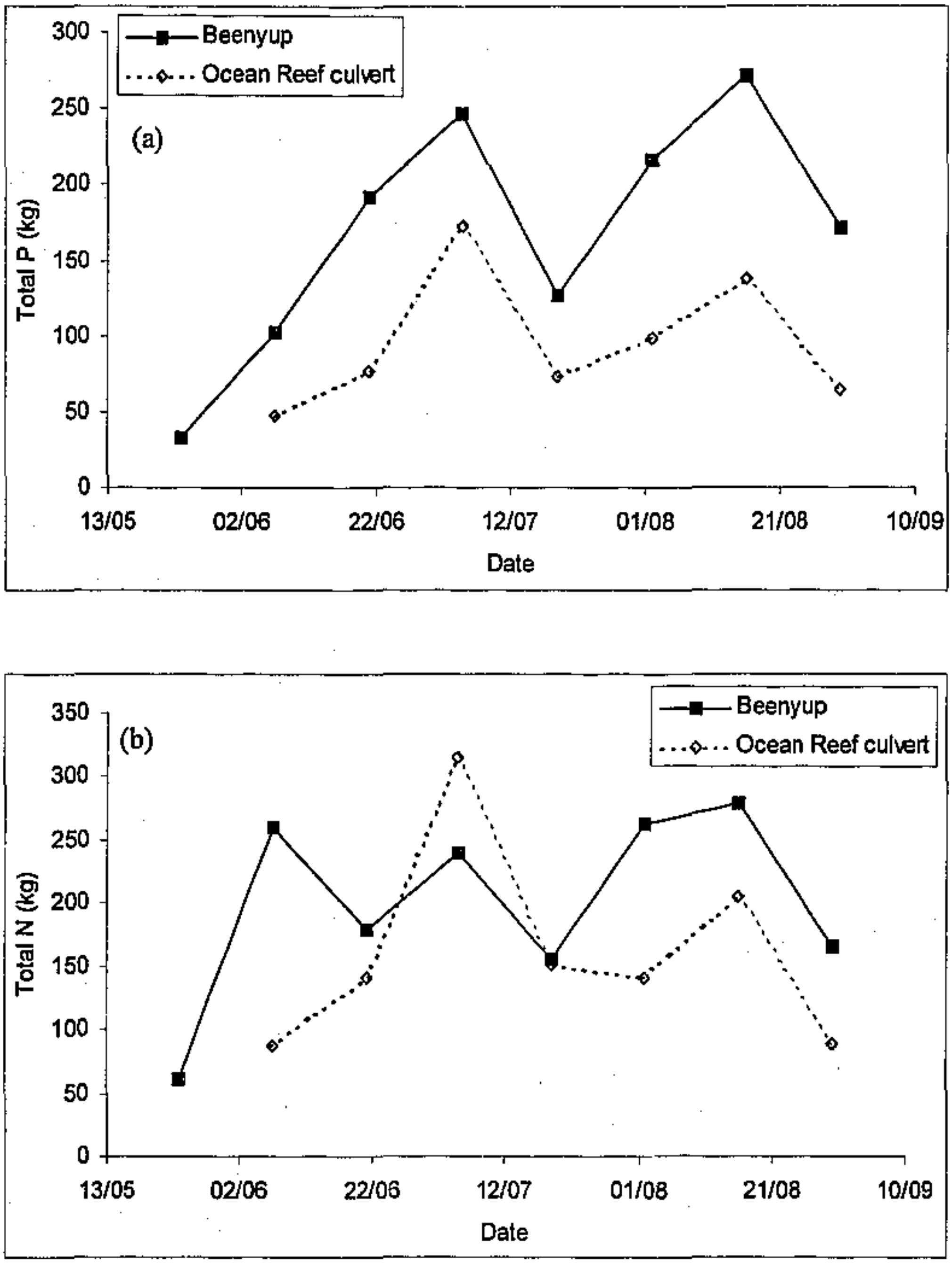


Figure 3.27 Comparison of a) total phosphorus loads and b) total nitrogen loads for the two surface water sites, Beenyup Swamp and Ocean Reef Road culvert, over the sampling period.

Concentrations of total nitrogen progressively decreased at the surface water sites during the sample period, until the last sample where the concentrations slightly increased (Figure 3.28a and b). Total nitrogen concentrations were higher for Ocean Reef culvert, though this is generally not reflected in total loads, compared to

Beenyup connection, mimicking the Beenyup pattern for the majority of the samples except for an increase in early July.

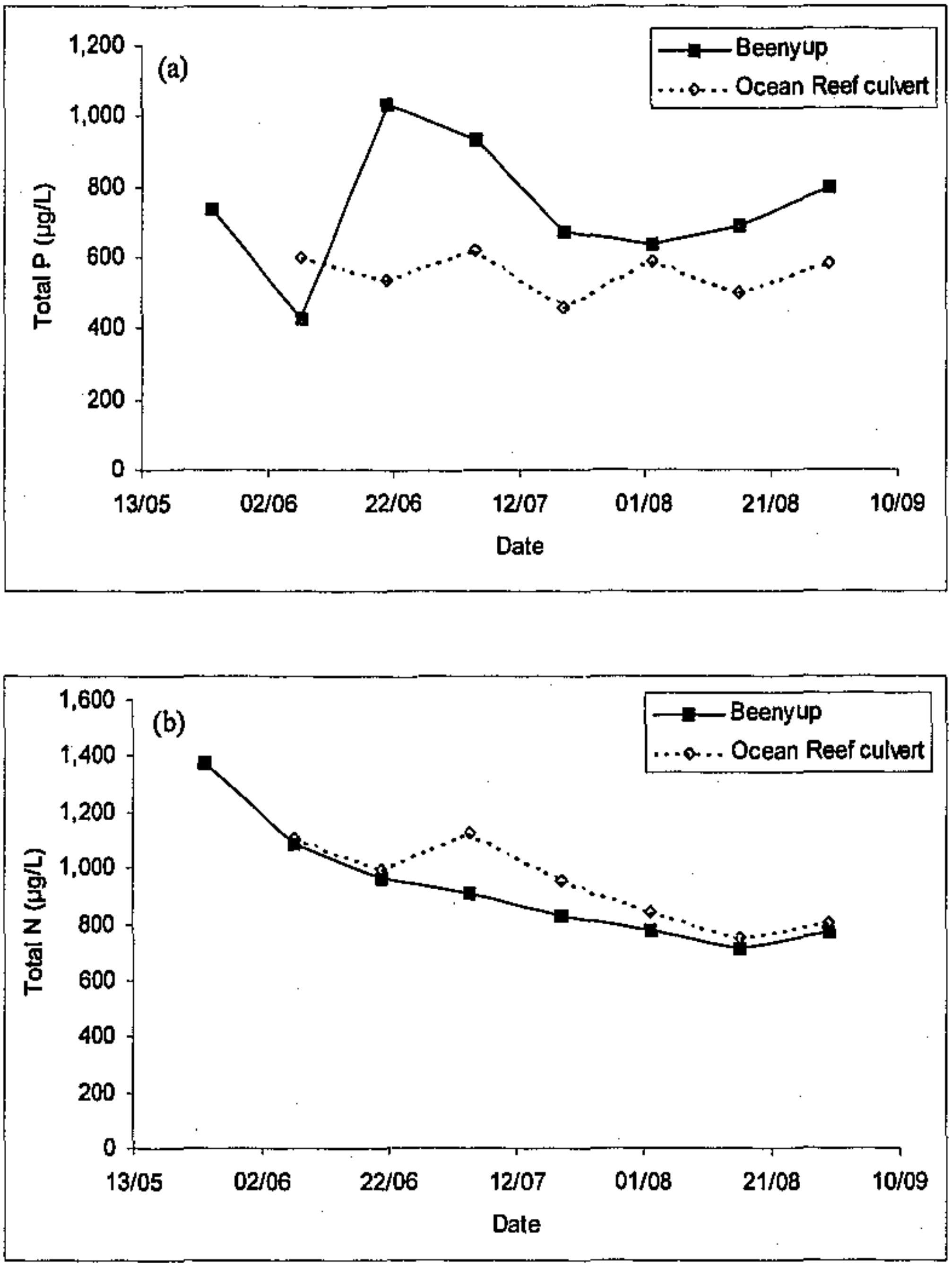
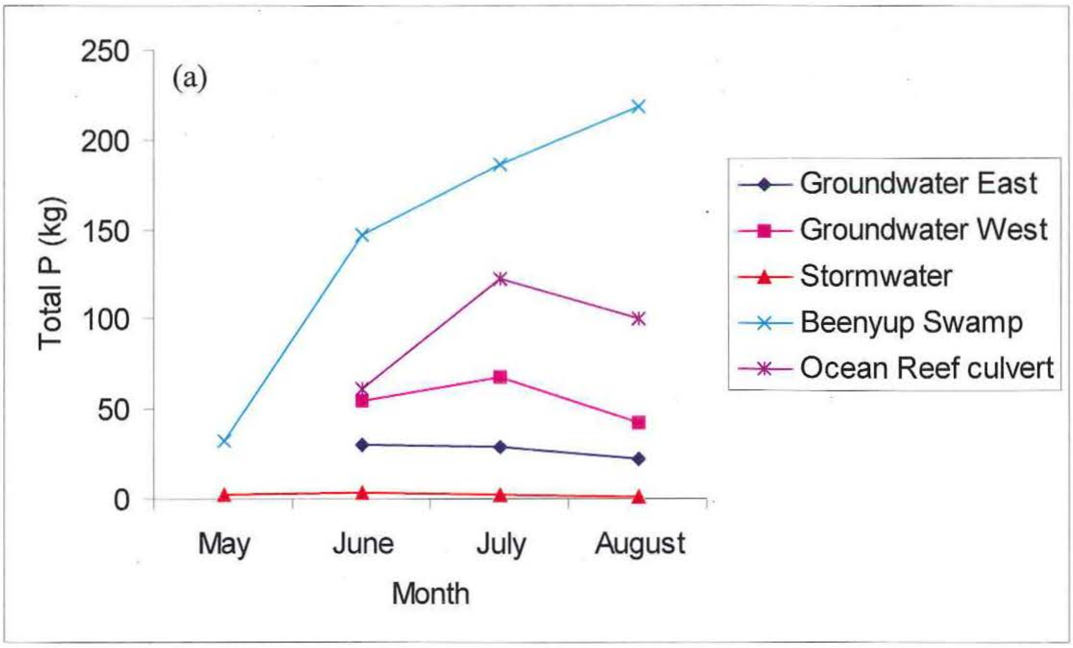


Figure 3.28 Comparison of a) total phosphorus and b) total nitrogen concentrations for the two surface water sites, Beenyup Swamp connection and Ocean Reef Road culvert, over the sampling period.

A comparison of all the parameters sampled in this study showed that Beenyup Swamp was the greatest source of phosphorus loads to the southern and main section of Lake Joondalup, as indicated by loads recorded at Ocean Reef culvert (Figure 3.29a). Stormwater was the least influential compared to Beenyup Swamp and groundwater. It can also be seen that the phosphorus load for groundwater west of the lake, ie loss, was less than the combined sources of phosphorus. In contrast to total phosphorus it would appear that there is a net loss of nitrogen from Lake Joondalup as indicated by the loads associated with the western bores (Figure 3.29b). Beenyup Swamp and groundwater east contribute similar loads of nitrogen, although all contribute more than stormwater.



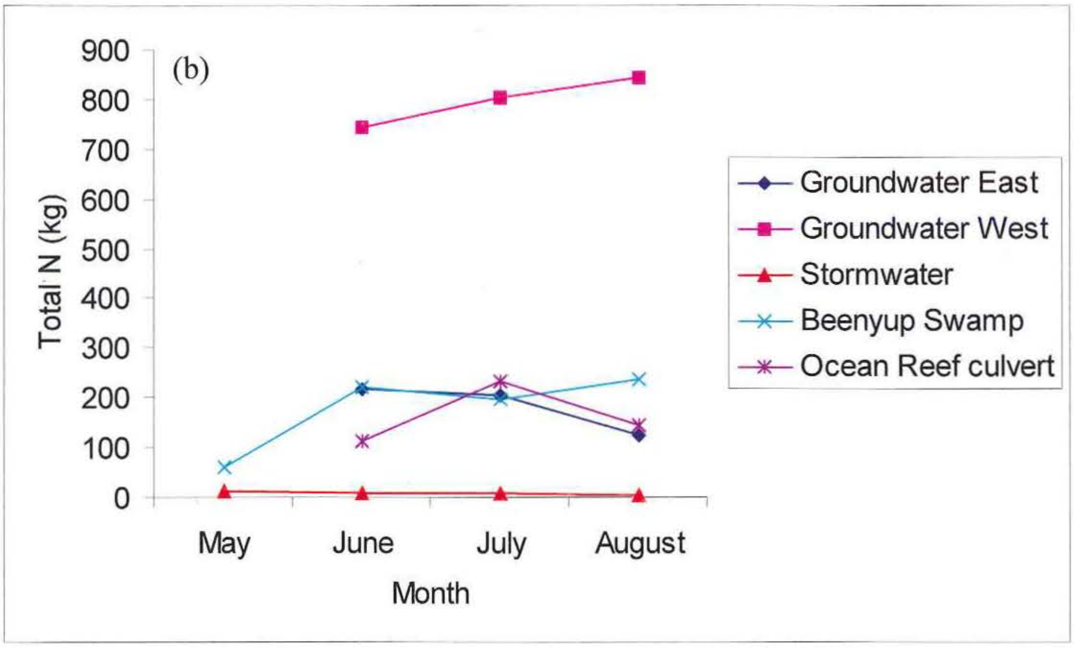


Figure 3.29 Comparison of **a)** total phosphorus and **b)** total nitrogen loads contributed or lost from the various parameters measured in this study.

Total nutrient concentrations indicate the quantity that will eventually be contributed to the system. It is the bio-available nutrients that are important for plants to acquire and increase production. The majority of nitrogen entering Lake Joondalup is in the organic form, with considerably high proportions of ammonium recorded as leaving the system as indicated by western bores. Contributions of phosphate were similar for all sources though Beenyup Swamp was the highest. Notably higher phosphate proportions were identified in the west suggesting a large export of bioavailable nutrients. Surface water flows from Beenyup Swamp were considered the primary contributor of total nitrogen, though the majority is organic (Table 3.7). The same can be said for stormwater, with groundwater contributing the most but at the same time more is being exported from the lake as indicated by samples collected from bores west of Lake Joondalup. In terms of phosphate, which is the most important in a phosphorus limited lake, all components can have a similar high contribution, though much is also leaving the system via the groundwater as well.

Table 3.7 Indication of the average nutrient concentrations and standard error, and percentage range that the various soluble forms occupied of the total phosphorus and nitrogen concentrations.

Source/Input	PO_4 (%)	NO_x (%)	NH_4 (%)
Stormwater	46 ± 2.7	13 ± 0.8	14 ± 0.9
	10 - 93	3 - 29	2 - 28
Groundwater			
East	50 ± 4.5	12 ± 4.3	17 ± 2.4
	17 - 87	0.1 - 56	5 - 32
West	90 ± 3.7	0.1 ± 0.06	88 ± 4.9
	62 - 100	Below detectable limit – 0.6	46 - 100
Surface water flow			
Beenyup connection	65 ± 9.8	6 ± 1.1	12 ± 2.6
	18 – 100	2 - 10	6 - 24
Ocean Reef Road culvert	54 ± 13.1	1 ± 0.5	8 ± 2.3
	22 - 100	0.1 - 4	3 - 20

4 DISCUSSION

Urbanisation is resulting in the eutrophication of many wetlands and without management action water quality will continue to decline, making later rehabilitation more difficult. Lake Joondalup has been classified as eutrophic for approximately two decades (Congdon 1986), however it is currently still in the macrophyte dominated stable state with occasional algal blooms. It is important that the lake is managed to prevent it from switching to a cyanobacterial dominated state. This alternative state would make rehabilitation difficult and have a severe impact on biodiversity within the lake.

4.1 Long term trends

The likelihood of a change in stable state is related to the current trajectory of the lake's nutrient status. The studies of 1979-1980 by Congdon (1986) and 1992-1993 by Kinnear *et al.* (1997) were considered different. These discrepancies arose due to increases in total nutrient concentrations in the main lake and coinciding decreases in concentration in the southern section, suggesting a net movement of nutrients northwards, possibly due to the widening of the culvert in 1996 (Upton 1996). However, concentrations began to decrease in the south section before this culvert was modified, so it could be explained by the cessation of nearby farming practices or the assimilation of nutrients within this section.

Total phosphorus concentrations in the main section of Lake Joondalup are largely driven by increases in concentrations in the northern section of the lake. This suggests that the natural northerly flow of water in the Regional Park is causing phosphorus to accumulate in the northern section as there is not an outflow past this point except in years of very high rainfall. Alternatively a northerly source of phosphorous that has not been measured, such as the Botanical Golf Gardens, could be having an impact, although stormwater and groundwater could also be influential.

Trends of total phosphorus concentrations over time indicate that the north and central sections are behaving differently, however, upon analysis there was no significant difference between them. Both are significantly different from the south section, which is likely to be because they have been disconnected for some time and, in biological terms, they may behave and support different biota. Kinnear *et al.* (1997) also found south Lake Joondalup to be different to the north and central sections based on total nitrogen, nitrate/nitrite, ammonium, chlorophyll a, pH, total phosphorus, reactive phosphorus, dissolved oxygen and conductivity. This finding supports the monitoring of two sections rather than three, which will make management easier, suggesting that one sample in the main section would be representative. However, it is recommended that more than one sample is collected if human resources and time permit, or perhaps a bulked sample could be taken.

Lake Joondalup is a freshwater system and therefore its productivity is expected to be limited by available phosphorus. If phosphorus concentrations in the main section increase too much it could result in shifts into a new stable state, particularly since algal blooms are becoming more prevalent in recent years, now occurring throughout the year providing the temperature is suitable (Kinnear *et al.* 1997; Upton 1996). Phosphorous concentration and time correlations were much stronger compared to nitrogen, which could be explained by the natural cycling of nitrogen. However, Kinnear *et al.* (1997) suggest that the lake is actually shifting to a more nitrogen-limited lake. This is a problem for the lake because cyanobacteria, particularly, can fix nitrogen from the atmosphere and with increased availability of phosphorus their biomass could greatly increase. Monitoring of the two main sections of Lake Joondalup, north and south of Ocean Reef Road, should continue to facilitate identification of further alterations within the lake. Continued monitoring would also facilitate the identification of cycles or trends associated with changing nutrient concentrations, including issues that this analysis did not incorporate such as evapo-concentration. The identification of the sources of these nutrients and possible explanations for changes is important.

4.2 Nutrient Budget

Beenyup Swamp was highlighted as the major source of nutrients to Lake Joondalup, as previously identified by Congdon (1986), Kinnear *et al.* (1997) and Upton (1996). The majority of the nitrogen contribution was constituted by organic matter which could be transported from the reed areas in Beenyup or the expanses from Walluburnup Swamp, which are dominated by the introduced species *Typha orientalis*. Harvesting of this vegetation could reduce nutrient sources to Beenyup. These high nitrogen organic loads could also be from stormwater draining the Wangara Industrial Area that overflows into Walluburnup Swamp contributing to Beenyup. The existence of caravan parks, market gardens and poultry farms near the swamp regions in the past may also influence nutrient concentrations based on the likely impact of contaminated groundwater or the volume of nutrients stored in the sediment that could be continually contributing nutrients (Congdon 1986).

Stormwater was not considered a major contributor of nutrients although in terms of the volumes of water contributed by this source the concentrations were sometimes higher than rainfall which had a volume 16 times that of stormwater. This suggests that while stormwater drained from residential areas it still contributed a large quantity of nutrients. Concentrations of nutrients in rainfall were also lower in this study compared to others (Congdon 1979). Waterbirds were particularly influential over the summer months when the largest population of birds were present throughout the wetland, using it as a summer refuge. Waterbirds were deemed insignificant by Congdon (1979) but this study shows that they could have a considerable impact, although this impact may also have increased since volumes for this study were based on bird abundances recorded during 1992. The combination of Beenyup Swamp flow and avifauna inputs ensures that there is a constant supply of nitrogen (in particular) all year round, which could be detrimental to the lake in future years if it becomes nitrogen limited.

Denitrification was a large estimated loss of nitrogen from the lake, even though it was the only recognised loss for the budget. Discrepancies between stored nutrient loads within the lake and the associated sources and losses of nutrients, suggest that much of the nutrient load is being exported via groundwater or is being assimilated by the sediment or vegetation. The hydrological contribution of groundwater was estimated as the residual for the extrapolated yearly budget, and this identified a net loss of water although this did not address nutrient additions or losses. During the three months of sampling groundwater east and west of Lake Joondalup, a net loss of water was identified in conjunction with an export of nutrients, particularly nitrogen. These consistent losses of water and nutrient loads could not be incorporated into the budget as groundwater does not export all year. In addition to this, the net groundwater movements between years for the same month are known to vary (Congdon 1986). Congdon (1985) recorded a net positive contribution from groundwater during the 1979-1980 study, specifically 770 000m^3 was contributed which contrasts to the negative net input for this study. However, groundwater is complex and the vast differences between the estimated residuals and calculated loads highlight the need for an extensive study of groundwater in the region.

The relative importance of the sediment and vegetation should also be determined as it could have management implications. The vegetation stores recorded by Congdon (1986) are likely to have increased due to the increased domination of *Typha orientalis*. In some situations the reduction of one nutrient source can lead to the increase of another. Sediment is recognised as a considerable source of nutrients to wetlands on the Swan Coastal Plain as many wetlands do not have an outlet for these nutrients to be washed out (Davis *et al.* 1993). The sediment of Lake Joondalup has been known to have large stores of nutrients which, given the right circumstances, could result in release from the sediments and a resultant internal loading. Congdon (1986) reported approximately 30 tonnes of phosphorus and 1 262 tonnes of nitrogen within the top 100 mm of sediment. Phosphorus release from sediment, groundwater and surface runoff were considered impacts by Upton (1996) who found increasing nutrient concentrations north of the Ocean Reef Road culvert before the Beenyup Swamp flow connection was established.

The lag time in phosphorus and nitrogen loads from Beenyup Swamp affecting Lake Joondalup could be due to time taken for Ocean Reef culvert to commence flowing.

Decreases prior to flow stopping could be the result of a net export of nutrients or assimilation of nutrients as described previously. The water level of Lake Joondalup corresponds very well with the major water inputs from Beenyup Swamp and rainfall, and losses through evaporation. This is demonstrated by the fact that the water level increases or decreases with these variables almost instantaneously. The impact of rainfall and evaporation is similar between the current study and Congdon (1985), however the current study had slightly higher values explainable by different years and climates. Whilst transpiration was not included by Congdon (1985) it was a considerable loss.

Stormwater was not a large contributor in comparison to other nutrient sources, though its contribution has approximately doubled since Congdon (1986). Its recorded loads show that the first flush is evident due to high nutrient concentrations although the volume of water associated with rainfall is more important in terms of loads. Ove Arup & Partners (1994) state that nutrient concentrations in the water column have increased since 1985-1986 and the time Kinnear *et al.* (1997) collected their data, which corresponds to the period when direct discharge of stormwater runoff to Yellagonga Regional Park was substantially increased. However, this does not correlate with the findings of this budget. Studies at Lake Monger found stormwater and groundwater to be the major nutrient sources to this lake (CyMod Systems Pty Ltd 2002). After modelling the lake to determine best management, reducing nutrients from drains was deemed to have less impact than controlling lake level and intercepting groundwater to stop it entering the lake (CyMod Systems Pty Ltd 2002).

Beenyup Swamp has been recognised as a major source of nutrients to Lake Joondalup for some time and this study reaffirms its importance. Stormwater is currently a focus of management at Lake Joondalup. This focus should shift to stormwater and other impacts on Beenyup Swamp and the identification of the importance of groundwater, sediment and vegetation at Lake Joondalup. It would appear that Congdon's (1986) budget is still relevant with regards to Beenyup Swamp being the main source with further studies on groundwater recommended.

4.3 Stormwater

Stormwater is regarded as a major contributor of pollutants to a water body, particularly with regards to the first flush. The first flush event is recognised as providing a flux of nutrients following the accumulation of pollutants over the summer months (McFarlane 1983; Newman & Bishaw 1983). This study found much higher nutrient concentrations in the first sampling event than later rainfall events. The volume of water associated with these concentrations is more important in terms of loads. Higher nutrient concentrations and less rainfall can have the same loads as less nutrient concentrations and high rainfall. Other factors that may affect the stormwater quantity and quality are the time lapsed between rainfall, the rate of rainfall, the time since stormwater first started flowing and the time of the year depending on the start, or end, of the rainfall season (Lantzke, Gabriel & Haynes 1989).

All sampling occasions showed the pattern of initial high concentrations that decreased as rainfall continued. This indicated that some contaminants still accumulated over the winter periods. Concentrations of nutrients slightly decreased throughout the sampling period, although none ever reached the concentrations of rainfall, suggesting there is still a large quantity of nutrients coming from the catchment whether it is organic matter or sediment erosion for nitrogen and phosphorus respectively (Martinick McNulty Pty Ltd 1998b; McFarlane 1983; Newman & Bishaw 1983). Generally, following the initial first flush the predominantly residential catchments contributed similar quantities of nutrients; therefore one outfall cannot be specifically targeted for remediation. Nonetheless this would not be advised regardless of this fact based on the low nutrient loads that stormwater contributed in relation to other parameters of the budget.

Total nitrogen concentrations were higher than total phosphorus for all sampling, similar to previous results from examination of Lake Monger, and could be a result of the organic matter as is supported by analysis of the soluble nutrient forms recorded during this study (Martinick McNulty Pty Ltd 1998b; McFarlane 1983;

Newman & Bishaw 1983). Actual nutrient concentrations entering Lake Joondalup via outfalls were never as high as those recorded at Lake Monger and, considering the control of stormwater at Lake Monger was considered inadequate to cause any change, control measures would be even less so for Lake Joondalup (CyMod Systems Pty Ltd 2002). However, if the treatment of stormwater outfalls, and resultant reduction in nutrients entering Lake Joondalup, were to stop the lake from crossing the threshold into a cyanobacteria-dominated wetland then it could be a beneficial management technique. Total phosphorus generally had a higher soluble fraction than nitrogen with a less soluble fraction being found in other catchments (Tan 1992). The soluble forms could promote algal blooms, however, the loads of these bioavailable nutrients is not considered a large contributor in terms of the budget in comparison with surface water and stormwater.

In comparison to samples taken from a sump in Congdon (1986), values in this study generally had higher soluble concentrations, though these were compared to a sump where settling could have occurred. In general the concentrations of nutrients did not appear to have changed between these two studies; the only great difference was for those nutrient concentrations recorded during the first flush event.

4.4 Groundwater

Larger loads of nutrients were calculated to be exiting Lake Joondalup than entering. This could facilitate management of Lake Joondalup if this occurs all year, in conjunction with a reduced nutrient load from Beenyup Swamp, but this is not known and deserves further investigation. The easterly export of water from the lake recorded in May could be a result of the methods used. A landfill site located near the Neville bore could have caused the highest negative flow at this site. Groundwater flows into Lake Joondalup through the landfill were higher than those recorded by Woodward (2003) for a landfill at Lake Monger (105.6m^3/day or 528m^3/day) however, this could be due to the landfill characteristics such as their accepted wastes that are having an impact.

Average total phosphorus concentrations were quite consistent compared to nitrogen which could be a result of differences in the natural cycling of these nutrients. A covered landfill site near Neville bore operating during the 1950s and 1960s (Whincup Pty Ltd 2000) is suggested to cause the elevated total phosphorus concentrations at the Neville and Wallawa bores. Phosphorus concentrations at Neville bore were highest in May and then increased to be high in August, corresponding to initial rains and high rainfall months respectively. Wallawa bore exhibited the inverse relationship of Neville bore suggesting that whilst this bore may be impacted by the same landfill site, the lateral movement of groundwater may delay the effects. The Wallawa bore may also be exhibiting a water quality associated with a market garden that previously operated nearby (Whincup Pty Ltd 2000). The Pines and Poinciana bores appeared to be much less impacted by past land uses in terms of phosphorus, which included non-sewered residential areas, orchards and pine plantations (Whincup Pty Ltd 2000).

A saturated soil profile after initial rains allowed greater leaching of nitrogen following the first sampling month so average nitrogen increased. The landfill site increasingly impacted the groundwater quality at Neville bore. This impact differed to phosphorus, however, groundwater is known to be complex and impacts contaminants differently (Woodward 2003). Woodward (2003) states differences in mobility of nitrogen and phosphorus in groundwater flow as being derived largely from spatial variations in the composition of the landfill. Wallawa bore did not appear to be as affected by the landfill in terms of nitrogen compared to phosphorus. This may suggest that denitrification is occurring so lateral movement ceases, or that the old market garden is of greater importance to this bore. The water quality at Poinciana bore again remained constant, being slightly elevated possibly due to the area previously being unsewered. The spike in nitrogen concentration at the Pines bore resembles a point source contaminant, as it only occurred once and could be due to activities at the nearby orchard/farm or development in the east. Groundwater movement is slow so the findings could be a result of activities that occurred some distance to the east months or years beforehand.

The slightly lower average phosphorus concentrations west of Lake Joondalup compared to east may suggest assimilation of nutrients within the lake, although loads show this may not be the case. The consistency of water quality between the west bores indicates that point source contamination does not occur, with all increasing as rainfall increased. They may be buffered by the lake. Central Park West had the highest water table and this could explain its consistently high phosphorus concentrations resulting from greater contact with soil stores. Central Park East is in close proximity to this bore and it exhibited a vastly different water quality which may be due to the impact of the wetland or may just highlight the complexity of groundwater or the impact different soil types can inflict on groundwater quality due to their binding capacities and leaching. The consistency of water quality at Quarry Ramble bore could be due to the buffering effect of the lake. Lower nutrient concentrations at this bore could be associated with its proximity to the lake suggesting that the other bores are exhibiting nutrient concentrations affected by contamination between the lake and the bores.

Higher average nitrogen concentrations for the western bores could be due to losses from Lake Joondalup or differences in sampling technique. The higher nitrogen concentrations in groundwater at Lakeside Drive could be explained by its proximity to Neil Hawkins Park and the nitrogenous waste from elevated bird abundance, including the pollution from feeding these birds. Central Park East, Central Park West and Edith Cowan University are possibly collecting smaller quantities of nutrients from the associated constructed wetlands that are inhabited by avifauna, particularly ducks. Again soil types could play a large role in determining concentrations.

Differing groundwater nutrient concentrations east and west of Lake Joondalup could be attributed to actions in the lake and differing soil types. An additional explanation could be the bores themselves and the sampling technique. Within a bore there are certain screens and if these are not placed correctly the bore could be receiving a mixture of water which would give an inaccurate reading (Appelo & Postma 1994). Additionally, sampling of the catchment group bores was conducted with disposable bailers whilst the irrigation bores were pumped. Due to the volumes of water discarded, this could impact the composition of water collected (Appelo & Postma 1994). The depth the two different bore types were being pumped from, could also impact on water quality.

The bioavailable constituents show greater soluble proportions on the west, similar to total concentrations that may be due to error and variability in sampling the two different bores. On average greater phosphate entered the lake, which is an issue for this lake depending on what was exiting and what was assimilated. Phosphate generally seemed to be less for this study compared to that recorded by the Yellagonga Catchment Group, though concentrations at the Neville bore have increased. The differences in concentrations in comparison to the 2001 and 2003 data from the catchment group may either reflect the different methods of nutrient analysis or the high seasonality in the groundwater nutrients.

Ammonium concentrations in the groundwater are generally lower than nitrate due to the higher soil binding capacity of the soil for ammonium (Wood, 1975). However, this study showed a much higher concentration of ammonium than nitrate. This could suggest that the soil is saturated with ammonium and therefore cannot retain nutrients so they are being transported to the lake; or that the soil associated with the lake is having a considerable influence on the contaminants. Additionally, ammonium is likely to be more concentrated in anaerobic conditions and these conditions are evident with groundwater.

Much more phosphorus and nitrogen enter Lake Joondalup due to the landfill site compared to surrounding areas and this needs to be continually monitored to determine the impact over the whole year. Whilst the concentrations of nutrients from this landfill are not as high as those recorded for Lake Monger, they still exhibit an approximately double nutrient concentration compared to surrounding areas (Pierce, 1997). The extent of the nutrient contamination associated with this landfill and where the nutrients end up needs to be ascertained (Dunnet 2004; Jorstad, Jankowski & Acworth 2004; Lamontagne 2002). Further, the potential impact it may be having on contributing heavy metals to the lake needs clarification. This could most accurately be determined using radio-isotope techniques (Mandel &

Shiftan 1981). If the landfill is a serious problem it is difficult to manage unless groundwater is somehow diverted but this will impact the hydrology of Lake Joondalup and is likely to be quite expensive. Regardless of whether this will occur, investigation is still required to determine the impact.

The landfill site seems to be exerting the greatest consistent impact on the water quality of groundwater entering Lake Joondalup, though this could be counteracted by the losses of nutrients to the west of Lake Joondalup. At Lake Monger, the low permeability of the lake bed facilitated the accumulation of nutrients within the lake, as it acted as an aquitard (Woodward 2003). Therefore, such parameters are important to determine for Lake Joondalup. The differing flow rates determined during this study were greatly dependent on the accuracy of parameters such as hydraulic conductivity and aquifer thickness. It is important that the accuracy of these parameters is determined to better understand the lake's hydrology. This study would be long term to accommodate the variability of groundwater both within and between sampling years.

4.5 Surface water inflow

Ocean Reef Road culvert phosphorus loads mimicked that of Beenyup Swamp suggesting they are highly connected and little processing occurs in the southern basin to change concentrations before they are discharged into main Lake Joondalup. This was the same for total nitrogen loads. Both phosphorus and nitrogen loads for the two sampling sites tended to be highly inconsistent in a similar fashion to the individual nutrient concentrations.

Total phosphorus and nitrogen concentrations recorded during this sampling period were classed as eutrophic and mesoeutrophic-eutrophic respectively maintaining the lakes eutrophic state. Total nitrogen concentrations generally decreased at Beenyup Swamp over the sampling period as a result of the loss of matter accumulated over the summer months, a similar pattern was identified by Upton (1996). Following the drying out of the lake, upon refilling there are nutrients released from the sediment to the water column (Baldwin & Mitchell 2000; Qiu & McComb 1994) which could also explain the higher initial nutrient concentrations. Concentrations at the end of August were slightly higher possibly corresponding with increased rainfall which may have flushed some nutrients out of Beenyup Swamp. Ocean Reef Road culvert concentrations followed the same pattern but were consistently higher than Beenyup Swamp, which could be the result of the rewetting of dry soil within its basin or perhaps a higher quantity of nutrients because of accumulation before the culvert commenced flowing. A spike in nitrogen concentration at the beginning of July is explained by the increased flow following the connection of South Lake Joondalup to the main lake.

Phosphorus concentrations were much less stable for both sites, with Beenyup having higher concentrations following the first flush, which has occurred in previous studies (Kinnear *et al.* 1997; Upton 1996). The phosphorus concentrations recorded at Ocean Reef Road culvert whilst varying throughout the sampling period, had a smaller range of variability, suggesting the mediation of phosphorus in the south section which could be a result of assimilation by vegetation and the sediment. Variability in the phosphorus concentrations during the sampling period was experienced in a study conducted by Upton (1996), who determined that this pattern could be a result of the dense stands of macrophytes as they absorb nutrients and release nutrients to the water column. These plants may also absorb nutrients from the sediments and release them into the water column (Upton 1996).

A great deal of the total nitrogen and at least half of the total phosphorus was in organic form, coinciding with a study by Kinnear *et al.* (1997), owing to large plant matter exiting Beenyup Swamp. Nitrate/nitrite and ammonium were slightly lower at Ocean Reef Road culvert as has occurred before suggesting that some soluble forms are being assimilated in the south section by aquatic flora or sediment.

Total and soluble nutrient concentrations recorded from Beenyup Swamp and Ocean Reef Road culvert were towards the higher end or much higher than what Kinnear *et al.* (1997) recorded, though this could be a result of the different areas sampled. In comparison to Congdon (1986), phosphorus concentrations have increased whilst nitrogen concentrations have generally decreased. This trend coincides with the identification of the possible switch of Lake Joondalup from a phosphorus limited lake to a nitrogen limited lake.

4.6 Conclusions and Recommendations

Nutrient concentrations within the main section of Lake Joondalup have significantly increased over the last three decades, corresponding to increased occurrences of algal blooms. The decreases in nutrient concentrations in south Lake Joondalup suggest that much is being exported to the main lake thus detrimentally impacting it. However, it should be restated that the lake has a high variability of water quality between years and the data were not transformed to account for confounding factors such as evapo-concentration. Regardless, management of the nutrient sources to Lake Joondalup is required to ensure algal blooms do not become the normal condition for the lake.

Sampling of stormwater, groundwater and surface flow from adjoining swamps has indicated that Beenyup Swamp is the major contributor of nutrients to Lake Joondalup. This source has such an influence that Kinnear *et al.* (1997) suggest that it may be responsible for changes in the lake causing total nitrogen : total phosphorus and inorganic nitrogen : filterable phosphorus ratios to decrease and nitrogen to become the more limiting nutrient. Beenyup Swamp has been identified as a major source of nutrients since Congdon (1986), however little management has followed.

The Yellagonga Regional Park Management Plan (Dooley *et al.* 2003) suggests implementing stormwater upgrades as a priority. This may be beneficial for keeping the lake below the cyano-bacteria dominated threshold, but it is unlikely to produce a drastic reduction in terms of the total nutrient supplies to the lake. The Management Plan encourages the development of an integrated Catchment Management Plan to reduce pollutants to the lake and this is the recommended strategy based upon results from this study. External pollutants entering Beenyup Swamp via Walluburnup Swamp necessitate identification and reduction. The harvesting of proportions of macrophytes may also be beneficial, though further investigation is required into this avenue. Continued monitoring of water quality is essential, to ensure the condition of the lake does not decline further and also to outline the effectiveness of the management implemented.

In conjunction with this, further studies are recommended to be conducted on the stores of nutrients in groundwater, sediment and vegetation. Sediments are known to store large quantities of nutrients and, if anaerobic conditions become prevalent in the lake, it may be a considerable source. Further research into the impact of groundwater and an understanding of its movements should be a priority. The impact of the landfill requires verification, and though the remediation of this source may be costly it could be quite important to ensure the conservation values of the lake are upheld.

This study suggests that Lake Joondalup has degraded further over the years. Beenyup Swamp contributed the majority of nutrients, its influence has increased since studies in 1986. In terms of cost effectiveness, both short and long term, Beenyup Swamp should be the foremost focus of management for nutrient reductions with investigations into groundwater undertaken as a close secondary consideration. Constructive management is paramount to prevent further deterioration of Lake Joondalup.

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6 APPENDICES

APPENDIX I Bore Monitoring Calculation Sheet

Length to bottom of bore + Length of fox whistle = **Depth to bore**

___________m + 0.22m = __________m

Length to water + Length of fox whistle = **Depth to water**

___________m + 0.22m = __________m

Depth to bore – Depth to water = **Length of water column**

______m - ______m = ______m x 100 = ________cm

π (radius of casing)^2 = **Area of casing**

For 20mm casing 3.14 (1 cm)^2 = 3.14 cm^2

3.14 cm^2 x length of water column = **Volume of water in bore**

3.14 x ___________cm = __________cm^3 ÷ 1000 = ___________L

Volume of water in bore x 3 = Volume of water to be purged from bore

___________L x 3 = ___________L

Volume of water to be purged x 4 = number of full bailers (250mL each) to be purged (ie. taken out of bore, before a sample is taken for analysis)

___________L x 4 = ___________

APPENDIX II Monthly lake-to-pan coefficients for the estimation of lake evaporation from class A pan evaporation (Black & Rosher, 1980 cited in Congdon, 1985).

Month	Pan factor
January	0.6
February	0.6
March	0.7
April	0.8
May	0.9
June	1.0
July	1.0
August	1.0
September	0.8
October	0.8
November	0.7
December	0.7
Annual Average	**0.8**

APPENDIX III Location of Discharge Points surrounding Lake Joondalup

All discharge points are numbered according to that of Ove Arup & Partners (1994).

Discharge point/ Description	Type	WGS 84	Aus Geod 84	Comments
1A - Wanneroo Rd	Swale, outfalls, pipes connecting swales	S 31° 43.288' E 115° 47.106'	S 31° 43.362' E 115° 47.016'	GPS coordinates taken while standing on western side of road, southern most pipe.
1B - Wanneroo Rd	Bubble up grate	S 31° 43.239' E 115° 47.084'	S 31° 43.311' E 115° 46.994'	GPS coordinates taken while standing on the top of the grate.
1C - Wanneroo Rd/Pines	Possible sump/swale	S 31° 43.661' E 115° 47.305'	S 31° 43.733' E 115° 47.214'	GPS coordinates taken while standing in the middle of the depression next to the road.
1D - Water Depot on Wanneroo Rd	Sump	S 31° 43.835' E 115° 47.446'	S 31° 43.909' E 115° 47.356'	GPS coordinates taken while standing over pipe, outside the fence closest to the carpark.
1E - Sommerville Waters	Sump	S 31° 44.163' E 115° 47.358'	S 31° 44.236' E 115° 47.269'	GPS coordinates taken while standing on top of the grate.
2	Bubble up grate	S 31° 44.310' E 115° 47.388'	S 31° 44.382' E 115° 47.297'	GPS coordinates taken while standing on top of the grate.
3	Bubble up grate	S 31° 44.436' E 115° 47.463'	S 31° 44.510' E 115° 47.375'	GPS coordinates taken while standing on top of the grate.
3A – after Woonan St	Bubble up grate	S 31° 44.514' E 115° 47.565'	S 31° 44.587' E 115° 47.475'	GPS coordinates taken while standing on top of the grate.
4	Outfall over terrain	S 31° 44.517' E 115° 47.606'	S 31° 44.590' E 115° 47.516'	GPS coordinates taken while standing on top of the outflow pipe.

5	Outfall in tunnel	S 31° 44.567' E 115° 47.628	S 31° 44.641' E 115° 47.539'	GPS coordinates taken while standing on top of pipe, on weeds etc.
6	2 bubble up grates in a sump	S 31° 44.611' E 115° 47.665'	S 31° 44.684' E 115° 47.575'	GPS coordinates taken while standing on the eastern edge of the sump.
8	2 outfalls into lake	S 31° 44.903' E 115° 47.597'	S 31° 44.976' E 115° 47.508'	GPS coordinates taken while standing in front of the outflow pipes.
9	Outfall into wetland	S 31° 45.163' E 115° 47.704'	S 31° 45.236' E 115° 47.614'	GPS coordinates taken while standing on top of the outflow pipe.
11	Outfall	S 31° 45.597' E 115° 47.904'	S 31° 45.672' E 115° 47.815'	GPS coordinates taken while standing on top of the outflow pipe.
12	Constructed wetland	S 31° 45.700' E 115° 47.918'	S 31° 45.773' E 115° 47.829'	GPS coordinates taken while standing approximately over the inflow pipe. Lots of erosion, creating gullies.
13	Sump	S 31° 45.993' E 115° 48.078'	S 31° 46.066' E 115° 47.988'	GPS coordinates taken while standing on top of the grate.
14	Outfall	S 31° 46.312' E 115° 48.172'	S 31° 46.384' E 115° 48.083'	GPS coordinates taken while standing on top of the pipe.
14A - James Spiers Dr	Constructed wetland	S 31° 46.448' E 115° 48.130'	S 31° 46.519' E 115° 48.041'	GPS coordinates taken while standing on the bridge.
Future Sump 31 & 17	Swale/sump	S 31° 46.588' E 115° 47.756'	S 31° 46.660' E 115° 47.666'	GPS coordinates taken while standing over underpass.
30	Sump	S 31° 46.591' E 115° 47.569'	S 31° 46.663' E 115° 47.481'	GPS coordinates taken while standing at gate in fence.
30A - Opposite Fox Tce	Sump/Bubble up grate	S 31° 46.790'	S 31° 46.863'	GPS coordinates were taken while standing on top of the grate.

		E 115° 47.534'	E 115° 47.444'	
30B - Opposite McCubbin Bvd roundabout	Sump/Bubble up grate	S 31° 46.852' E 115° 47.675'	S 31° 46.927' E 115° 47.582'	GPS coordinates taken while standing on top of the grate.
30C - Opposite Fullwood Wk	Sump	S 31° 46.966' E 115° 47.769'	S 31° 47.036' E 115° 47.675'	GPS coordinates taken while standing on top of the grate.
16	Sump	S 31° 46.218' E 115° 47.536'	S 31° 46.294' E 115° 47.445'	GPS coordinates taken while standing over the outflow pipe.
15	Sump	S 31° 45.781' E 115° 47.347'	S 31° 45.850' E 115° 47.257'	GPS coordinates taken while standing next to the bubble-up grate, within the fence.
15A - Edgewater Drive	Sump	S 31° 45.340' E 115° 46.851'	S 31° 45.419' E 115° 46.763'	GPS coordinates taken while standing at the gate.
15B - Lakeside Drive	Sump C	S 31° 45.240' E 115° 46.661'	S 31° 45.310' E 115° 46.572	GPS coordinates taken while standing approximately directly opposite the outflow pipe
15C - Lakeside Drive	Sump B	S 31° 45.183' E 115° 46.675'	S 31° 45.258' E 115° 46.582'	GPS coordinates taken while standing at the fence, approximately over the top of the outflow pipe.
15D - Lakeside Drive	Sump A	S 31° 45.012' E 115° 46.631'	S 31° 45.086' E 115° 46.544'	GPS coordinates taken while standing at the gate, approximately over the top of the outflow pipe.
15E - Cockatoo Ridge	Sump	S 31° 44.791' E 115° 46.672'	S 31° 44.866' E 115° 46.588'	GPS coordinates taken while standing at the gate.
15F - Bend in Cockatoo Ridge	Sump	S 31° 44.717' E 115° 46.632'	S 31° 44.792' E 115° 46.547'	GPS coordinates taken while standing at the gate. Were some large green tanks next to sump, for further investigation later.
15G - Neil Hawkins Park	Bubble up grate/sump	S 31° 44.629' E 115° 46.739'	S 31° 44.706' E 115° 46.652'	GPS coordinates taken while standing on the grate.

15H - Discharge in Neil Hawkins bush	Outfall with a tiny little depression of less than a metre.	S 31° 44.561' E 115° 46.604'	S 31° 44.634' E 115° 46.514'	GPS coordinates taken while standing next to the outfall pipe.
15I - Lakeside Dve just before Upney Mews	Sump	S 31° 44.233' E 115° 46.496'	S 31° 44.307' E 115° 46.405'	GPS coordinates taken while standing at the gate.
15J - Lakeside Dve just after Upney Mews	Sump	S 31° 44.116' E 115° 46.475'	S 31° 44.188' E 115° 46.386'	GPS coordinates taken while standing at the gate.
15K - Piped outfall off far northern part of Lakeside Drive	Sump with outfall	S 31° 43.887' E 115° 46.457'	S 31° 43.958' E 115° 46.368'	GPS coordinates taken while standing approximately opposite the outfall site not that I could see the outfall.
15L - South of Joondalup Dr roundabout	Sump/Swale	S 31° 43.139' E 115° 46.224'	S 31° 43.213' E 115° 46.136'	GPS coordinates taken while standing on the first site of drainage as you enter the roundabout on Joondalup Dr.
15M - North of Joondalup Dr/Burns Beach Rd roundabout	Sump	S 31° 43.063' E 115° 46.258'	S 31° 43.135' E 115° 46.168'	GPS coordinates taken while standing at COJ sign near Water Corporation hole.
15N - Eastern end of Drovers Pl	Bubble up grate	S 31° 43.025' E 115° 46.808'	S 31° 43.100' E 115° 46.718'	GPS coordinates taken while standing on top of the grate.
Caves near Neil Hawkins	Swale?	S 31° 44.198' E 115° 46.608'	S 31° 44.278' E 115° 46.526'	GPS coordinates taken while standing on the bridge just south of the caves.
[redacted]				
Pines	Bore	S 31° 43.538' E 115° 47.059'	S 31° 43.612' E 115° 46.972'	GPS coordinates taken while standing next to the bore.
Wallawa	Bore	S 31° 44.224' E 115° 47.336'	S 31° 44.297' E 115° 47.246'	GPS coordinates taken while standing next to the bore.
Neville	Bore	S 31° 44.635' E 115° 47.628'	S 31° 44.708' E 115° 47.540'	GPS coordinates taken while standing next to the bore.

Poinciana	Bore	S 31° 46.285' E 115° 48.142'	S 31° 46.359' E 115° 48.053'	GPS coordinates taken while standing next to the bore.
Ashley Road	Bore	S 31° 43.508' E 115° 47.284'	S 31° 43.582' E 115° 47.198'	GPS coordinates taken while standing next to the bore.
Caporn Street	Bore	S 31° 44.016' E 115° 48.655'	S 31° 44.088' E 115° 48.568'	GPS coordinates taken while standing next to the bore.
Togno Park	Bore	S 31° 45.052' E 115° 48.454'	S 31° 45.126' E 115° 48.365'	GPS coordinates taken while standing next to the bore.
Christie Court	Bore	S 31° 44.675' E 115° 47.749'	S 31° 44.750' E 115° 47.658'	GPS coordinates taken while standing next to the bore.
Nannatee Park	Bore	S 31° 45.736' E 115° 48.304'	S 31° 45.809' E 115° 48.217'	GPS coordinates taken while standing next to the bore.
Edith Cowan University	Bore	S 31° 45.215' E 115° 46.342'	S 31° 45.288' E 115° 46.251'	GPS coordinates taken while standing next to the bore.
Quarry Ramble	Bore	S 31° 45.791' E 115° 47.349'	S 31° 45.863' E 115° 47.260'	GPS coordinates taken while standing next to the bore.
Lakeside Drive	Bore	S 31° 44.679' E 115° 46.607'	S 31° 44.752' E 115° 46.518'	GPS coordinates taken while standing next to the fence around the bore.
Central Park West	Bore	S 31° 44.805' E 115° 46.222'	S 31° 44.877' E 115° 46.133'	GPS coordinates taken while standing next to the bore.
Central Park East	Bore	S 31° 44.737' E 115° 46.321'	S 31° 44.811' E 115° 46.233'	GPS coordinates taken while standing next to the bore.

Ocean Reef Rd connection	Culvert	S 31° 46.612' E 115° 47.746'	S 31° 46.685' E 115° 47.656'	GPS coordinates taken while standing on top of the underpass.
Beenyup and SLJ connection	Lake	S 31° 47.079' E 115° 47.926'	S 31° 47.155' E 115° 47.834'	GPS coordinates taken while standing in the middle of the lake.

APPENIDX IV Average nutrient concentrations from various studies used to determine the current trajectory of water quality at Lake Joondalup.

North section of Lake Joondalup

Year	Day/Month	Total P (µg/L)	Reactive P (µg/L)	Organic P (µg/L)	Total N (µg/L)	Organic N (µg/L)
1973	February	38.5	15	23.5	2908.5	2672.5
	March	40.25	32.5	7.75	3078	2853.25
	April	57.25	27.5	29.75	2647.75	2408.5
	June	38	3.75	34.25	1534.25	1522.5
	August	42.75	4.5	38.25	1706.5	1674.5
	October	61.5	23.75	37.5	2036.25	1472.5
	December	62.25	9	53.25	1455.75	1178.25
1978	September	13	9	4	1838	1701
	October	12	8	4	1558	1404
	November	26	14.5	11.5	1553.5	1412.25
	December	30.96	14.92	16.04	1550.71	1496.83
1979	January	42.40	12.95	29.45	2427.75	2374.75
	February	39.25	19.25	19.5	2392.25	2366
	March	89.79	19.71	70.07	2837.89	2780.75
	April	78.00	37.67	40.34	3592.92	3559.17
	May	84.73	60.40	24.33	3302.70	3247.73
	June	81.88	37.38	44.50	2999.75	2969.63
	July	55.29	39.38	15.92	2579.59	2542.04
	August	49.60	39.85	9.75	2448.85	2411.05
	September	55.13	45.63	8.75	2481.25	2445.00
	October	64.88	57.75	7.13	1535.50	1509.38
	November	57.00	57.45	5.95	2716.90	2682.45
	December	70.50	61.00	9.50	3043.38	2965.88
1980	January	64.78	35.06	29.71	3254.99	3187.24
	February	97.63	61.38	36.25	5411.38	5341.00
	March	163.25	127.25	36	12199.25	12145.25
	April	160.5	97	63.5	8280.25	8216.25
	May	71.6	27.2	44.4	2018.8	1983
	June	65.59	29.47	36.13	2511.63	2480.28
	July	47.92	18.68	29.24	1758.02	1723.01
	August	31.10	17.01	14.08	1020.32	990.28
	September	35.69	22.03	13.67	1210.89	1195.15
	October	37.62	18.68	18.94	1123.93	1105.19
	November	39.25	26.53	12.72	1540.89	1527.33
	December	77.67	40.67	37	1545.67	1509.67
1985	April	200	190	10	11500	11500
	May	80	50	10	4000	4000
	June	70	20	20	2500	2500
	July	50	10	15	1000	1000
	August	40	15	10	1500	1500
	September	60	50	10	2000	2000
	October	50	10	15	2000	2000
	November	20	10	15	2500	2500
	December	100	20	50	2000	2000
1986	January	90	65		3500	3500
	February	80	30	20	3000	3000
	March	100	20	50	10000	9500
	April	10	10	0	4500	4000
1992	January	50.40	16.40		1611	1636
	February	35.88	8.75		2212	2199
	March	50.92	20.00		2632	2614
	April	68.75	39.75		2938	2912

	May	79.63	42.00		2801	2766
	June	18.13	16.75		2282	2265
	July	121.50	21.63		1662	1652
	August	86.13	16.50		1659	1645
	September	64.00	51.33		1494	1487
	October	142.88	16.38		1425	1415
	November	71.50	19.75		1677	1661
	December	71.88	8.75		1621	1592
1993	January	88.88	11.00		1658	1636
	February	70.00	9.00		2144	2124
	March	241.42	25.00		2966	2944
1995	July	114.73	32.82		2469.11	
	August	35.90	6.62		1506.89	
2001	April	253.75			10100	
	May	181			4000	
	June	252.5			4750	
	July	333.75			5725	
	August	193			4066.667	
	September	100			3000	

Nitrate/Nitrite N (µg/L)	Ammonium N (µg/L)	Chlorophylla (µg/L)	Source
	236		Congdon (1973)
	224.75		Congdon (1973)
	239.5		Congdon (1973)
	36.75		Congdon (1973)
	34.5		Congdon (1973)
	563.75		Congdon (1973)
	265		Congdon (1973)
8	129	0.6	Congdon (1986)
6	148	1.5	Congdon (1986)
4.25	136.75	18.425	Congdon (1986)
2.96	50.71	8.69	Congdon (1986)
5.30	40.20	7.04	Congdon (1986)
3.25	24	8.6	Congdon (1986)
1.89	59.89	13.60	Congdon (1986)
5.42	28.34	16.67	Congdon (1986)
3.30	51.67	16.62	Congdon (1986)
2.63	27.50	15.85	Congdon (1986)
1.50	36.04	8.37	Congdon (1986)
1.90	35.90	11.68	Congdon (1986)
3.38	32.88	11.73	Congdon (1986)
3.13	23.00	14.45	Congdon (1986)
2.75	31.70	25.71	Congdon (1986)
4.00	73.50	24.13	Congdon (1986)
2.94	64.81	32.51	Congdon (1986)
2.50	67.88	99.29	Congdon (1986)
5	49	169.55	Congdon (1986)
2.5	61.5	104.35	Congdon (1986)
3.4	44.4	42.2	Congdon (1986)
3.44	27.91	30.40	Congdon (1986)
7.20	27.81	6.90	Congdon (1986)
4.03	26.01	4.68	Congdon (1986)
1.61	14.13	4.71	Congdon (1986)
3.34	15.40	3.04	Congdon (1986)
1.69	11.86	9.79	Congdon (1986)
2	34	21.2	Congdon (1986)
All less than 40	All less than 200	All less than 25 mg/m3	Davis & Rolls (1987)
4.00	17.17	6.65	
3.63	9.75	18.49	
1.33	16.42	24.26	
2.75	22.88	18.96	

2.75	31.88	17.19	Kinnear *et al.* (1997)
9.25	8.25	6.90	
2.75	6.38	6.38	
6.50	7.63	5.74	
2.58	4.17	3.26	
2.25	7.75	7.14	
3.71	17.50	4.56	
4.75	24.75	6.94	
2.63	19.00	7.23	
4.75	14.63	1.73	
4.25	17.08	3.45	
18.94	147.90	4.00	Lund, Brown & Lee (2000)
9.94	69.80	1.81	
		24.5	Lamb (2001)
		20	
		1.75	
		1.25	
		1.43	
		1.4	

Central section of Lake Joondalup

Year	Day/Month	Total P (µg/L)	Reactive P (µg/L)	Organic P (ug/L)	Total N (µg/L)	Organic N (µg/L)
1973	February	94	32	62	3819	3042
	March	60.5	40	20.5	3997	3367
	April	56	7.5	48.5	3010.5	2211
	June	85	42.5	42.5	1322	1238
	August	128	14.5	113.5	2100.5	1944.5
	October	119	78.5	40.5	2339	1609
	December	127.5	25.5	102	1236	953.5
1978	September	159.33	126.67	31.67	1656.00	1427.67
	October	129.67	105.67	24.00	1380.33	1311.33
	November	83.11	42.22	40.89	1593.44	1506.56
	December	91.72	38.19	53.53	1669.03	1633.13
1979	January	161.90	46.23	115.68	2430.83	2386.83
	February	159.25	72.67	86.58	2733.58	2637.50
	March	140.44	56.25	84.13	3168.88	3060.44
	April	146.96	65.25	81.71	2689.21	2407.21
	May	156.16	82.75	73.41	3041.93	2819.23
	June	139.50	55.00	84.50	2424.92	2315.42
	July	161.50	124.25	37.25	2058.83	2015.42
	August	157.60	124.47	33.13	2161.80	2091.33
	September	168.08	142.67	25.42	2122.17	2048.50
	October	120.33	93.33	27.00	2203.92	2149.50
	November	144.53	101.13	43.27	2819.93	2761.33
	December	165.42	114.75	50.67	3019.00	2887.42
1980	January	90.88	50.15	40.73	3647.08	3563.66
	February	176.50	50.63	125.88	4148.25	3923.63
	March	176.75	100.50	73.75	11349.75	11294.25
	April	117.88	67.88	50.00	4647.88	3770.75
	May	92.83	31.13	61.70	1922.65	1625.40
	June	276.65	148.70	127.96	2810.75	2759.36
	July	102.24	60.25	40.21	1460.82	1432.29
	August	88.81	57.94	30.87	1048.67	956.16
	September	85.13	59.76	25.38	1285.08	1229.49
	October	75.84	37.31	38.54	1230.70	1210.82
	November	71.46	44.65	26.81	1589.99	1568.86
	December	206.00	176.00	30.00	1840.00	1647.00
1985	April	200	0	0	11500	
	May	100	60	25	3000	
	June	60	20	40	1000	
	July	50	25	20	1000	
	August	60	10	50	1900	
	September	50	60	25	1900	Virtually exactly the same as for Total N
	October	25	10	20	1000	
	November	20	10	0	1900	
	December	60	20	50	1800	
1986	January	70	25	50	2200	
	February	180	15	150	3000	
	March	100	20	60	6700	
	April	10	10	0	1800	
1992	January	65.67	21.71		2234	2215
	February	59.50	7.50		2651	2625
	March	92.42	33.33		2586	2570
	April	93.13	37.00		2731	2702

	May	89.88	43.00		2484	2424
	June	27.75	24.88		1832	1788
	July	222.38	52.25		1370	1339
	August	116.00	40.50		1400	1361
	September	76.83	57.50		1324	1311
	October	232.25	40.88		1995	1985
	November	116.38	35.25		1495	1458
	December	61.50	10.00		2122	2094
1993	January	137.63	10.88		2080	2057
	February	105.20	43.80		2574	2560
	March	217.33	28.67		2945	2926
1995	August	98.33	61.96		1641.87	
	September	220.68	112.22		1816.91	
2000	August	146	26.5		580.5	
	September	66.5	5.5		368.5	
	October	41.5	4		427.5	
2001	May	316.67			12000.00	
	June	156.25			6500.00	
	July	417.50			6050.00	
2001	August	278.73	27.40		3692.46	
	September	251.36	15.79		3076.19	
	October	67.37	14.12		3400.00	
	November	93.65	23.97		4428.57	
	December	86.04	9.47		5428.57	
2002	January	133.11	24.98		5857.14	
	February	646.80	91.94		11333.33	
	July	70.04	5.41		3285.71	
	August	60.90	4.06		4000.00	

Nitrate/Nitrite N (µg/L)	Ammonium N (µg/L)	Chlorophyll a (µg/L)	Reference
0	777		Congdon (1973)
0	630		
0	799.5		
0	84		
0	156		
0	730		
0	282.5		
24.33	204.00	3.63	Congdon (1986)
5.67	63.33	17.43	
5.67	55.86	23.23	
4.56	31.31	13.68	
5.75	38.25	9.45	
6.50	93.25	10.50	
7.50	100.94	25.89	
6.50	275.50	24.96	
13.91	208.79	31.67	
16.50	93.00	15.35	
2.75	40.67	26.49	
8.00	62.47	11.17	
20.17	53.50	8.04	
11.50	38.83	8.90	
10.73	51.27	60.17	
6.92	124.67	35.82	
3.04	80.39	34.84	
2.75	221.88	29.89	
4.50	51.00	74.20	
3.63	873.50	87.06	
23.00	273.63	15.57	
5.24	46.15	69.88	
8.67	14.88	19.94	
10.97	79.29	3.96	
5.25	50.34	4.46	
2.24	17.64	5.08	
5.99	15.14	26.67	
5.00	188.00	42.40	
All less than 25	All less than 100	All less than 20mg/m3	Davis & Rolls (1987)
5.17	16.83	25.60	
2.75	47.38	29.30	
3.33	13.33	32.22	
11.88	18.00	24.16	

16.00	44.63	14.26	Kinnear *et al.* (1997)
6.88	36.88	7.18	
6.00	21.38	15.69	
6.50	32.00	5.35	
2.50	10.42	4.48	
2.50	7.25	45.34	
1.38	35.63	6.15	
1.88	25.63	27.88	
1.00	21.63	56.59	
5.80	11.00	39.18	
3.67	15.17	11.48	
12.19	165.03	2.20	Lund, Brown & Lee (2000)
32.83	356.40	2.66	
39.5	124		
22.5	69		
32.5	30		
		40.50	Lamb (2001)
		14.63	
		2.88	
30.00	144.03		Lund (2002 unpublished)
17.61	221.1		
16.88	16.98		
3.63	11.75		
9.47	11.22		
8.03	31.14		
8.68	52.49		
5.68	28.60		
5.68	29.03		

South section of Lake Joondalup

Year	Day/Month	Total P (µg/L)	Reactive P (µg/L)	Organic P (ug/L)	Total N (µg/L)	Organic N (µg/L)
1978	November	814.5	605	159.5	3184	1701.5
	December	543	390.5	165	4382	3817
1979	January	1002.2	820	243.4	3662	3571.8
	February	750.25	589.25	186	2892	2787.5
	March	757	700	42.5	3682.75	3496
	April	525.33	475.67	49.67	3757.67	3728.67
	May	204	191.5	12.5	1970	1940
	June	269.75	178.25	91.5	2127.5	2089.25
	July	343.5	282	61.5	1777	1763
	August	344.4	246.2	98.2	1744.8	1610.8
	September	304.5	276.75	27.75	1759	1639.5
	October	318	233	85	1772.75	1702.75
	November	532.20	387.81	144.39	5219.35	5069.72
	December	449.5	409.33	40.167	2106.67	1585.33
1980	January	544.571	376.14	168.429	2655.57	2606
	February	399	300	99	2716.14	2675.43
	March	371.85	288.95	82.9	5618.7	5589.1
	April	783.25	287.25	496	14375.13	14270.88
	May	384.5	265.5	119	1804	1563.83
	June	233.003	177.503	55.500	1621.498	1549.000
	July	348.875	255.25	93.625	1350.375	1255.375
	August	320.5	271.5	49	884.5	833
	September	364.5	259.5	105	1087.5	1010.5
	October	270	226.5	43.5	1114	1093
	November	221	194	27	1114.5	1104
1992	January	440.50	310.00		3827	3505
	February	337.00	211.50		2025	1774
	March	389.00	331.67		1370	1330
	April	236.00	108.00		1414	1290
	May	185.50	141.50		1085	1064
	June	81.50	88.00		1190	1150
	July	327.50	252.50		962	896
	August	240.00	145.00		1192	1116
	September	182.50	132.50		999	975
	October	459.50	64.75		981	972
	November	303.50	220.00		997	984
	December	100.75	71.25		958	945
1993	January	126.00	56.50		1963	1942
	February	115.50	93.00		1597	1563
	March	320.17	239.50		1638	1617

Nitrate/Nitrite N (µg/L)	Ammonium N (µg/L)	Chlorophyll a (µg/L)	Reference
16.5	1461	145.67	Congdon (1986)
136.25	428	153.725	
13.2	77	37.08	
9.5	153.5	19.025	
9.75	164.5	8.3	
2	27	21.07	
11	19	18.35	
3.5	34.75	83.875	
1.75	12.25	91.55	
19.6	114.4	9.24	
45.25	74.25	1.525	
25.75	44.25	8.725	
28.13	121.50	776.25	
4	517.33	59.7167	
5.286	44.286	82.314	
2.57	38.143	88.5	
2.75	26.85	151.56	
10	95.5	864.7375	
13.83	226.33	97.4	
14.253	55.748	1.200	
23.75	71.25	2.1375	
21.5	30	4.3	
39.5	37.5	3.85	
2	19	53.4	
3	7.5	4.85	
9.50	313.00	102.75	Kinnear *et al.* (1997)
180?	71.00	51.15	
11.00	14.67	24.60	
16.00	30.00	2.30	
6.00	14.50	7.20	
20.00	20.50	0.25	
31.00	35.00	2.35	
30.00	46.50	0.95	
7.25	17.25	1.03	
5.00	4.50	3.08	
5.00	8.75	1.70	
1.50	11.75	70.43	
2.25	18.75	14.48	
20.50	13.50	6.65	
4.00	17.17	5.28	

Main section of Lake Joondalup

Year	Day/Month	Total P (µg/L)	Reactive P (µg/L)	Inorganic P (ugP/L)	Organic P (ugP/L)	Total N (µg/L)
1973	February	66.25	23.50	42.75		3363.75
	March	50.38	36.25	14.13		3537.50
	April	56.63	17.50	39.13		2829.13
	June	61.50	23.13	38.38		1428.13
	August	85.38	9.50	75.88		1903.50
	October	90.25	51.13	39.00		2187.63
	December	94.88	17.25	77.63		1345.88
1975	January	25.00	24.00		1.00	1123.00
	February	52.00	1.00		51.00	1234.00
	March	55.00	10.00		45.00	3801.00
	April	44.00	35.00		9.00	3527.00
	May	36.00	2.00		34.00	2090.00
	June	40.00	20.00		20.00	1740.00
	July	45.00	12.00		33.00	1845.00
	August	40.00	32.00		8.00	2400.00
	September	62.00	28.00		34.00	195.00
	November	48.00	12.00		36.00	2355.00
	December	38.00	33.00		5.00	3378.00
1978	September	86.17	67.83		17.83	1747.00
	October	70.83	56.83		14.00	1469.17
	November	54.56	28.36		26.20	1573.47
	December	61.34	26.55		34.79	1609.87
1979	January	102.15	29.59		72.56	2429.29
	February	99.25	45.96		53.04	2562.92
	March	115.11	37.98		77.10	3003.38
	April	112.48	51.46		61.02	3141.06
	May	120.45	71.58		48.87	3172.31
	June	110.69	46.19		64.50	2712.33
	July	108.40	81.81		26.58	2319.21
	August	103.60	82.16		21.44	2305.33
	September	111.60	94.15		17.08	2301.71
	October	92.60	75.54		17.06	1869.71
	November	100.77	79.29		24.61	2768.42
	December	117.96	87.88		30.08	3031.19
1980	January	77.83	42.61		35.22	3451.04
	February	137.06	56.00		81.06	4779.81
	March	170.00	113.88		54.88	11774.50
	April	139.19	82.44		56.75	6464.06
	May	82.21	29.16		53.05	1970.73
	June	171.12	89.08		82.04	2661.19
	July	75.08	39.47		34.73	1609.42
	August	59.95	37.48		22.48	1034.49
	September	60.41	40.89		19.52	1247.99
	October	56.73	27.99		28.74	1177.32
	November	55.35	35.59		19.76	1565.44
	December	141.84	108.34		33.50	1692.84
1985	April	200.00	95.00		5.00	11500.00
	May	90.00	55.00		17.50	3500.00
	June	65.00	20.00		30.00	1750.00
	July	50.00	17.50		17.50	1000.00
	August	50.00	12.50		30.00	1700.00

	September	55.00	55.00		17.50	1950.00
	October	37.50	10.00		17.50	1500.00
	November	20.00	10.00		7.50	2200.00
	December	80.00	20.00		50.00	1900.00
1986	January	80.00	45.00		25.00	2850.00
	February	130.00	22.50		85.00	3000.00
	March	100.00	20.00		55.00	8350.00
	April	10.00	10.00		0.00	3150.00
1987	December	40.00				1911.00
1989	January	50.70	TFP is 30.4 and FRP is 4.0		26.40	3202.00
1992	January	58.03	19.06			1922.50
	February	47.69	8.13			2431.50
	March	71.67	26.67			2609.00
	April	80.94	38.38			2834.50
	May	84.75	42.50			2642.50
	June	22.94	20.81			2057.00
	July	171.94	36.94			1516.00
	August	101.06	28.50			1529.50
	September	70.42	54.42			1409.00
	October	187.56	28.63			1710.00
	November	93.94	27.50			1586.00
	December	66.69	9.38			1871.50
1993	January	113.25	10.94			1869.00
	February	87.60	26.40			2359.00
	March	229.38	26.83			2955.50
1995	July	114.73	32.82			2469.11
	August	67.12	34.29			1574.38
	September	220.68	112.22			1816.91
1996	June		95.00			
	July		72.50			
	August		65.00			
2000	August	146.00	26.50			580.50
	September	66.50	5.50			368.50
	October	41.50	4.00			427.50
2001	April	253.75				10100.00
	May	248.83				8000.00
	June	204.38				5625.00
	July	375.63				5887.50
	August	235.87	27.40			3879.56
	September	175.68	15.79			3038.10
	October	67.37	14.12			3400.00
	November	93.65	23.97			4428.57
	December	86.04	9.47			5428.57
2002	January	133.11	24.98			5857.14
	February	646.80	91.94			11333.33
	July	70.04	5.41			3285.71
	August	60.90	4.06			4000.00

Organic N (µg/L)	Nitrate/Nitrite N (µg/L)	Ammonium N (µg/L)	Chlorophyll a (µg/L)	Reference
2857.25	0.00	506.50		Congdon (1973)
3110.13	0.00	427.38		
2309.75	0.00	519.50		
1380.25	0.00	60.38		
1809.50	0.00	95.25		
1540.75	0.00	646.88		
1065.88	0.00	273.75		
0.00	1108.00	15.00	2.00	Gordon and Finlayson (1975)
0.00	1160.00	74.00	5.90	
2087.00	1680.00	34.00	7.10	
1605.00	1396.00	26.00	8.50	
1260.00	312.00	18.00	7.90	
1360.00	370.00	18.00	2.50	
1420.00	420.00	5.00	6.30	
1650.00	745.00	5.00	2.20	
0.00	190.00	5.00	1.20	
1947.00	400.00	8.00	2.00	
2475.00	903.00	0.00	2.10	
1564.33	16.17	166.50	2.12	Congdon (1986)
1357.67	5.83	105.67	9.47	
1459.40	4.96	96.31	20.83	
1564.98	3.76	41.01	11.18	
2380.79	5.53	39.23	8.24	
2501.75	4.88	58.63	9.55	
2920.59	4.70	80.42	19.75	
2983.19	5.96	151.92	20.82	
3033.48	8.61	130.23	24.14	
2642.52	9.56	60.25	15.60	
2278.73	2.13	38.35	17.43	
2251.19	4.95	49.18	11.43	
2246.75	11.77	43.19	9.88	
1829.44	7.31	30.92	11.68	
2721.89	6.74	41.48	42.94	
2926.65	5.46	99.08	29.97	
3375.45	2.99	72.60	33.68	
4632.31	2.63	144.88	64.59	
11719.75	4.75	50.00	121.88	
5993.50	3.06	467.50	95.71	
1804.20	13.20	159.01	28.89	
2619.82	4.34	37.03	50.14	
1577.65	7.93	21.34	13.42	
973.22	7.50	52.65	4.32	
1212.32	3.43	32.23	4.58	
1158.00	2.79	16.52	4.06	
1548.10	3.84	13.50	18.23	
1578.34	3.50	111.00	31.80	

				Davis & Rolls (1987)
			5.34	Davis, Rolls & Wrigley (1991)
3114.00	12.10	76.40	N/A	Anon (n. d.)
1925.50	4.58	17.00	16.13	Kinnear *et al.* (1997)
2412.00	3.19	28.56	23.89	
2592.00	2.33	14.88	28.24	
2807.00	7.31	20.44	21.56	
2595.00	9.38	38.25	15.73	
2026.50	8.06	22.56	7.04	
1495.50	4.38	13.88	11.03	
1503.00	6.50	19.81	5.54	
1399.00	2.54	7.29	3.87	
1700.00	2.38	7.50	26.24	
1559.50	2.54	26.56	5.36	
1843.00	3.31	25.19	17.41	
1846.50	1.81	20.31	31.91	
2342.00	5.28	12.81	20.45	
2935.00	3.96	16.13	7.46	
	18.94	147.90	4.00	Lund, Brown & Lee (2000)
	11.06	117.42	2.01	
	32.83	356.40	2.66	
	31.50		157.50	Upton (1996)
	56.50		20.00	
	42.50		12.50	
	39.50	124.00		Lund (2002 unpublished)
	22.50	69.00		
	32.50	30.00		
			24.50	Lamb (2001)
			30.25	
			8.19	
			2.06	
	30.00	144.03	1.43	Lund (2002 unpublished)
	17.61	221.10	1.40	
	16.88	16.98		
	3.63	11.75		
	9.47	11.22		
	8.03	31.14		
	8.68	52.49		
	5.68	28.60		
	5.68	29.03		

APPENDIX V Raw data from stormwater sampling at Lake Joondalup between May–August 2004.

Discharge Point	Date	Time	Water depth (m)	Estimated flow rate	Temperature (C)	pH
Outfall 9	05/07	7:47			15.2	7.47
		7:53	0.3			
		7:55	0.45			
		7:57	0.615			
		8:00	0.874			7.13
		8:05	0.96			
		8:10	0.96			
		8:15	0.96			
		8:20	0.96			
		8:25	0.904			
		8:30	0.849			
		8:35	0.789			
		8:40	0.689			
		8:45	0.724			
		8:50	0.709		19.1	6.77
		9:00	0.699		19.1	6.99
		9:15	0.694			
		9:30	0.679		19.2	7.11
		9:45	0.671			
		10:00	0.657		19.6	7.04
Outfall 14	11/05	9:57				
		9:45				
Outfall 9	11/05	10:07				
Outfall 4	11/05	9:45				
Outfall 5	21/05	11:40	0.14		17.3	7.82
		11:53	0.3		17.2	7.03
		12:00	0.39		17.3	7.44
		12:10	0.379		17.3	7.22
		12:20	0.379		17.3	7.3
		12:30	0.344		17.3	7.22
		12:40	0.359		17.3	7.25
		12:50	0.389		17.3	7.1
		13:00	0.354		17.2	7.11
		13:10	0.269		17.2	7.36
		13:20	0.199		17.3	7.22
		13:30	0.14		17.3	7.09
		13:40	0.055			
Sommerville Sump	06/06	16:45		Flow	17.8	8.77
Kulindi Bubble up		17:10		Flow	18	7.41
Warruga Bubble up		17:20		Flow	18.2	7.14
Bubble up 3 near outfall 4		17:30		Flow	18.2	7.11
Outfall 9/10		17:43		Very slow flow	18.2	6.82
Outfall 9/10 front		17:45		Extremely fast flow	18	6.62
San Rosa Sump		18:00		No flow	18	6.94
Outfall 17	27/06	11:25		Slow if any	18.4	6.50

Discharge Point	Date	Time	Water depth (m)	Estimated flow rate	Temperature (C)	pH
Bubble up near Outfall 17		11:25		Slow if any	18.9	6.76
Fullwood sump		11:40		Flow	18.6	6.88
McCubbin/Fox Sump		11:50		Flow	13.1	6.73
Neil Hawkins Sump		12:15		Slow if any	18.4	6.51
Outfall 4	02/07	9:10	0.38	Slow	13.7	7.97
		9:20	0.35	Very slow flow	13.5	7.59
		9:30	0.345	Very slow flow	13.5	7.28
Wanneroo Road Bubble up		9:50		Dribble	13.2	7.71
Wanneroo Road Pipe under road		10:00		Slow flow	13.3	8.47
Joondalup Drive roundabout		10:45		Very slow flow	13	8.04
Outfall 12	05/07	9:45		Medium	14.9	6.54
Outfall 8	05/08	11:15	0.4	Slow	15.8	7.17
		11:23	0.43	Slow	15.7	7
		11:30	0.43	Slow	15.7	6.94
		11:37	0.41	Slow	15.6	4.78
		11:42	0.43	Slow	15.5	4.12
		11:50	0.42	Slow	15.6	4.14
		11:50 top	0.42	Slow	15.6	5.37
Outfall 11	25/08	7:35	0.14		13.2	6.26
		7:50	0.09	Medium/fast	13.2	5.71
Outfall 9	26/08	6:35 all				
		6:35 top				
Outfall 9	27/08	12:15	0.75		16.1	6.63
		12:23	0.825		15.8	6.85
		12:30	0.96		15.4	6.89
		12:35	0.96		14.7	6.72
		12:37	0.96			
		12:40	0.925		14.7	6.6
		12:45	0.9		14.8	6.63
		12:50	0.915		14.9	6.57
		12:55	0.855		15	6.48
		13:00	0.8		15.2	6.34
		13:05	0.755		15.4	6.26
		13:10	0.715		15.5	6.35
		13:15	0.695	Flow virtually stopped, quite slow	15.7	6.28

Conductivity (µS/cm)	Discharge Point	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Total P (µg/L)	Filterable Reactive P (µg/L)	Total N (µg/L)
690	Outfall 9	2.69		514.54	383.16	6494.58
				635.35	407.06	6640.87
				662.19	457.51	4483.18
119				581.66	128.68	3900.26
				480.98	46.51	3343.65
				501.12	242.34	3384.62
				266.22	160.55	2113.67
				286.35	168.51	2201.27
				299.78	240.21	2183.75
				266.22	247.12	2214.41
				380.28	347.68	2897.83
				561.52	452.35	3073.39
				631.7	539.14	3154.9
152		8.66		638.31	559.57	3288.29
167		8.66		737.56	659.13	3538.7
				816.95	725.5	4037.15
177		8.41		942.66	730.61	4286.38
				816.95	623.39	3852.94
166		7.99		922.81	602.97	4113
	Outfall 14			87.68	46.49	437.48
				134.59	47	498.58
	Outfall 9			107.95	54.8	560.49
	Outfall 4			102.3		560.49
88.3	Outfall 5			164.7	86.13	1032.8
64.2				144.1	68.24	821.16
55.4				124.56	73.35	642.81
47.8				117.25	80	553.63
45				101.63	67.98	414.15
45.2				123.9	71.02	521.62
43.1				108.94	66.19	414.15
39.1				104.62	60.06	318.11
41.4				91.99	59.29	320.39
42.9				99.64	70.54	359.27
60.1				122.82	98.92	603.94
58.4				124.9	93.8	535.34
54	Sommerville Sump	9.09	96	129.22	32.15	298.34
36	Kulindi Bubble up			36.19	20.3	207.51
47	Warruga Bubble up			62.38	35.58	263.55
47	Bubble up 3 near outfall 4			39.7	26.85	209.44
51	Outfall 9/10			72.71	37.07	203.38
81	Outfall 9/10 front			111.6	32.53	296.82
63	San Rosa Sump			63.93	29.64	261.76
31	Outfall 17			113.54	245.83	626.88

Conductivity (µS/cm)	Discharge Point	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Total P (µg/L)	Filterable Reactive P (µg/L)	Total N (µg/L)
29	Bubble up near Outfall 17			109.89	55.8	609.48
35	Fullwood sump			99.19	50.85	236.49
38	McCubbin/Fox Sump			59.75	57.23	193.98
41	Neil Hawkins Sump			142.77	86.48	455.23
28	Outfall 4			87.68	26.92	257.75
40				57.45	17.66	195.91
57				49.56	25.9	164.99
92	Wanneroo Road Bubble up			73.75	23.63	316.17
138	Wanneroo Road Pipe under road			208.94	36.34	664.5
279	Joondalup Drive roundabout			120.16	31.4	832.6
480	Outfall 12			99.19	56.05	242.29
54	Outfall 8			123.03	42.22	539.91
110				129.47	41.46	613.35
59				115.62	30.39	454.88
51				86.44	31.65	306.07
47				75.2	32.41	272.59
41				71.88	30.14	261.76
25				72.61	25.11	296.41
417	Outfall 11			55.56	16.39	294.25
442				55.2	15.05	259.59
	Outfall 9			156.16	71.31	405.14
				150.39	65.81	521.66
87	Outfall 9			289.08	29.13	763.28
57				126.52	96.2	581.01
31				156.16	25.72	620.07
28				139.91	22.84	522.29
26				108.45	23.37	411.76
37				91.32	23.89	322.79
37				76.27	20.75	279.4
29				89.17	27.3	305.44
32				78.06	24.94	296.76
32				67.96	26.25	279.4
33				63.02	23.37	242.51
36				73.05	21.27	244.68

Nitrate/Nitrite (µg/L)	Ammonium (µg/L)
1767.54	1093.57
1967.11	1274.37
926.75	1141.33
570.61	755.85
378.73	496.59
329.61	336.26
244.36	370.37
276.58	302.14
314.77	332.85
401.75	366.96
527.38	394.25
741.6	459.06
836.63	503.41
889.78	523.88
991.26	575.05
1070.18	602.34
1091.12	619.4
1013.81	554.58
981.59	544.35
83.94	85.3
115.5	85.09
101.35	121.6
183.11	148.08
142.17	114.83
106.49	115.84
87.71	122.56
80.32	92.67
69.55	86.17
51.39	76.81
43.23	63.12
41.84	64.83
51.08	74.47
112.95	69.2
118.18	72.05
75.28	13.61
32.56	23.57
34.57	23.05
45.67	24.01
41.96	57.41
22.32	30.04
27.12	37
92.2	82.46

Nitrate/Nitrite (µg/L)	Ammonium (µg/L)
109.65	61.98
43.7	24.23
43.35	31.79
38.44	61.26
11.51	28.13
11.82	31.75
15.38	30.94
51.44	79.83
102.68	67.11
131.54	212.1
50.85	34.9
79.61	46.39
83.43	45.45
58.74	45.24
44.48	46.16
40.67	37.22
42.7	37.87
34.3	34.62
21.4	24.9
16.92	26.43
27.52	71.55
28.11	63.34
67.03	15.55
48.32	29.87
18.46	12.82
18.16	12.48
27.37	14.86
29.3	15.55
31.53	14.86
21.72	53.75
21.43	48.98
22.62	39.42
20.09	30.21
22.76	26.8

APPENIDX VI Raw data from groundwater sampling at Lake Joondalup between May–August 2004.

Bore	Date	Time	Water Depth (m)	Temperature (C)	pH
Huntingdale irrigation	20/05	~ 7:50	SWL 32.6	19.9	7.47
Balanus irrigation	20/05	~ 8:10	SWL 28.4	20.0	7.61
Poinciana	31/05	10:45	4.97	17.9	6.41
	28/06	13:00	0.60	20.0	6.35
	26/07	15:00	0.47	19.2	6.11
	22/08	13:15	0.55	18.1	6.42
Neville	31/05	11:45	3.50	19.0	6.62
	28/06	11:30	2.44	20.5	6.53
	26/07	14:10	2.28	20.8	6.38
	22/08	12:35	2.28	19.4	6.48
Wallawa	31/05	12:30	3.54	17.1	6.92
	28/06	11:50	1.66	19.1	6.65
	26/07	13:45	1.70	18.2	6.41
	22/08	11:35	1.50	17.7	6.31
Pines	31/05	13:10	3.65	17.9	5.78
	28/06	10:45	2.18	18.7	5.57
	26/07	13:30	1.01	18.1	5.81
	22/08	11:10	1.93	17.8	5.39
Ashley	28/06	10:25	9.06		
	26/07		9.17		
	22/08	10:45	8.85		
Christie Crt	28/06	11:00	3.21		
	26/07		3.17		
	22/08	12:15	3.00		
Togno Park	28/06	12:15	28.57		
	26/07		28.63		
	22/08	12:00	28.42		
Caporn St	28/06	12:30	16.91		
	26/07		17.15		
	22/08	11:50	16.68		
Nannatee Park	28/06	12:35	11.23		
	26/07		11.13		
	22/08	12:50	11.00		
Edith Cowan University Bore	01/07	9:30	SWL 28.5	20.1	7.04
	29/07	10:30		19.7	6.97
	24/08	10:30		19.5	7.21
Quarry Ramble	02/07	7:15	SWL 12	19	6.78
	05/08	7:45		19	6.81
	24/08	7:35		19.5	6.7
Lakeside Dve	02/07	8:47	SWL 31.5	18.8	7.14
	05/08	7:30		18.4	7.11
	24/08	7:23		18.4	7.06
Central Park West	02/07	8:09	SWL 42.6	19.4	7.05

	05/08	7:05		19.3	7.11
	24/08	7:05		19.4	7.04
Central Park East	02/07	8:20	SWL 45.9	18.4	7.24
	05/08	7:20		19.3	7.2
	24/08	7:10		19.2	7.13

Conductivity (µS/cm)	Total P (µg/L)	Filterable Reactive P (µg/L)	Total N (µg/L)	Nitrate/Nitrite (µg/L)	Ammonium (µg/L)
1408	173.61	142.28	1107.07	Below detectable limit	995.65
1179	196.87	170.11	696.41	Below detectable limit	597.7
1218	140.77	58.76	603.94	60.59	177.85
1102	157.33	82.93	827.04	6.1	192.85
1178	113.52	76.02	737.7	3.64	219.6
1162	137.51	58.23	705.75	5.03	218.95
1131	514.54	218.89	1130.98	253.94	141.32
1110	386.83	217.22	2030.57	727.39	200.03
1085	211.3	150.02	2600.59	984.48	175.89
1085	422.11	231.52	3496.71	1983.22	158.28
282	209.99	127.54	358.94	13.28	84.68
273	314.11	148.33	1098.38	160.24	78.81
272	342.31	158.7	699.97	8.12	105.89
278	209.54	182.37	549.81	3.77	74.16
367	132.54	22.38	418.72	5.79	88.68
363	118.63	42.56	2610.74	2.72	243.29
339	139.44	82.4	1304.21	22.83	189.47
356	125.01	23.71	374.38	4.41	119.99
2040	195.65	120.69	1865.05	6.99	1763.68
2050	252.99	273.48	1954.49	2.16	1676.84
2010	187.07	140.46	1921.4	0.39	1723.6
1913	154.62	195.59	1357.89	3	623.8
1963	182.53	164.11	1423.58	Below detectable limit	715.13
2110	146.71	211.27	1602.62	0.99	1015.22
1623	207.55	210.57	5262.78	3.83	5517.11
1502	229.05	245.51	3273.36	5.975	3624.63
1459	119.15	137.55	3331.37	1.57	3604.11
1990	252.21	157.87	2190.23	1.745	2385.21

1960	254.18	263.04	2467.25	4.32	2509.16
1961	249.41	223.73	2521.54	7.59	2483.07
1984	82.05	217.22	2521.54	14.61	2471.69
1959	171.61	211.54	2611.35	0.86	2798.98
1965	171.61	130.5	2598.25	1.225	2812.34

APPENDIX VII Raw data from surface water sampling at Lake Joondalup and from adjoining swamps between May–August 2004.

Site	Date	Time	Water Depth (m)	Temperature (C)	pH	Conductivity (µS/cm)
Beenyup Swamp connection	24/05	10.35	0.44	12	7.34	913
	07/06	7:30	0.44	13.7	7.24	923
	21/06	8:17	0.43	13.2	7.0	651
	05/07	10:25	0.4975	12.2	7.0	726
	19/07	8:45	0.3825	10.5	6.9	632
	02/08	8:20	0.43	11.3	N/A	756
	16/08	7:50	0.405	10.7	6.6	N/A
	30/08	7:45	0.51	11.2	6.95	578
Ocean Reef Road culvert	07/06	8:05	0.195	15.4	7.27	994
	21/06	7:50	0.245	13.9	7.12	722
	05/07	10:10	0.325	12.9	7.1	703
	19/07	8:20	0.265	11.6	7.05	670
	02/08	7:55	0.275	12.8	N/A	689
	16/08	7:20	0.325	13	7.02	650
	30/08	7:15	0.36	12.8	7.15	604

Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Total P (µg/L)	Filterable Reactive P (µg/L)	Total N (µg/L)	Nitrate/Nitrite (µg/L)	Ammonium (µg/L)
		737.56	431.71	1376.84	33.11	340.81
3.2	30.8	426.59	424.75	1085.35	112.19	230.52
1.23	13.2	1035.29	792.87	963.67	91.58	143.69
1.42	13.1	936.04	720.48	911.52	79.71	107.5
2.58	22.5	671.39	628.44	828.95	60.62	53.42
3.71	33.3	638.81	117.26	778.98	44.61	47.15
4.5	43	689.35	257.83	711.62	21.99	42.4
3.35	30.3	798.48	442.91	770.73	22.37	49.66
4.39	43.8	597.93	175.54	1109.25	3.67	28.9
0.99	9.4	539.07	495.5	991.92	1.06	75.48
1.79	16.6	618.46	442.34	1128.8	3.03	227.26
3.56	32.7	458.07	480.16	951.5	13.68	108.68
5.09	47.9	590.27	211.54	841.99	32.92	79.2
7.9	74	503.41	110.4	752.91	11.37	35.17
8.45	78.8	585.16	142.97	801.05	2.57	24.68

APPENDIX VIII Stormwater data for flow velocities, volumes and nutrient loads for this study and the extrapolated budget, September 2003 – August 2004.

Table showing flow volumes, nutrient concentrations and loads during this study

Date	Rainfall (m)	Catchment area (m2)	Days between sampling	Total flow volume incuding base flow (L) for each period	Total P (µg/L)	Total N (µg/L)	Average Total P (µg/L)	Average Total N (µg/L)	Total P load (kg)	Total N load (kg)
07/05	0.0438	216440	4	10516872	449.44	3696.03	278.70	2128.26	2.93	22.38
11/05	0.0338	216440	10	9907672	107.95	560.49	113.46	560.21	1.12	5.55
21/05	0.0476	216440	16	14449744	118.96	559.93	94.84	401.37	1.37	5.80
06/06	0.1344	216440	29	36606336	70.72	242.82	84.96	242.55	3.11	8.88
05/07	0.079	216440	31	25133960	99.19	242.29	99.73	325.19	2.51	8.17
05/08	0.0988	216440	20	26568272	100.27	408.09	77.83	342.51	2.07	9.10
25/08	0.0118	216440	1	2813192	55.38	276.92	55.38	276.92	0.16	0.78
26/08	0.0048	216440	1	1298112	156.16	405.14	156.16	405.14	0.20	0.53
27/08	0.0142	216440	1	3332648	113.25	405.78	106.07	394.14	0.35	1.31

Table showing flow volumes, nutrient concentrations and loads extrapolated for the budget

	Rainfall (m)	Catchment area (m2)	Days	Total flow volume including base flow (L) for each month	Total P (µg/L)	Total N (µg/L)	Total P load (kg)	Total N load (kg)
September	0.0954	216440	30	28424376	106.07	394.14	3.02	11.20
October	0.0222	216440	31	12840168	106.07	394.14	1.36	5.06
November	0.0464	216440	30	17818816	106.07	394.14	1.89	7.02
December	0.0028	216440	31	8641232	106.07	394.14	0.92	3.41
January	0	216440	31	8035200	449.44	3696.03	3.61	29.70
February	0.0092	216440	29	9508048	449.44	3696.03	4.27	35.14
March	0.0004	216440	31	8121776	449.44	3696.03	3.65	30.02
April	0.006	216440	30	9074640	449.44	3696.03	4.08	33.54
May	0.118	216440	31	33575120	225.45	1605.48	7.57	53.90
June	0.11	216440	30	31584400	70.72	242.82	2.23	7.67
July	0.1016	216440	31	30025504	99.19	242.29	2.98	7.27
August	0.1496	216440	31	40414624	106.27	373.98	4.29	15.11

APPENDIX IX Groundwater data showing the determination of the hydraulic gradient and nutrient loads during the study period.

Table showing the determination of the hydraulic gradient

Bore	Date	Water Depth (m)	Water level elevation (mAHD)	Surface water level (mAHD)	Water table elevation change (m)	Distance between bores and lake (m)	Hydraulic gradient
Poinciana	31/05/2004	4.97	15.03	16.24	-1.21	300	-0.00403333
	28/06/2004	0.60 (0.39)	19.4	16.41	2.99	300	0.009966667
	26/07/2004	0.47	19.53	16.57	2.96	300	0.009866667
	22/08/2004	0.55	19.45	16.73	2.725	300	0.009083333
Neville	31/05/2004	3.50	15.50	16.24	-0.74	50	-0.0148
	28/06/2004	2.44 (2.25)	16.56	16.41	0.15	50	0.003
	26/07/2004	2.28	16.72	16.57	0.15	50	0.003
	22/08/2004	2.28	16.72	16.73	-0.005	50	-0.0001
Wallawa	31/05/2004	3.54	15.46	16.24	-0.78	60	-0.013
	28/06/2004	1.66 (1.6)	17.34	16.41	0.93	60	0.0155
	26/07/2004	1.70	17.30	16.57	0.73	60	0.012166667
	22/08/2004	1.50	17.50	16.73	0.775	60	0.012916667
Pines	31/05/2004	3.65	16.033	16.24	-0.207	110	-0.00188182
	28/06/2004	2.18 (2.1)	17.503	16.41	1.093	110	0.009936364
	26/07/2004	1.01	18.673	16.57	2.103	110	0.019118182
	22/08/2004	1.93	17.753	16.73	1.028	110	0.009345455
WM16	28/06/2004	9.06	18.188	16.41	1.778	490	0.003628571
	26/07/2004	9.17	18.083	16.57	1.513	490	0.003087755
	22/08/2004	8.85	18.398	16.73	1.673	490	0.003414286
Christie Crt	28/06/2004	3.21	18.164	16.41	1.754	220	0.007972727
	26/07/2004	3.17	18.204	16.57	1.634	220	0.007427273
	22/08/2004	3.00	18.374	16.73	1.649	220	0.007495455
Togno Park	28/06/2004	28.57	36.951	16.41	20.541	1340	0.015329104
	26/07/2004	28.63	36.896	16.57	20.326	1340	0.015168657
	22/08/2004	28.42	37.101	16.73	20.376	1340	0.01520597
5025	28/06/2004	16.91	37.65	16.41	21.24	2100	0.010114286
(Capom)	26/07/2004	17.15	37.42	16.57	20.845	2100	0.00992619
	22/08/2004	16.68	37.88	16.73	21.155	2100	0.01007381

Nannatee Park	28/06/2004	11.23	27.32	16.41	10.91	790	0.013810127
	26/07/2004	11.13	27.42	16.57	10.85	790	0.013734177
	22/08/2004	11.00	27.55	16.73	10.825	790	0.013702532
ECU Bore	1/07/2004	SWL 28.5	6.5	16.425	9.925	860	0.011540698
	29/07/2004		6.5	16.585	10.085	860	0.011726744
	24/08/2004		6.5	16.73	10.23	860	0.011895349
Quarry Ramble	2/07/2004	SWL 12	15	16.425	1.425	140	0.010178571
	5/08/2004		15	16.625	1.625	140	0.011607143
	24/08/2004		15	16.73	1.73	140	0.012357143
Lakeside Dve	2/07/2004	SWL 31.5	8.5	16.425	7.925	310	0.025564516
	5/08/2004		8.5	16.625	8.125	310	0.026209677
	24/08/2004		8.5	16.73	8.23	310	0.026548387
Central Park West	2/07/2004	SWL 42.6	2.4	16.425	14.025	840	0.016696429
	5/08/2004		2.4	16.625	14.225	840	0.016934524
	24/08/2004		2.4	16.73	14.33	840	0.017059524
Central Park East	2/07/2004	SWL 45.9	4.1	16.425	12.325	750	0.016433333
	5/08/2004		4.1	16.625	12.525	750	0.0167
	24/08/2004		4.1	16.73	12.63	750	0.01684

Table showing the calculation of loads for the various segments of Lake Joondalup to determine the total inputs and outputs

Bore	Date	Flow velocity (m/day)		Length of segment (m)	Avg. thickness of aquifer over segment (m)	Flow volume through segment (m3/day)
NLJ-Pines	31/05/04	-0.02508	-9.4E-05	920	5	-115.39
	28/06/04	0.132452	0.000497	920	5	609.28
	26/07/04	0.254845	0.000956	920	5	1172.29
	22/08/04	0.124575	0.000467	920	5	573.04
Pines-Wallawa	31/05/04	-0.09919	-0.00037	1343.31	5	-666.20
	28/06/04	0.169533	0.000636	1343.31	5	1138.68
	26/07/04	0.208514	0.000782	1343.31	5	1400.49
	22/08/04	0.148377	0.000557	1343.31	5	996.58
Wallawa-Neville	31/05/04	-0.18529	-0.00069	889.32	5	-823.90
	28/06/04	0.123303	0.000462	889.32	5	548.28
	26/07/04	0.101086	0.000379	889.32	5	449.49
	22/08/04	0.085423	0.00032	889.32	5	379.84
Neville-Poinciana	31/05/04	-0.12552	-0.00047	3161.18	5	-1984.02
	28/06/04	0.086423	0.000324	3161.18	5	1365.99
	26/07/04	0.085756	0.000322	3161.18	5	1355.46
	22/08/04	0.059874	0.000225	3161.18	5	946.36
Poinciana-SLJ	31/05/04	-0.05376	-0.0002	1290	5	-346.78
	28/06/04	0.132856	0.000498	1290	5	856.92
	26/07/04	0.131523	0.000493	1290	5	848.32
	22/08/04	0.121081	0.000454	1290	5	780.97
SLJ - Quarry Ramble	2/07/04	0.13568	0.000509	2250	5	1526.40
	5/08/04	0.154723	0.00058	2250	5	1740.64
	24/08/04	0.164721	0.000618	2250	5	1853.11
Quarry Ramble -ECU	2/07/04	0.144759	0.000543	1911.15	5	1383.28
	5/08/04	0.15552	0.000583	1911.15	5	1486.11
	24/08/04	0.161643	0.000606	1911.15	5	1544.62
ECU Bore-Lakeside Dv	1/07/04	0.247306	0.000928	1076.83	5	1331.53
	29/07/04	0.252846	0.000948	1076.83	5	1361.36
	24/08/04	0.256228	0.000961	1076.83	5	1379.57
Lakeside Dve-NLJ	2/07/04	0.340775	0.001278	3040	5	5179.78
	5/08/04	0.349375	0.00131	3040	5	5310.50
	24/08/04	0.35389	0.001327	3040	5	5379.13

m3	L	Flow volume through segment	m3	L	Total P (ug/L)	Total P kg	
-3577.07	-3577069	-0.43	-13.42	-13417.36	132.54	**-0.47**	**-0.00178**
18278.34	18278338	2.29	68.56	68560.91	118.63	**2.17**	**0.008133**
36340.95	36340949	4.40	136.31	136312.64	139.44	**5.07**	**0.019007**
17764.38	17764382	2.15	66.63	66633.09	125.01	**2.22**	**0.00833**
-20652.09	-2.1E+07	-2.50	-77.46	-77464.72	171.27	**-3.54**	**-0.01327**
34160.38	34160379	4.27	128.13	128133.46	216.37	**7.39**	**0.027724**
43415.23	43415235	5.25	162.85	162847.84	240.88	**10.46**	**0.039226**
30894.04	30894036	3.74	115.88	115881.60	167.28	**5.17**	**0.019384**
-25540.81	-2.6E+07	-3.09	-95.80	-95802.00	362.27	**-9.25**	**-0.03471**
16448.31	16448307	2.06	61.70	61696.57	350.47	**5.76**	**0.021623**
13934.14	13934136	1.69	52.27	52266.08	276.81	**3.86**	**0.014468**
11775.11	11775111	1.42	44.17	44167.71	315.83	**3.72**	**0.013949**
-61504.70	-6.2E+07	-7.44	-230.70	-230700.28	327.66	**-20.15**	**-0.07559**
40979.72	40979720	5.12	153.71	153712.38	272.08	**11.15**	**0.041822**
42019.14	42019137	5.08	157.61	157611.17	162.41	**6.82**	**0.025598**
29337.20	29337195	3.55	110.04	110041.99	279.81	**8.21**	**0.030791**
-10750.18	-1.1E+07	-1.30	-40.32	-40323.25	140.77	**-1.51**	**-0.00568**
25707.57	25707572	3.21	96.43	96427.50	157.33	**4.04**	**0.015171**
26297.96	26297957	3.18	98.64	98642.00	113.52	**2.99**	**0.011198**
24210.11	24210113	2.93	90.81	90810.63	137.51	**3.33**	**0.012487**
45792.12	45792121	5.73	177.49	177488.84	154.62	**7.08**	**0.027443**
53959.72	53959721	6.53	202.40	202399.55	182.53	**9.85**	**0.036944**
57446.35	57446349	6.95	208.53	208526.79	146.71	**8.43**	**0.030593**
41498.40	41498404	5.19	160.85	160846.53	175.14	**7.27**	**0.02817**
46069.52	46069523	5.57	172.80	172803.91	217.76	**10.03**	**0.03763**
47883.18	47883181	5.79	173.81	173813.06	166.89	**7.99**	**0.029008**
39946.02	39946018	4.99	154.83	154829.53	201.60	**8.05**	**0.031214**
42202.23	42202226	5.11	158.30	158297.92	241.02	**10.17**	**0.038153**
42766.59	42766586	5.17	155.24	155240.13	153.11	**6.55**	**0.023769**
155393.40	1.55E+08	19.43	602.30	602300.00	207.55	**32.25**	**0.125007**
164625.50	1.65E+08	19.92	617.50	617500.00	229.05	**37.71**	**0.141438**
166752.97	1.67E+08	20.18	605.30	605303.23	119.15	**19.87**	**0.072122**

Total N (ug/L)	Total N kg	
418.72	-1.50	-0.00562
2610.74	47.72	0.178995
1304.21	47.40	0.17778
374.38	6.65	0.024946
388.83	-8.03	-0.03012
1854.56	63.35	0.237631
1002.09	43.51	0.163188
462.095	14.28	0.053548
744.96	-19.03	-0.07137
1564.475	25.73	0.096523
1650.28	23.00	0.086254
2023.26	23.82	0.089363
867.46	-53.35	-0.20012
1428.805	58.55	0.219625
1669.145	70.14	0.263076
2101.23	61.64	0.231224
603.94	-6.49	-0.02435
827.04	21.26	0.079749
737.7	19.40	0.072768
705.75	17.09	0.06409
1357.89	62.18	0.24101
1423.58	76.82	0.288132
1602.62	92.06	0.334189
1611.47	66.87	0.259199
1689.035	77.81	0.291872
1762.01	84.37	0.30626
2582.525	103.16	0.399851
2613.925	110.31	0.413779
2626.385	112.32	0.40772
3300	512.80	1.98759
3273.36	538.88	2.0213
3331.37	555.52	2.016489

APPENDIX X Surface water data for flow velocities, volumes and loads during the study period as well as the extrapolation for Beenyup Swamp for the budget.

Ocean Reef culvert flow velocities, volumes and loads for the study period

Date	Water Depth (m)	Flow = turns/50s	Velocity (m/s)	Cross sectional area (m2)	Discharge (m3/sec)	Seconds between each sample period	Flow for the sampling period (L)	Total P (ug/L)	Total P load (kg)	Total N (ug/L)	Total N load (kg)
07/06	0.195	7.28	0.664	0.195	0.12948	604800	78309504	597.93	46.8236	1109.25	86.86482
21/06	0.245	5.12	0.477	0.245	0.116865	1209600	1.41E+08	539.07	76.20288	991.92	140.2177
05/07	0.325	7.82	0.709	0.325	0.230425	1209600	2.79E+08	618.46	172.3785	1128.8	314.6215
19/07	0.265	5.34	0.496	0.265	0.13144	1209600	1.59E+08	458.07	72.82847	951.5	151.2788
02/08	0.275	5.4	0.501	0.275	0.137775	1209600	1.67E+08	590.27	98.37005	841.99	140.3199
16/08	0.325	7.62	0.694	0.325	0.22555	1209600	2.73E+08	503.41	137.343	752.91	205.4129
30/08	0.36	5.48	0.508	0.36	0.18288	604800	1.11E+08	585.16	64.7221	801.05	88.6008

Beenyup Swamp flow velocities, volumes and loads for the study period

Date	Water Depth (m)	Surface velocity = L(m)/t(secs) Site 1	Surface velocity = L(m)/t(secs) Site 2	Surface velocity mutiplied by a correction factor for roughness (k=.85) Site 1	Surface velocity mutiplied by a correction factor for roughness (k=.85) Site 2	Cross sectional area (m2)	Discharge (m3/s) Site 1	Discharge (m3/s) Site 2	Individual or average discharge of the sites (m3/s)	Seconds between sampling periods
24/05	0.44	0.032609	N/A	0.027717391	N/A	2.64	0.0731739	N/A	0.073173913	604800
07/06	0.44	0.088235	N/A	0.075	N/A	2.64	0.198	N/A	0.198	1209600
21/06	0.45	0.065217	0.068182	0.055434783	0.057954545	2.7	0.1496739	0.1564773	0.153075593	1209600
05/07	0.4975	0.071429	0.1	0.060714286	0.085	2.985	0.1812321	0.253725	0.217478571	1209600
19/07	0.3825	0.044118	0.115385	0.0375	0.098076923	2.295	0.0860625	0.2250865	0.155574519	1209600
02/08	0.43	0.088235	0.166667	0.075	0.141666667	2.58	0.1935	0.3655	0.2795	1209600
16/08	0.405	0.1	0.214286	0.085	0.182142857	2.43	0.20655	0.4426071	0.324578571	1209600
30/08	0.51	0.136364	0.136364	0.115909091	0.115909091	3.06	0.3546818	0.3546818	0.354681818	604800

Flow for the sampling period (L)	Total P (ug/L)	Total P load (kg)	Total N (ug/L)	Total N load (kg)
44255583	737.56	32.64115	1376.84	60.93286
2.4E+08	426.59	102.1686	1085.35	259.9422
1.85E+08	1035.29	191.6945	963.67	178.4334
2.63E+08	936.04	246.2366	911.52	239.7863
1.88E+08	671.39	126.3441	828.95	155.9942
3.38E+08	638.81	215.9709	778.98	263.3601
3.93E+08	689.35	270.6459	711.62	279.3893
2.15E+08	798.48	171.2832	770.73	165.3305

Hydrological and nutrient inputs from Beenyup Swamp during the budget period September 2003-August 2004

	Days	Seconds per month	Discharge	Volume (m3)	Total P (ug/L)	Total P load (kg)	Total N (ug/L)	Total N load (kg)
September	30	2592000	0.3195868	828369.5	708.88	587.21	753.78	624.41
October	31	2678400	0.3195868	855981.8	708.88	606.79	753.78	645.22
November	30	2592000	0.3195868	828369.5	708.88	587.21	753.78	624.41
December	31	2678400	0.3195868	855981.8	708.88	606.79	753.78	645.22
May	31	2678400	0.0731739	195989	737.56	144.55	1376.84	269.85
June	30	2592000	0.1643067	425883	730.94	311.29	1024.51	436.32
July	31	2678400	0.1865265	499592.7	803.72	401.53	870.24	434.76
August	31	2678400	0.3195868	855981.3	708.88	606.79	753.78	645.22

APPENDIX XI Monthly values of various parameters for the extrapolated hydrological and nutrient budgets, September 2003 - August 2004.

Monthly breakdown of hydrological budget (m3)

	September	October	November	December	January	February	March	April	May
Lake volume	3324417.66	465016.5	-944958.39	-893321.4	-764318	-194849	-603543	-67164.2	75202.9
Rainfall	615330	143190	299280	18060	0	59340	2580	38700	761100
Evaporation	435859.2	694195.2	767116.56	826526.4	650630.4	430010.3	258367.2	168771.7	147206.5
Transpiration	233437.5	241218.8	233437.5	241218.75	241218.8	225656.3	241218.8	233437.5	241218.8
Beenyup Swamp	828369.504	855981.8	828369.5	855981.82	0	0	0	0	195989
Stormwater	28424.376	12840.17	17818.816	8641.232	8035.2	9508.048	8121.776	9074.64	33575.12
Groundwater as a residual	2521590.48	388418.5	-1089872.6	-708259.3	119496.1	391969	-114659	287270.4	-527036

Monthly breakdown of nitrogen budget (kg)

Lake Surface	4652.06	1763.76	-1944.75	-856.67	-1289.56	84.37	-1396.23	-102.86	136.09
Rainfall	68.0394994	15.83309	33.092587	1.9969664	0	6.561461	0.285281	4.279214	84.15787
N fixation	4.33333333	4.333333	4.3333333	4.3333333	4.333333	4.333333	4.333333	4.333333	4.333333
Denitrification	-84	-84	-84	-84	-84	-84	-84	-84	-84
Avifauna	25.8	32.44	53.68	58.12	128.44	288.68	468.28	382.84	227.72
BeenyupSwamp	624.405631	645.2192	624.40563	645.21915	0	0	0	0	269.8455
Stormwater	11.20317	5.060818	7.0230997	3.4058511	29.69831	35.14199	30.0183	33.54011	53.90426

Monthly breakdown of phosphorus budget (kg)

Lake Surface	242.85	491.82	-453.14	-150.03	-53.96	-28.24	-21.34	-1.9	7.64
Rainfall	3.52255916	0.819715	1.7132782	0.1033875	0	0.339702	0.01477	0.221545	4.357044
Avifauna	4.8375	6.0825	10.065	10.8975	24.0825	54.1275	87.8025	71.7825	42.6975
Beenyup Swamp	587.214574	606.7884	587.21457	606.78839	0	0	0	0	737.56
Stormwater	3.01505599	1.361994	1.8900935	0.9166005	3.611348	4.273307	3.650259	4.078515	7.569567

June	July	August	TOTAL
769668.4	746320.2	450501	**2362972**
709500	655320	964920	**4267320**
188539.6	251248.8	342000	**-5160472**
233437.5	241218.8	241218.8	**-2847938**
425883	499592.7	855981.3	**5346149**
31584.4	30025.5	40414.62	**238063.9**
24678.11	53849.59	-827596	**-2001742**

1337.92	497.51	715.81	**3597.45**
78.45225	72.46135	106.6951	**471.8546**
4.333333	4.333333	4.333333	**52**
-84	-84	-84	**-1008**
153.24	79.76	50.52	**1949.52**
436.3213	434.7631	645.2187	**4325.398**
7.669166	7.274879	15.11442	**239.0544**

-5.96	306.05	-88.1	**245.69**
4.061651	3.751489	5.523845	**24.42898**
28.7325	14.955	9.4725	**365.535**
730.94	803.715	708.88	**5369.101**
2.233649	2.97823	4.294668	**39.87329**