COASTAL EUTROPHICATION

A STUDY OF ORIELTON LAGOON

by

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Submitted in partial fulfilment of the requirement for the degree of Master of Environmental Studies (By Coursework).

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any other University, and to the best of my knowledge contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text.

M Brett

Margaret Anne Brett,
University of Tasmania,
March 1992

UTAS

"The best-laid schemes o' mice and men
Gang aft a-gley"

To a Mouse
Robbie Burns
November 1785

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Abstract

Orielton Lagoon, an enclosed estuary, was created in 1953 following the extension of a road causeway between Midway Point and Sorell.

Over the past 30 years, decomposition of excessive macrophytic growth has been blamed, for the periodic occurrence of unpleasant, nauseating odours. The growth of macrophytes appears to be associated with rainfall patterns, temperature and nutrient levels in the lagoon.

A biological survey of the lagoon indicated a highly eutrophic, hypersaline water body, rich in phytoplankton. Diatoms dominated the phytoplankton and there was a suppressed zooplankton population throughout the year. Average monthly chlorophyll levels varied between 10 and 43 µg/L.

The prime source of nutrients measured in 1991 was a sewage treatment plant at Midway Point which has discharged primary treated sewage into the lagoon since 1969. Nitrate levels were similar to those in the adjacent Pittwater area but phosphate levels in the lagoon were approximately double those in Pittwater.

Computer modelling of water movement through the lagoon was used to estimate water exchange within the system. This highlighted the very limited water exchange with the existing restricted outlet and demonstrated the significant additional water movement that could be achieved by minor modification.

The study has predicted changes in water quality that would result from both increased water flow and removal of nutrient input. To achieve a water quality similar to that in the neighbouring Pittwater area, with a chlorophyll level between 1 and 5 µg/L, both the removal of the nutrient source and increased flushing of the system must be undertaken.

The importance of the area as an internationally recognised wetland, important for migratory wading birds, is a prime consideration in any management plans to improve the water quality in the lagoon. The presence of a profitable aquacultural industry in the adjacent Pittwater area is also important in formulating future management practices.

COASTAL EUTROPHICATION
A STUDY OF ORIELTON LAGOON

CONTENTS

PAGE NO.

SCHEDULE OF MAPS

ABBREVIATIONS

Names

BOAT	Bird Observers Association of Tasmania
DEP	Tasmanian Department of Environment and Planning
DMR	Tasmanian Department of Main Roads
DPWH	Tasmanian Department of Parks, Wildlife and Heritage
IFC	Inland Fisheries Commission
RWSC	Rivers and Water Supply Commission, Tasmania

Units

cumecs	m^3/second
kL	10^3 litre
mL	10^{-3} litre
mg	10^{-3} gram
mS	10^{-3} seimens
nm	10^{-9} metre
ppb	parts per billion
ppm	parts per million
µg	10^{-6} gram
µm	10^{-6}metre

Others

AHD	Australian Height Datum
BOD	Biological Oxygen Demand
Chll	Chlorophyll
DO	Dissolved Oxygen
FTU	Formazin Turbidity Unit
NFR	Non-Filterable Residue
RL	Relative Level
Z_{SD}	Secchi Disc Transparency

Chapter 1

Introduction

Historically, human populations have depended on water bodies which have provided food, water and transport to the villages and cities that have been established around them. Water bodies have also acted as a ready site for waste disposal. In both the freshwater and marine environments this use has led to large pressures on a limited resource, resulting in environmental degradation of the very water supplies that have been the life-line for communities.

In Australia urban development has been concentrated on the coastal fringes due to the arid nature of the majority of the continent. This has led to high utilisation of many estuarine areas.

Eutrophication has been one of the major problems associated with enclosed estuarine systems. There is some evidence that these areas naturally tend to a eutrophic state; when this is exacerbated by the activities of man it is referred to as cultural eutrophication.

Nutrient enrichment of water bodies can result in dramatic changes in water quality brought about by increased primary productivity. The resulting increase in plant growth, either as macrophytes or as phytoplankton, can severely affect the amenity of the water body by restricting water flow, trapping litter, becoming unsightly and interfering with boating and swimming. The odour produced when this material decays, and the resulting oxygen deficit, are particular associated problems (Cullen & Smalls 1981).

Typically, nutrients are responsible for the problem of eutrophication, with phosphorous and nitrogen levels usually implicated as controlling plant growth in an enclosed or semi-enclosed water body (Hillman et al. 1990).

As macrophytes are also responsible for trapping increased amounts of sediment, excessive growth can lead to more rapid siltation of the area. The high oxygen demand resulting from dense macrophytic growth during the respiration phase, and during their decomposition, can result in the death of other organisms. The odours produced during the decomposition can also become a local problem.

Increased productivity of phytoplankton may result in less desirable plankton assemblages with blue-green algae and dinoflagellates dominating the community. These algae are considered less desirable as they are noxious due to toxicity, cause scum formation, accumulate on shores (Granéli et al. 1990) and are regarded as low in nutritive value for grazing zooplankton. The development of toxic blue-green algae in water supplies and reservoirs is a major concern to water management authorities. There have been a series of reports aimed at the early identification and the provision of management procedures to be undertaken in these cases (Anon. 1990). Excessive numbers of diatoms in the phytoplankton can also cause problems in water supplies where they are responsible for blocking filters and producing unpleasant tastes and odours.

Nutrient levels and trophic status of water bodies have been the subject of wide ranging studies for the last 40 years. Much work has concentrated on the freshwater bodies of the Northern Hemisphere where the problem of eutrophication has had more impact, particularly in areas where it has an effect on potable water supply.

The most extensive study undertaken has been the Organisation for Economic Co-Operation and Development (OECD) report on eutrophication (OECD 1982). The relationship between available nutrients and the algal population (usually measured by chlorophyll levels) has been quantified. This can now be used as a useful tool enabling water managers to predict the changes likely to occur if the levels of nutrients are altered. Improvements in the trophic level of the water can normally be expected if external nutrient sources are removed.

In most situations examined, the water bodies were fresh water and appeared to be limited by phosphorous. Marine waters have received relatively little attention with the main work being done in the Baltic Sea. This is one example of an area where the effects of eutrophication have remained close to the source of nutrients. In some situations the impact of nutrient enrichment is only evident in areas distant from the source, particularly if the source is a diffuse source such as that from agricultural run-off. The Baltic supports a viable fishing industry and hence any impact on this area is likely to have a detrimental effect on the human population.

In Australia there has been a recent and dramatic example of disruptive eutrophication with the occurence of a massive blue-green algal bloom through the Darling River system. This has had a massive social and economic impact apart from the ecological damage to the river system.

This thesis describes a study of Orielton Lagoon, a semi-enclosed water body, in southern Tasmania, which is an example of a eutrophic estuarine system. Originally part of the Pittwater estuary system, it has been enclosed by the construction of road causeways and acts as an endorheic system for much of the year.

Evaporation and poor tidal flushing, particularly during the summer months, allow the lagoon to become hyper-saline and this adds another component of stress to the system.

Initially the aim of this study was to examine the occurrence of odours from Orielton Lagoon and to propose a strategy to alleviate the problem.

To achieve this aim, several areas of study were pursued as follows:

1 examination of the historical developments associated with the lagoon and the causeway system.
2 measurement of physical, chemical and biological baseline parameters to determine the trophic status of the lagoon.
3 mathematical modelling of the movement of water through the lagoon.
4 review of the nutrient balance within the lagoon by examination of the relative nutrients inputs from various sources.

Results of the study were used to recommend a management strategy for the area.

Chapter 2

Geography

2.0 General

Orielton Lagoon is part of the Pittwater complex of bays and estuaries, in south-east Tasmania protected by a coastal barrier (Harris 1968). Pittwater is a very shallow water body with a single tidal inlet into Frederick Henry Bay and can be described as an enclosed sea (Healy & Harada 1991). Orielton Lagoon is further enclosed by the construction of a road causeway in 1953; concrete culverts connect the two water bodies (See Map 1)

Pittwater and Orielton Lagoon lie about 20 km north-east of Hobart, latitude 147°30′ E and longitude 42°35′S.

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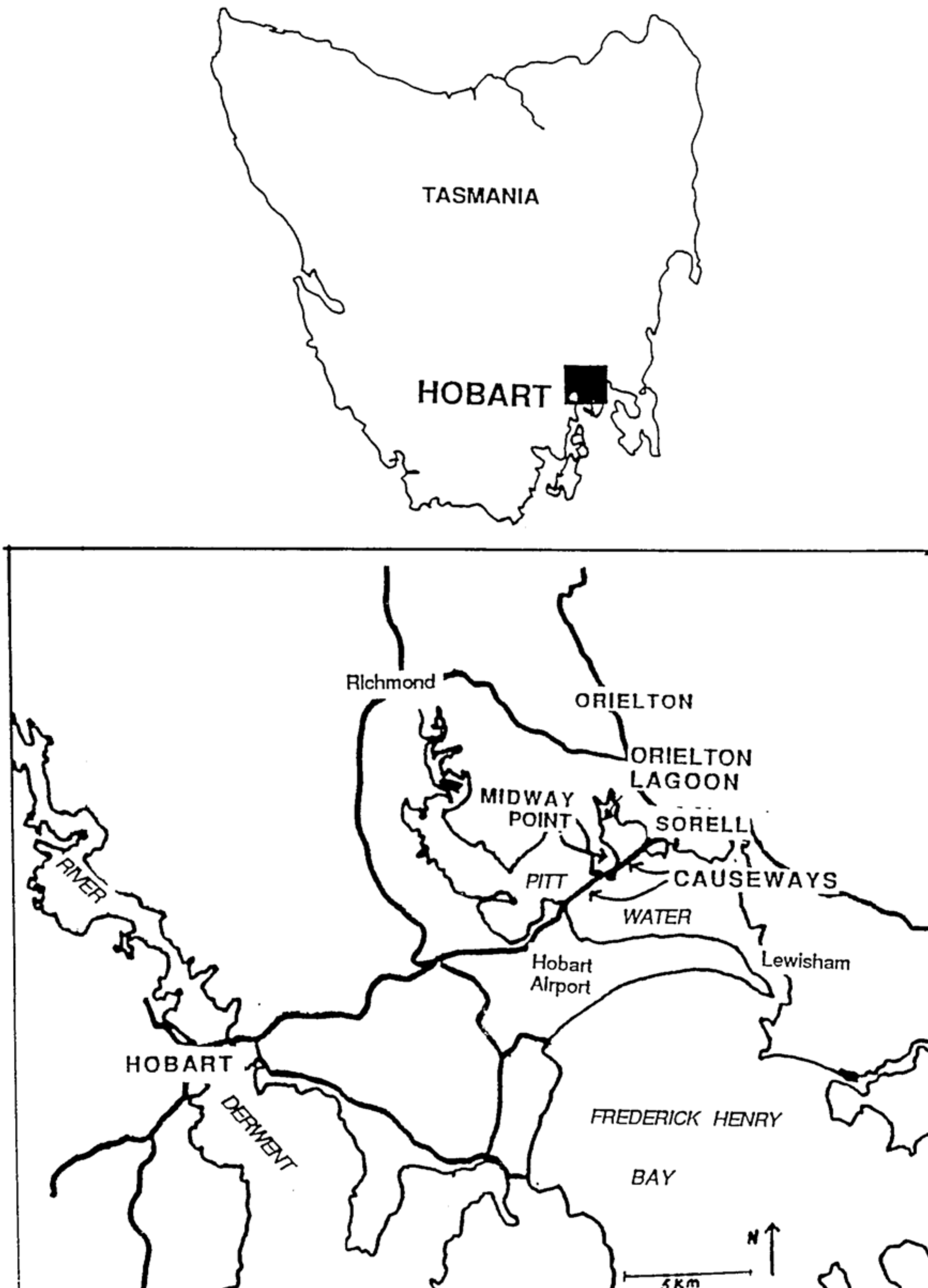
The lagoon is fed by, two small streams, Orielton Rivulet and Frogmore Creek, with a combined catchment area of approximately 60 km^2 (Spratt 1984). The catchment has a north-south length of 12 km and is approximately 5 km wide (See Map 2).

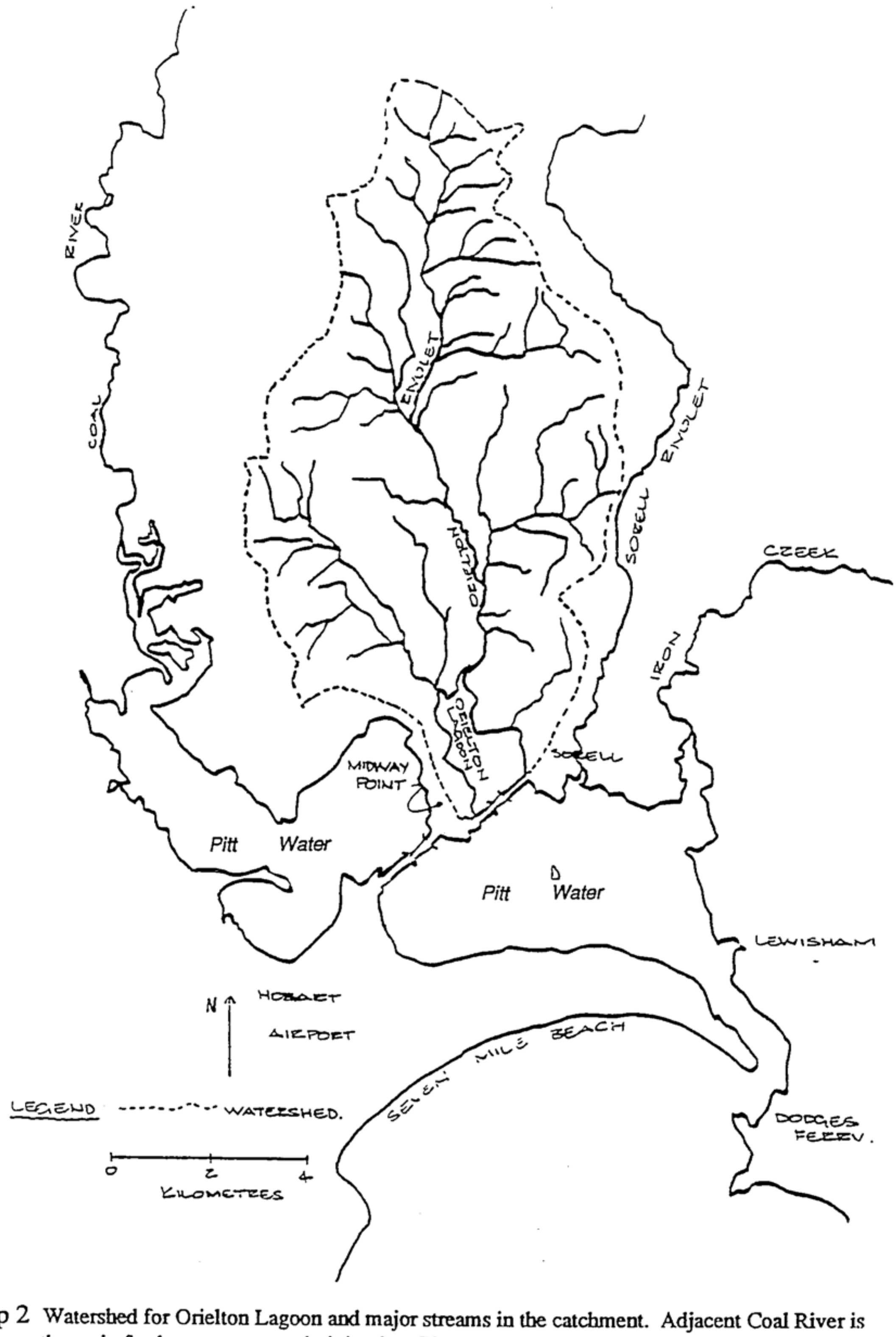
Midway Point on the western side of the lagoon is a Ross Sandstone (Triassic) formation, " a strongly bimodal sand and clay" (Harris 1968, p. 5). The eastern side of Orielton Lagoon is bordered by Tertiary basalt and the north-western section of the lagoon is Quaternary alluvium (Harris 1968). Part of this now forms the saltmarsh area of the lagoon.

The rivulets drain low lying alluvial river flats which are described as a clay loam surface over a dark greyish brown to brown, heavy clay (Davies 1988). The river terraces have a self mulching light clay over dark greyish brown heavy clay (Davies 1988) so sediment carried by the rivulets would be dominated by clay paticles.

Tasmania is in the latitudes that include the "Roaring Forties", the strong westerlies that dominate the weather patterns for much of the year. The winters are dominated by continental anti-cyclones which are broken down to some extent during the summer months and replaced by low pressure areas over the north of Australia (Davies 1965). At Pittwater the dominant winds in the summer are from the NW in the mornings, with SE sea breezes in the afternoons. The winds in the winter remain from the NW most of the day and can sometimes become gale force.



Map 1 Location of Orielton Lagoon, Pittwater estuary, the causeways and towns, in SE Tasmania.



Map 2 Watershed for Orielton Lagoon and major streams in the catchment. Adjacent Coal River is the main fresh water system draining into Pittwater.

Rainfall in the catchment, is generally low, averaging 600 mm per year with the main falls in late winter or early spring. However, there are years on record with extremely low winter rainfall and flooding in summer. Average minimum and maximum monthly temperatures at the nearby Hobart Airport range from 11 °C to 22 °C in summer and 3 °C to 12 °C in winter. The temperature in spring and autumn can vary dramatically with the most settled weather in autumn. Evaporation at the Hobart Airport ranges from 1.4 mm/day in June and July to 6.4 mm/day in January (Bureau of Meteorology 1975).

2.1 Physical Parameters

The lagoon has an average depth of 1.3 m with channels up to 2 m deep. The average surface area is 265 ha. (Steane 1975). The volume of the lagoon varies between 1.96 and 2.2 x 10^6 m^3 depending on the depth relative to the sill level of the culvert (Steane 1975). The shoreline length is 7 km excluding 1.3 km of causeway (Spratt 1984).

The annual inflow to the lagoon was estimated at 3.56 x10^6 m^3 during this study. This represents the sum of annual average flow rates for Orielton Rivulet, using information from the Rivers and Water Supply Commission (RWSC) gauging weir north of the lagoon, (RWSC, 1991) and a tidal input of 764 000 m^3 per year, estimated from a hydraulic model (ref. Section 4.17). The hydraulic residence time, T(w), was estimated at 0.47 years. (T(w) equals water volume (m^3) divided by the inflow (m^3 /yr).)

The main rivulet which drains the catchment, Orielton Rivulet, meanders through a low lying alluvial plain for approximately 7.5 km before it reaches the upper reaches of the lagoon (Tas Maps 1985). The lagoon features a narrow, tidal estuary upstream of the Shark Point Road bridge but this is generally not considered as part of the lagoon proper. The rivulet frequently does not flow during summer (RWSC 1991).

Water outflow is difficult to estimate but some indication can be obtained from a study done in 1975 by RWSC (Steane 1975), when a Rimco 2-pen water level recorder was installed at the culverts in the causeway. Reliable information was only obtained for a short period of time (9/9/1975 to 29/9/1975). This indicated that after 14/9/1975 there was no further outflow from the lagoon despite a high tidal inflow late in the study period. From this report an estimation of the loss of water due to seepage through the causeway was calculated to be 162 000 m^3 for 20 days.

2.2 Water Movement

The movement of water in the lagoon is controlled by stream inflow, tidal inflow, wind and seepage through the causeway.

2.3 Sewage, Agricultural and Urban Discharge

2.3.1 Sewage Treatment at Midway Point

Until December 1991 the population at Midway Point was serviced by a primary sewage treatment plant which discharged its effluent into the lagoon. This commenced operations in 1969.

The initial sewage treatment plant was a simple Imhoff tank design with a capacity for 2800 people. The plant consisted of inlet screens and a tank for settling and digestion of sewage sludge (Spratt 1983).

Monitoring of the discharge has been undertaken since 1986. The treatment plant has had a licence to discharge a total of 230 kL/day but the estimated current discharge has been given as 475 kL/day (Department of Environment and Planning (DEP) 1986). The permitted levels of discharge as set by the Department of Environment and Planning (DEP) are Biological Oxygen Demand, BOD 40 mg/L, Non Filterable Residue, NFR 60 mg/L and faecal coliform levels of 1000 cfu/100 mls. These values have not been met, with levels of discharge for BOD ranging from 170 to 300 mg/L, NFR ranging from 80 to 140 mg/L and faecal coliform counts from 2.8×10^6 to 7×10^7 (DEP Files 1990). These values are apparently within the normal range for such a plant operating for the number of people at Midway Point (Spratt 1983).

Concern over the situation has led to a number of options being proposed over the years with the result that a new treatment plant will be fully commissioned and operational by March 1992. The new plant, a Pasveer ditch, with denitrification lagoons, is expected to have an effluent quality with a BOD of 15 mg/L and NFR of 15 mg/L and a total nitrogen load of 5 mg/L (Chong 1987). This plant should be able to meet the discharge requirements laid down by the DEP (Spratt 1983).

2.3.2 Agricultural Run-Off and Non-point Discharge

Agricultural discharge is directly related to inflow from the two small rivulets draining into the lagoon. A gauging station on Orielton Rivulet gives daily flow rates and has been operational since 1975. Average flow rates in the rivulet (Fig. 2.1), clearly show the greatest flow rate occurring in August.

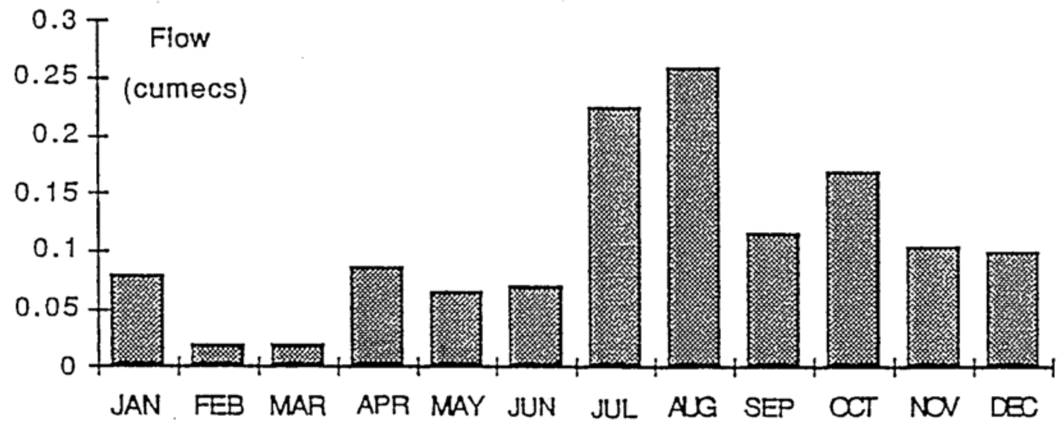


Figure 2.1 Average monthly flow rates in Orielton Rivulet from 1975-1991. Supplied by the RWSC.

The flow rate for Frogmore Creek, the other small creek flowing into the lagoon, has not been recorded. However, for most of 1991 there was no flow from this source and during late winter and early spring the high tides made it difficult to determine whether water in the creek was inflow or back-up from the tides. Total discharge from the creeks is usually very low with an annual average of 3.562×10^6 m^3 (RWSC 1991).

A further small stream discharges into the lagoon from Sorell but this only flows during storms. There are storm-water outlets from the Midway Point development that discharge urban run-off.

2.4 Land Use and Vegetation

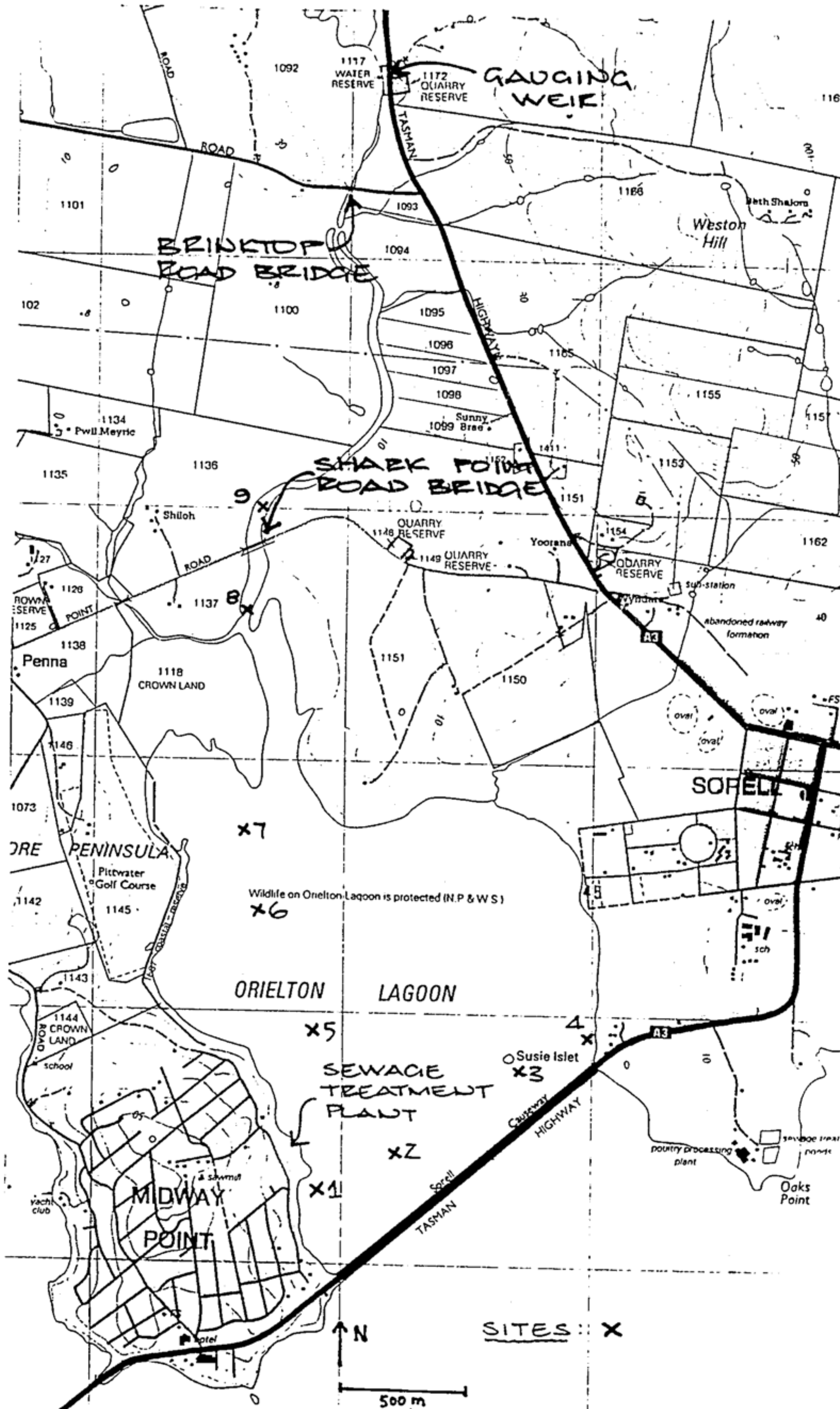
Orielton Lagoon is bordered on one side by the urban development of Midway Point but this is separated from the lagoon by a reserve 5 m wide. The urban development extends the length of the western side of the lagoon until it reaches the Pittwater Golf Club. The golf club land extends to the high-water mark and the club extended one of the tees into the lagoon in 1975. The southern edge of the lagoon is bordered by the causeway with the eastern side bordered by a narrow reserve backing on to rural land

and an area zoned "light industrial" by the Sorell Council (DEP Files 1987). Part of this latter area is occupied by a wood supplier and the rest is vacant.

The north-eastern boundary of the lagoon is bordered by agricultural land which is presently used to grow cereal crops. There is a small width of uncultivated land acting as a riparian strip. The most important area of vegetation, from a conservation viewpoint, is the salt-marsh occupying the north-western boundary of the lagoon. This area is dominated by dead *Sclerostegia arbucula*. Live *Sarcornia quinqueflora* borders the rivulet adjacent to pasture land (Kirkpatrick & Glassby 1981) Both in this area and on the reserve bordering the eastern boundary, there are populations of the rare *Calocephalus citreus*, a small composite plant normally found only in the local area on road verges. There is evidence that *Sclerostegia* previously extended into other areas of the lagoon. Now normally inundated for most of the year, these areas must have formed part of the mud flats prior to the construction of the causeway. The dead *Sclerostegia* bordering the lagoon died after burning in 1975 (J. Kirkpatrick pers. comm.) although one source dates its demise to major flooding on Anzac Day 1960 (Parks, Wildlife & Heritage (DPWH) Files, 1960). Rainfall data indicate a record monthly total for April of that year (244 mm), corresponding to approximately 40% of the annual rainfall. This might have been responsible for siltation and the formation of anoxic conditions in the root zone, thus killing the plants.

The lagoon extends in a northerly direction, for four km through low lying farmland where it is subject to stock activities. It is brackish in the upper reaches with a tidal influence to just above the bridge on Brinktop Road (See Map 3). The vegetation along this section of the lagoon includes pasture land and *Juncus* species.

The woodlands in the catchment area are dominated by *Eucalyptus viminalis* with an understorey of *Acacia dealbata*, *Acacia melanoxylon*, *Acacia vertisillata*, *Casuarina stricta*, *Dodonea viscosa*, *Exocarpus cupressiformis*, and *Leptospermum lanigerum*, *Pomerderris apetala* in the river terraces (Davies 1988). This is the vegetation pattern that would have dominated the region before it was cleared for agricultural purposes although there may have been areas of open grassland (Reid 1979).



Map 3 Location of sampling sites on Orielton Lagoon, for 1991 study. From Tasmap No. 5426.

2.5 Population Patterns

The two population centres at least partially within the catchment of Orielton Lagoon are the small town of Sorell and the residential area of Midway Point.

The district has grown slowly since the early years of the 20th century but during the early 1960's the development of Midway Point produced a rapid change in the population of the area. The population of the census area for Midway Point has grown from 2029 in the 1971 census to 2882 in the last count (1986), increasing 13.3% between 1981 and 1986 (Australian Bureau of Statistics, ABS, 1971-86). The median age for this area was 29.1 and a breakdown of the figures indicates a population of young families.

Figures from the 1986 census indicated a population of 2104 in the collection areas which cover only Midway Point (ABS 1986).

The population of Sorell has remained largely unchanged during that time (ABS 1986). The surrounding areas have seen an increase, since the early 1980's, in the number of small hobby farms and dwellings established for a rural lifestyle.

Orielton, after which the lagoon is named, is a hamlet on the upstream river flats. The district features only a small shop and one church, which appears disused, and no nearby dwellings.

2.6 Water Usage

The Pittwater area is used extensively as a water-based recreational facility for local residents and visitors from Hobart. There is also a well established aquaculture industry in the mouth of the Coal River (which is the major freshwater input for the entire waterbody). This industry produces oysters of extremely high quality - Barilla Bay oysters are a well known delicacy in top restaurants such as the Athenaeum Club in Victoria (D. Baker, pers. comm.). This industry is valuable for the Tasmanian economy so its maintenance is an important consideration in any plans for Orielton Lagoon.

Orielton Lagoon itself is not used for recreation except for walking on paths bordering parts of the foreshore. The water quality is such that generally the lagoon would be considered unpleasant, and the addition of primary treated sewage, with attendant health risks, does not enhance its potential for use by people.

However, as will be discussed later (ref. Section 3.6), the lagoon is an important refuge for non-breeding migratory wading birds from the Northern Hemisphere and as such is popular as a bird-watching area.

Chapter 3

History

3.1 General History

The Coal River Valley developed rapidly as the main wheat growing district of the new European colony in Tasmania. The early towns of Richmond and Sorell became important and prosperous centres during this period of early settlement.

The land surrounding Orielton Lagoon has been used extensively for agriculture since these earliest colonial times. The importance of the wheat production led to the area becoming known as "The Granary of New South Wales" and by 1842, Tasmania supported 48% of the total acreage in Australia. (Tilt 1965). However, the discovery of gold in Victoria at this time reduced the population of Van Dieman's Land by one third and there was no subsequent increase in wheat production.

Nevertheless the township of Sorell grew and after the introduction of a railway from Kangaroo Bay to Sorell, towards the end of the 19th century, it became a popular day trip location. Shark Point, at the northern end of Pittwater, "was a very popular picnic spot and many people would alight to spend a day's picnicking and fishing before catching the afternoon train back to Bellerive" ("Back to Sorell" Celebrations 1960).

The district grew slowly through the early years of the 20th century but, during the early 1960s, the development of Medway Point (now Midway Point) produced a rapid change in the population of the area. Although physically close to Hobart, the area was isolated by the Pittwater estuary and this led to the development of a causeway (See Map 1) across the estuary.

3.2 Causeway Construction

A road was constructed to Sorell shortly after establishment of the settlement at Hobart, with a ferry service used to cross Pittwater. This serviced the area for 60 years ("Back to Sorell" Celebrations 1960). The road passed around the northern end of Pittwater passing across the land bordering the present Lagoon. However, the isolation of the area initiated proposals for the development of a causeway as early as 1847 and, in 1859, plans were approved for its construction. The project was jointly funded by private contribution and equal Government funding. By 1864 the initial construction had been halted, but it was recommenced in 1865 and completed in 1874 (Jones 1988).

The original work consisted of causeway and bridge sections between the Bluff and Medway Point (now Midway Point, see Map 1), and between there and the Sorell shore. The plans for the first section, between the Bluff and Medway Point., show a bridge section 10.67 m (35 ft) long. This was to be a swing bridge to allow sailing vessels to proceed to within one mile of Richmond to load grain bound for Botany Bay. This section was actually constructed using a conventional timber bridge. There were three spans of bridge in the section between Midway Point and Sorell (Jones 1988).

Much of the timber, especially that used for piles, was blue gum and stringy bark from the Tasman Peninsula. There was a total of more than 1000 piles and 600 000 feet of sawn timber, mostly from Southport (Reid 1979).

The opening of the causeway on 22 June, 1874 was a gala occasion with the Governor, Charles du Cane, and other officials coming from Hobart. The official opening was followed by a luncheon at Sorell and was reported extensively in the local newspaper of the day, "The Mercury".

Sections of the wooden bridges were replaced in 1902 but by the end of the late 1940's their condition was of such concern that it became necessary to reduce the speed limit and control the weight of vehicles using them (Department of Main Roads, Tasmania (DMR) Files). In 1952 a report by the DMR (DMR Files 1953) showed that the traffic using the causeway had trebled in the previous 14 years since the opening of the Hobart Bridge and had almost doubled since 1948.

Various proposals were put forward to resolve the problem. These included:
(i) abandoning the causeway route and relocating the highway along the old Bellerive-Sorell Railway track,
(ii) completely filling the bridge sections, or
(iii) partially extending the causeways but reducing the amount of bridgework.

Costs at the time ruled out the first alternative. The third option was adopted for the section between the Bluff and Midway Point. with the second option being adopted for the section between Midway Point and Sorell. The option of filling in the former section, to create a freshwater lake, was rejected due to problems associated with seepage, evaporation and the extensive spillway that would be needed. Furthermore the Freshwater Fisheries Commission and the Fisheries Division of the Department of Agriculture were concerned about possible damage to marine fisheries in the upper reaches of the bays.

The decision to fill the Midway Point to Sorell section was made on purely economic grounds. A proposal featuring reduced bridgeworks, still totalling 128 m (420 ft), was going to be twice as expensive as the infilling, with culvert spillways, adopted.

Eventually the causeway was enlarged and reconstructed until little if any of the original structure is visible today. The option of replacing bridgework with infill and culverts on the Midway Point to Sorell section resulted in three bridges with a total length of 195 m being replaced by two culverts with a total length of 36 m with spillway crests corresponding to average high-tide level. The work was completed in 1953.

A perceived additional benefit of the infilled causeway construction was the idea of converting the lagoon to a freshwater lake which it was thought may provide irrigation and recreational facilities (DMR Files 7/8/1953). It was hoped that frequently occurring higher-than-normal tides would offset the problem of evaporation and the resulting salinity increases, and that cleansing of the lake would be performed by the outflowing flood waters (DMR Files 1952).

Following the construction of the causeway between Midway Point and Sorell, odour problems were reported to be the result of decomposition of aquatic weed.

3.3 Odour Problem

Prior to the construction of the 1953 causeway, Orielton Lagoon had been a safe area to learn to swim, being a favourite picnicking spot for local residents. There was easy access to Susie Islet during low tide (L. Wall, 1991, pers. comm.). However, by 1959 local residents were complaining that the lagoon was often covered with a slimy weed and its subsequent decomposition produced unpleasant smells. There were urgent requests that the spillways be lowered as residents saw the stagnation of the waters as the main reason for the production of the weed and the resulting problems (DMR File 1959).

Odour problems continued to occur throughout the next thirty years despite various investigations and recommendations (ref. Section 3.3.3). Reports of odour problems have been documented in the DEP files since 1972. Descriptions of the odour vary;

some describe the typical mud-flat odour of hydrogen sulphide. Similar smells have been associated with the decomposition of large quantities of macro-algae in the Peel Inlet in Western Australia (Hillman et al. 1990).

Following the introduction of the sewage treatment plant discharge to the lagoon in 1969, residents complained about odours with an emphasis on sewage being the source of the problem. "Sewage-like smell", "an old fashioned toilet smell", "the smell of a night cart " were some of the descriptions of the odour from a survey done by the DEP on 26/11/1975.

Reports do not clearly indicate the exact nature or source of the odours reported. Some reports of odour have been clearly associated with rotting macro-algae but others have, equally clearly, been associated with the sewage treatment plant. At other times the investigating officers from the (DEP) have found decomposing algae releasing no smell, but a strong odour still coming from the lagoon. A detailed list of the reports of the odours recorded in the DEP files from 1972 to 1991 is presented in Appendix C. The information from the DEP files is summarised in Table 1, which includes a brief description of the odour as recorded.

During the summer of 1990-91, the spring of 1991 and early summer of 1991-92 there were no reports of odours from Orielton Lagoon. There were small mats of filamentous algae in the northern area of the lagoon during early November but these dried on the shore without releasing any odours. Mats of filamentous algae, identified as a *Cladophora* sp. and a red filamentous algae (G. Edgar, pers. comm.) are shown in Plate 1.

A local resident has claimed to be able to predict the problem of odour by watching mats of algae which appear in the far north of the lagoon, where it passes through agricultural land. In years when the algae becomes a nuisance, mats move through this section of the lagoon before entering the lagoon proper and spreading throughout (J.Reynolds, pers. comm.). Their subsequent odorous decomposition appears to be the main source of complaints.

Date	Description and Location of Odours
Summer, 1959/60	Bay covered with slimy weed, decays with obnoxious odours. This has happened over the last two years. *
March, 1973	High smells reported by phone call.
Autumn, 1975	Pungent odour reported in SE corner
Spring,1975	Survey results describe odour, descriptions range from sewage odour to silage pit and sulphur smells.
Spring,1978	R. Buttermore investigated odours, found decomposing Ruppia maritissa did not smell, neither did Sewage Treatment Plant, STP.
Spring, 1981	Offensive odour from green weed on lagoon.
Spring, 1983	Five complaints of odour reported, decomposing algae on shore.
February,1984	Letter complaining of odour accompanied by rotting vegetation.
December, 1984	Odour reported from STP.
December, 1985	Accumulation of rotting algae in SW corner, giving off stench.
Spring,1989	Frequent and continued phone calls complaining of odour. Green algal mat and smell from the lagoon.

Table 1 : Date of occurrence, location and description of the odour as reported to DEP, for Orielton Lagoon, from 1973 to 1990. * Reported in Department of Main Road Files.

There has been at least one report of blue-green algae appearing in the lagoon although this problem is generally restricted to fresh or brackish waters with salinities to 20‰ (Granéli et al. 1990). The algae was identified as *Aphanizomenon* sp. (G. Hallegraeff, pers. comm.) and the resulting scum is shown in Plate 2. Although an odour has been associated with blue green algal mats elsewhere (Hillman et al. 1989), no particular odour was reported to the DEP at the time of their identification at Orielton.

Plate 1: Mats of filamentous algae at the northern end of Orielton Lagoon, November 1991

Plate 2: Green scum accumulating on the surface of Orielton Lagoon, February 1986.

photo - G. Hallegraeff

There have been several studies related to the odour problem at Orielton Lagoon.

A CSIRO officer investigated the odour problem in 1960 and concluded that the seaweed was dying due to the brackish nature of the water and that the problem would be overcome when the lagoon became entirely fresh water. However, this was happening "unevenly" (DMR Files 1960). Upon this advice it was decided to reduce the salinity more rapidly by preventing the inflow of any sea water; weirs of 0.5 m were added to the spillway in 1962. The lagoon was then stocked with brown trout each year and provided easy-access recreational trout fishing. However, by 1973 there were deaths of fish on a regular basis and although most of these were not trout the Inland Fisheries Commission (IFC) ceased stocking the lagoon with trout (Lynch 1974) and the baffles on the weirs were removed in 1975. This improved the flow of water but did not eliminate the odour problem.

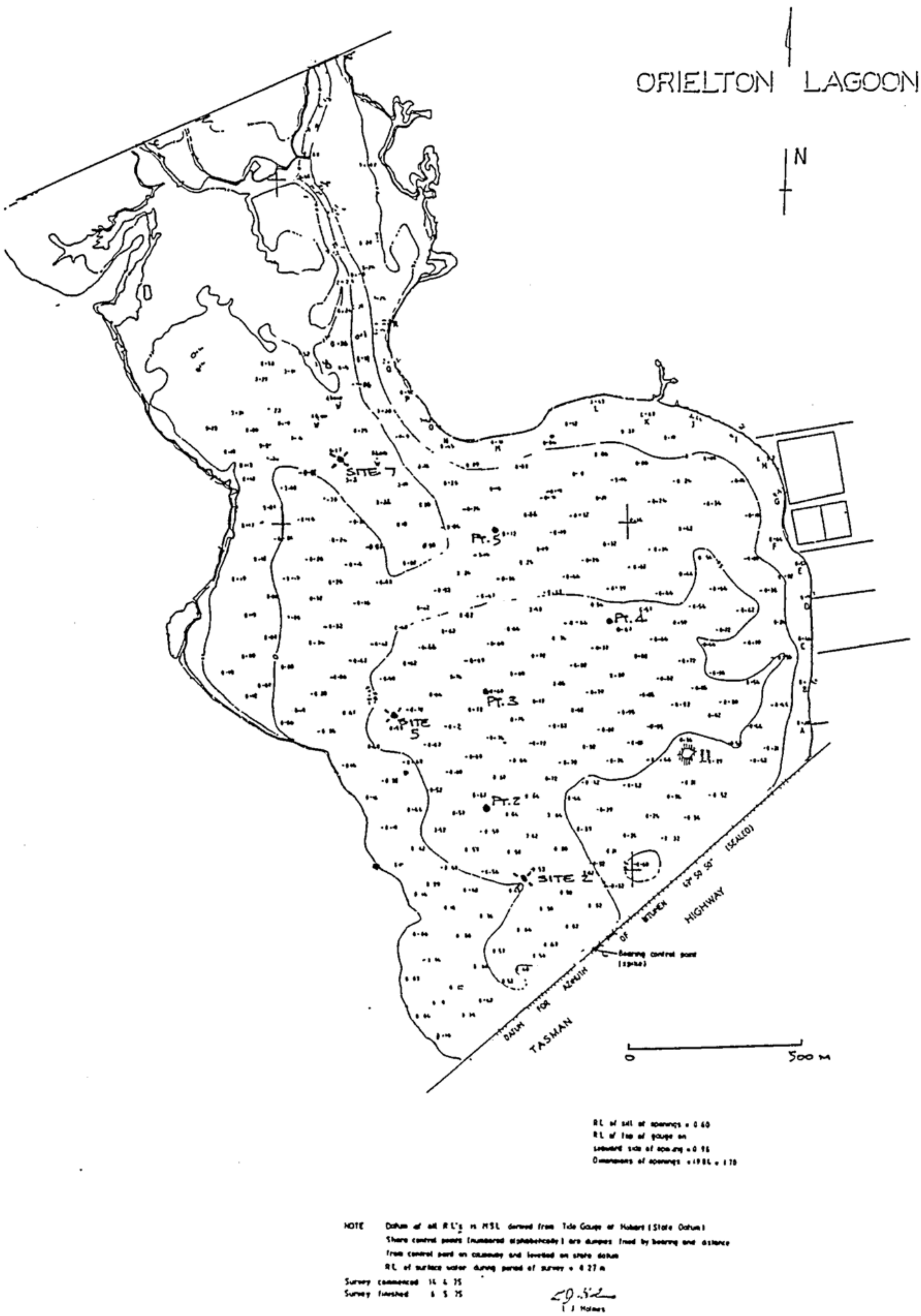
M. Roper's study on the *Escherichia coli* in 1972, showed particularly high levels of *E.coli* near the sewage outlet. The study also indicated that the *E.coli* were being protected from phage attack by the high salinities and that they would be released when the sediments were subject to fresh water (Buttermore, 1977).

A further report by Professor Jackson (Botany Department, University of Tasmania) in 1971 recommended strong anti-pollution measures (Parks, Wildlife & Heritage Files, 1972).

A hydrological study was undertaken by RWSC in 1972 to supplement work done by Professor Jackson. In this study, level recorders were installed on the measuring weir on Orielton Rivulet and at the culverts through the Sorell causeway, to record both the level in the lagoon and the tidal level in Pittwater.

Reliable data were not obtained until 1975 when a "water balance" for the lagoon was calculated for a short period, 9/9/75 to 29/9/75. Using these data an estimation of the seepage rate was calculated (Steane 1975).

At the same time a level survey of the lagoon was undertaken by the Department of Lands which produced a plan showing surface contours at 0.5 m intervals (Map 4), with mean sea level at Hobart being taken as the datum (State Datum) (Steane 1975).



Map 4 Lagoon depth survey from 1975 and location of points measured in 1991 depth survey. From: Orielton Lagoon - A Preliminary Water Balance, Unpublished Report, 1975, RWSC, J.D. Steane.

In 1975 a study was commenced by R. Buttermore which set out to collect physical, chemical and biological data (Buttermore 1977). The study concentrated on basic physical and chemical parameters in the water-body with no information being presented on the sediments, the phytoplankton or the productivity of the system. The study indicated that the lagoon was eutrophic as a result of nutrient enrichment. The conclusion was that there was no quick solution to the problem but it was suggested that removal of algal growth prior to its decomposition may alleviate the odour problem in a temporary way.

The Southern Regional Metropolitan Sewerage Study,1977, examined Orielton Lagoon and proposed alternatives for the disposal of the sewage effluent from Midway Point. One option was for the disposal of the effluent on land near Penna, at the northern end of the lagoon. Although the land disposal option was recommended, and land purchased, the plan was later rejected, primarily on economic grounds (Spratt 1983).

A study by the consulting engineers England Newton Spratt & Murphy Pty. Ltd. in 1984 (Spratt 1984) indicated, from very variable results, that sediments were the main source of nutrients and that these had been deposited in floods. It was also suggested that, as the odour problem was present prior to the introduction of sewage, the sewage had little impact on the eutrophication problem. The report from 1983 formed the basis for management proposals which included dredging the sediments (Spratt 1989).

This report was heavily criticised by the DEP which then carried out its' own study concentrating on nutrient inflow and outflow through the lagoon (DEP 1986). In this report it was estimated that 50% of the sediment carried in the stream during floods passed straight through the lagoon. There were wide discrepancies in the figures quoted for agricultural run-off.

3.4 Agricultural History

As already mentioned, the area was important for the production of cereal crops for early European settlers in Australia. In 1874, during the opening of the causeway, the Governor commented on the state of the land when he responded to the toast to the causeway. After praising the people of the district for their industry he pointed out that "when he visited the district three years previously he had been surprised to see that the soil was showing signs of becoming exhausted. Now he believed that this state of affairs was being improved through such practices as rotation of crops, manuring and the use of better farm equipment" (Reid 1974).

At about the turn of the century, agriculture changed from predominantly wheat growing to sheep and mixed farming. During this time there was the development of apricot orchards and small family-run dairy farms, in the Orielton district. This form of agriculture continued through the early part of this century with the use of superphosphate starting during the 1930s. The dairy farms had an average of 20 cows with only 1 sheep/acre being common (D. Wilson, pers.comm.). Other crops grown during this period of time included green and grey peas, wheat, barley and oats (E. Boyle, pers. comm.).

With the introduction of superphosphate and other artificial fertilisers the productivity of the area rose. Simultaneously there was the development of subterranean clover and these two factors improved the carrying capacity to 2 to 3 sheep/acre.

During the second World War there was a small amount of flax produced in the area but generally the mixed farming continued to dominate (D. Wilson, pers. comm.).

During the late 1950s and 1960s most of the apricot orchards were removed due to disease and old age. These trees were generally not replaced as they were labour intensive and there was no incentive to replant. The number of dairy farms also declined with larger farms and fewer people. The land was usually worked in a rotation of crop and pasture. The pastures were usually down for 5 to 10 years producing fat lambs and sheep. The land was then cropped to provide fodder crops such as rape and choumollier. At other times it was used for cereal crops but was not generally suitable for breeding cattle because of the low and unreliable rainfall. Sometimes store-cattle or calves were fattened as a side line (D. Wilson, pers. comm.).

The development of mixed farming in the area continues to this day with some areas being now in the hobby farm belt that surrounds Hobart. Professional people have moved to the area with 20 to 50 acre lots and the dairy farms have been divided up. This has led to an increase in the population of the area with a wider range of land uses. New land uses include flower growing but running of sheep, goats and horses is most common. On some of the larger properties there is share-cropping with less conventional crops such as alkaloid poppies, although this was apparently unsuccessful and has stopped (D. Wilson, pers. comm.).

The subdivision of the lower part of the catchment started about 1975 but accelerated rapidly through the 1980s. This lower end of the catchment consists of a series of plains of self-mulching black clays which are quite productive soils. Orielton Rivulet passes through these plains in a small gully. Stream bank erosion has not been considered a major problem (D. Wilson, pers. comm.) with cultivation generally ending 5 to 10 metres from the stream bank. There has however, been a slow widening of the gully due to stock erosion, but very limited washing of soils on the plains. Erosion has occurred further up the catchment with sheet and tunnel erosion towards the head of the rivulet.

3.5 Superphosphate Use

The use of superphosphate in the Orielton area can be traced back to its introduction in the early thirties and forties, and since then there has been a rapid increase in both the acreage treated and the application rate. In 1956-57 the application rate of artificial fertiliser was 1.73 cwt/acre and this treated a total of 1032 acres in the Sorell area. The application rate varied between the crops, with fruit receiving 5.5 cwt/acre and pastures only 1.52 cwt/acre. These rates increased through the next twenty years with the encouragement of the Australian Commonwealth Government through fertiliser subsidies. By 1966-67 the average had increased to 1.86 cwt/acre with a total area of 1819 acres being treated. There was a continued increase in the usage of artificial fertilisers through the 1970s until 1978-79 when the maximum usage was a total of 9223 cwt on 8278 acres, a rate of 1.11 cwt/acre. Since then there has been a decrease in the usage of artificial fertilisers with the lowest acreage being fertilised in 1983-84. Generally there has also been a decline in the proportion of "straight" superphosphate in the general application. In the four years from 1967-68 until 1970-71 there was a 35% drop in the usage of straight superphosphate but an increase in other artificial fertilisers, including superphosphate mixtures (Commonwealth Bureau of Census and Statistics 1969, ABS 1987).

The average rate of application from the statistics agrees with recommended rates suggested by a former agricultural officer of the area, Mr D. Wilson, who recommended 1 to 1.5 cwt/acre (125.4 kg/ha, 0.125 t/ha). This converts to an application rate of 11.375 kgP/ha as there is 9.1% P in superphosphate (Pasminco EZ Pty. Ltd., pers. comm.). This rate of application is less than that reported in Western Australia, in the Harvey district, where the application rate varied from 18 kg P/ha, in paddocks for grazing, in the coastal plain catchment, to 38 kgP/ha on irrigated pastures in the dairy farms (Birch 1982).

3.6 Conservation Status

The waterways of Pittwater and Orielton Lagoon have always been important to bird life. In 1820 the area was described in the following terms: "Prolific bird life on Pittwater, endless varieties of ducks, geese, pelicans, amid jet black swans" (Wood 1991).

The importance of the area as a wildlife sanctuary has been recognised for at least 20 years and Orielton Lagoon and several attempts have been made to declare the surrounding wetlands as protected areas.

In the early 1970s the area was initially considered for protection following complaints by Midway Point residents about excessive duck shooting on Orielton Lagoon. The proposal, put forward in 1972, was supported by government bodies provided that no financial assistance was to be sought from National Parks and Wildlife to correct the pollution in the lagoon (DPWH Files 1973). However, support for the proposal, which was initially supported by the Sorell Council , decreased when a clay pigeon shooting range was proposed for the northern end of the lagoon. Finally legislation was passed in 1973 that prohibited shooting on the lagoon (Wildlife Amendment Regulations, Tasmania, No. 2 1973).

The Bird Observers Association of Tasmania (BOAT) became interested in the wetlands and, in 1975, recommended the area for conservation in an article titled "Tasmanian Wetlands Conservation" in the Bird Observer, 1975. A report on Tasmanian wetlands by the CSIRO Division of Land Use Research also recommended that the lagoon be conserved (DPWH Files 1975).

The area is an important and major feeding ground for migratory wading birds from as far away as the Arctic tundra. "It is one of the most important wader habitats in Tasmania, particularly for the Eastern Curlew and Lesser Golden Plover" (Abbott 1991). Orielton Lagoon is also considered to be a significant refuge for waterfowl in times of drought and is becoming increasingly important as other wetland areas are modified (Abbott 1991, p. 11)

BOAT members continue bird counts and there is evidence that the total abundance of water birds decreased significantly between the 1960s and the 1980s (Parr 1986) and there is most likely a similar trend for the last five years. If the early descriptions of the areas are correct it is obvious that there has been a considerable decrease in the bird populations since European settlement.

In 1980 there was a proposal for a Nature Reserve including Pittwater, Orielton Lagoon, Sorell estuary and the Coal River estuary; this reserve was to be known as the Koomeela Nature Reserve. The proposal had strong resident support and was also well supported by BOAT members. However, exemptions for Barilla Bay, Sorell estuary, and objections from the Fisheries Department and duck shooters saw this reserve rejected by State Cabinet in 1986 (Parr 1986).

The area is not only important as a habitat for birds but the proposed reserve would have brought "the proportion of reservation of Tasmanian salt marsh to five percent, and would leave no major salt marsh species outside the State Reserve system" (Kirkpatrick & Glasby 1986).

A similar proposal for a reserve at George Town, in the north of Tasmania, was accepted. However, for Orielton Lagoon the Government called for more information on the importance of the area to the birds. This has since been provided and another proposal for a reserve was put to Cabinet for consideration in October 1991. This latest proposal is for a Nature Reservation for Barilla Bay (included since 1986), Orielton and the mouth of the Coal River, and a Wildlife Sanctuary (Conservation Area) for the rest of the area. The Department of Sea Fisheries has included a provision for future exploration of the areas with aquaculture potential. The latest proposal has been further delayed but may be reconsidered at a later date.

The area also has international importance as it was one of approximately 38 wetland areas that Australia listed when it signed "The Convention on Wetlands of International Importance, Especially as Waterfowl Habitat" or "Ramsar" in 1971. It is also subject to two International agreements dealing with migratory birds. These agreements are the Japan-Australia Migratory Birds Agreement (JAMBA) and the China-Australia Migratory Birds Agreement (CAMBA). Both agreements provide a degree of co-operation between the contracting parties and protect migratory birds by controlling hunting, encouraging joint research and establishing sanctuaries preserving and enhancing the environment of migratory birds (Parr 1988).

While Orielton Lagoon is subject to these International treaties they are morally, rather than legally binding and their administration is not well co-ordinated. "Piece-meal action" tends to be the result (Parr 1988).

However, the DPWH has power, under the Wildlife Regulations, to act if it finds that disturbance to the birdlife or supporting environment is taking place (Blackhall 1991). Therefore, any management strategies undertaken must comply with the guide-lines set out in the International agreements and Tasmanian regulations, irrespective of any potential reservation schemes which might arise.

Chapter 4

Methods

4.1 General

As described in the introduction, this thesis has covered several different areas of study. This chapter describes the methods involved in collection of information, the analysis of material in the laboratory, and calculations and statistical analysis of the data.

The study commenced in February 1991 with monthly samples being collected until October 1991; an additional sampling was carried out in mid December.

4.2 Collection of Material

Data for this study were collected from the main body of the lagoon, from the water column and the sediments of the lagoon.

Data collected were based on a list of limnological variables outlined by the OECD, developed as a result of the OECD study of eutrophication (OECD, 1982).
The following list summarises the variables covered in this study:

a) Physical Variables
   Air temperature
   Water temperature
   Conductivity
   Transparency (Secchi Disc)
   Turbidity
b) Chemical Variables
   pH
   Dissolved oxygen
   Nitrogen as soluble nitrates and nitrites
   Phosphorus as soluble phosphates
   Total phosphorus
c) Biological Variables
   Chlorophyll a
   Dissolved organic matter, g440
   Phytoplankton
   Zooplankton

Other data collected from sediment samples included nutrient levels, sediment particle size and organic content.

The above information was gathered at nine sites (Sites 1 to 9) in the body of the lagoon, at the points shown on Map 3.

4.3 Sampling Procedures

Sampling of the above parameters was carried out using a 3.3 m aluminium dinghy with a 6 HP outboard motor and one assistant. Some sites were sampled from the edge of the lagoon.

The nine sites in the main body were selected to represent two transects through the lagoon. The first transect was parallel to the causeway in an east-west direction and the other transect was selected to include the major inflow point and the outflow. The transect parallel to the causeway incorporated the south-west corner of the lagoon, the area from which there had been the most complaints of odour (DEP Files 1973-91) and this area was also close to the sewage outlet. The transect then continued across the lagoon to an area that appeared to be least likely to be subject to the same problems.

The sampling sites were selected on these transects approximately equidistant and were then identified using markers and visual cues. The markers for the sites which were accessed by dinghy, were two litre plastic floats. These were attached to a concrete block anchor with a length of nylon rope, then lowered into position. Most of the markers remained secure throughout the study and were not visually obtrusive. These sites were also identified using visual clues to ensure that the sites could be identified if the markers were removed. The sites reached from the bank were readily identified by their location. Water depth for samples taken from the edge of the lagoon was 20 cm.

At each site a water sample was collected from beneath the surface at 5 to 10 cm depth, in a clean 1 L white plastic bottle. The bottles had previously been washed thoroughly in phosphate-free detergent and rinsed twice with distilled water. The bottles of water were kept cool until they were returned to the laboratory where they were immediately filtered.

Air temperature, water temperature, pH, conductivity, dissolved oxygen and Secchi disc measurements were all made in the field and noted. Simultaneously, general observations concerning weather, birds and other information were noted.

4.4 Temperature

The measurement of the temperature in an aquatic system can give not only the absolute temperature but can also give some indication of the structure of the water body. Daily and seasonal stratification can have a range of influences on the biological and chemical processes inwater. In Orielton Lagoon the ambient and water temperatures were measured using a portable meter (Hanna Instruments, HA8424, Microcomputer pH meter) which was regularly calibrated in the laboratory. Temperatures were measured to the nearest 0.1^{0}C and were taken in the surface waters (approx. 10 cm deep) and at the bottom of the lagoon where possible. Variations between surface and bottom temperatures were noted if they existed.

4.5 pH

The pH of a water body is a descriptive limnological variable which can affect the biological and chemical properties of the water body. Phosphorus release and absorption is affected by the pH of the water mainly due to the effect on the iron (III) and the aluminium (III) hydroxide gels to which phosphorous is absorbed (Fox et al. 1989). Changes in pH can also result in variations in the species composition of the phytoplankton which in turn alters the zooplankton populations (Harris 1986). Anthropogenic alterations to the pH of a waterbody can thus have significant impacts on the primary production. The pH was measured on the same instrument as that used for water temperature and was measured to the nearest 0.1 pH unit.

4.6 Salinity

Variations in salinity are characteristic of the estuarine environment with fluctuations from fresh water to hypersaline conditions. Variations in salinity can determine the development of specific phytoplankton groups, particularly the growth of cyanophytes. Salinity-temperature interactions were found to be determining factors in the germination and subsequent blooms of *Nodularia* akinetes in the Harvey Estuary (Hillman et al. 1990).

The resistance of a solution to electrical flow is related to the ionic concentration of the solution. The lower the ionic concentration the higher the resistance to electrical flow, thus saline and hypersaline waters would have less resistance than fresh water.

Temperature affects the conductance and any measurements should be standardised (Wetzel 1983). The conductivity was measured using a portable conductivity meter (Hanna Instruments, HI 8633, Accuracy +- 1% full scale, +- 1 digit) and adjusted to standard temperature. The conductivity at each sample site was measured in the surface water and at the bottom of the lagoon to establish the presence or lack of stratification. The conductivity results, measured in mS cm^{-1}, were converted to salinity, expressed as ‰, using a standard curve plotted from conductivity measurements obtained from standard artificial sea water (Fresenius et al. 1988)

4.7 Dissolved Oxygen

The oxygen available to organisms in the aquatic environment is an important regulating factor in species distribution and is the controlling factor for some chemical and physical reactions in the water. Anoxic conditions are reported to be responsible for the gradual depletion of the fauna and flora of the Baltic Sea (Baden et al. 1990) and maximum release of nutrients from the sediments (Rosich & Cullen 1981, Furumai & Ohgaki 1989). Although oxic conditions can appear to exist throughout a water body, the presence of stratification, thermal or salinity induced, can result in anoxic conditions in some areas. In highly productive aquatic ecosystems severe oxygen depletion can occur during respiration at night. So, although a system may appear to have sufficient oxygen it can be limiting for part of the day. Dissolved oxygen was measured on a portable digital dissolved oxygen meter (a WTW Microprocessor Oximeter) with an accuracy of +/- 1 digit of the measuring value, i.e. 1% or 0.1mg/L. The dissolved oxygen level was measured at the surface and the bottom of the water column. However, the instrument was not functional on all sampling trips so data were unavailable for some sites on some occasions.

4.8 Sediment Sampling

One sample of the sediment was collected at each site, for each month (except August) during the study. These samples were collected using a simple dredge made from a piece of galvanised water pipe, diameter 5.25 cm and length 39 cm, with a nylon rope attached to one end and the other end enclosed by a thick layer of overlapping fine nylon mesh. This was dragged through the sediments with a boat at low speed until the tube was full.

To ensure that the monthly samples were collected in the same area, the boat moved within a circle of about 10 m around the marker. Once on the surface excess water drained through the mesh at the bottom of the dredge and any water on the top of the dredge was allowed to drain. The samples were placed in clean plastic bags, secured, labelled and the dredge rinsed overboard. The dredge held approximately 320 cm^3 of sediment, (weight 1 to 2 kg, depending upon the substrate) when completely full; occasionally the dredge was not full so a second drag was necessary. At Site 4 (See Map 3) the sandy, rocky bottom made collection by this method difficult so this area was sampled by scooping up sediment by hand. Field observations on the odour or lack of odour associated with each sample were noted.

4.9 Redox Potential

The redox potential is proportional to the free energy levels in the aqueous solutions (Wetzel 1986) and in the sediments is related to the respiration activity of bacteria. It can give an indication of the extent and type of bacterial activity. Sediments with a ready supply of degradable organic matter and with circulating and well-oxygenated water, will have higher bacterial activity than sediments superimposed by stagnant bottom water (Håkanson & Jansson 1983).

Denitrification, the releases of phosphorus and the production of hydrogen sulphide in the sediments are processes controlled by the redox potential (Håkanson & Jansson 1983) but the lack of a redox probe until the last two months of the study precluded its use in the field work.

4.10 Secchi Disc

Visual transparency is one of the obvious ways in which one water body differs from another and this is readily characterised by using the Secchi disc. The Secchi depth (Z_{SD}), the depth at which the disc just disappears from view, is a convenient parameter for comparing the visual clarity of different water bodies and was used extensively in the OECD study of eutrophication (Kirk 1981, OECD 1982). In the present study the Secchi depth was only obtained for the last four months. It was used to collect data on those sites accessible from the boat but was not used for sites sampled from the edge of the lagoon. The 20 cm black-and-white disc was lowered into the water until it was no longer visible. This depth was then measured to the nearest 1 cm.

4.11 Nutrient Balance and Comparative Data

The data collected at the nine sites in the body of the lagoon were supplemented by the collection of extra information from June onwards. The basic physical and chemical properties of the inflow and outflow to the lagoon were recorded at the respective points as shown on Map 3. The inflow point was Orielton Rivulet, at the RWSC gauging weir, and the outflow data was collected at the outlet culverts. Information from Pittwater was collected from the bridge on the causeway between Cambridge and Midway Point. This additional material was used to calculate the nutrient balance for lagoon and to provide a reference point for some of the material collected from the lagoon.

4.12 Physical and Chemical Properties of the Water

4.12.1 Light/Turbidity

The penetration of solar radiation in water bodies is controlled by the optical properties of the water, so measurement of some of these prarameters is an important step in understanding the productivity of the aquatic system (Kirk 1981). The path of light entering a waterbody can be interrupted and the light absorbed or scattered. Light may be absorbed due to three factors; the water, dissolved humic substances (gilvin), and particulate (phytoplankton and inanimate substances, e.g. soil, organic detritus) (Kirk 1981). Nephelometric turbidity meters measure light scattered in a broad cone at an angle of 90^0 to the illuminating beam. These meters are calibrated using standardised formazin suspensions and give a value in Nephelometric Turbidity Units, NTU. (Kirk 1981). In this study the turbidity was measured on a Hach Spectrophotometer, DR/2000, Direct Reading, which measured the light passing through the water rather than the light scattered by the water. This gave values in Formazin Turbidity Units, FTU, (Accuracy +- 2FTU) as the machine was again calibrated against standard formazin suspensions (Hach Spectrophotometer Handbook 1990). Although it is not a direct measure of the light scattering properties of the water it was a readily available alternative and provided a quantitative value which could be used for comparative purposes throughout the study.

The absorption of light due to the presence of dissolved yellow humic substances (gilvin) is often the major single absorbing component in inland waters (Kirk 1981) and can be readily obtained by measuring the absorbence values on filtrate obtained by passing the water through a 0.22 μm filter. The dissolved organic matter, gilvin, was measured on samples throughout the year. The filtrate was obtained from water filtered to determine the chlorophyll a levels and was measured on the Hach Spectrophotometer used for the turbidity readings. The absorbence values at a wavelength of 440 nm were converted to a 1 m path-length and multiplied by 2.303 to give absorption coefficients in m^{-1}. The wavelength of 440 nm, while giving a high absorption value for gilvin, is also ecologically relevant as it corresponds approximately to absorption by photosynthetic pigment in the blue light region (Kirk 1981).

4.12.2 Chlorophyll Levels

The productivity of an aquatic environment is usually measured as the concentration of chlorophyll in the water (McComb & Lukatelich 1981). The algal biomass can be estimated by multiplying the chlorophyll a content by a factor of 67, assuming chlorophyll constitutes 1.5% of the dry weight of organic matter (Franson 1990).

The chlorophyll a content is one of the measures used to establish the trophic state of a water body and can be used to follow changes in that state. As chlorophyll content is associated with the level of phytoplankton it also partly determines the clarity of the water and can indicate to water managers critical levels at which phytoplankton become a nuisance. The problems associated with a high phytoplankton level have been discussed in the general introduction describing the undesirable effects of eutrophication.

Chlorophyll levels are known to be directly associated with nutrient levels and as such can provide an early indication of the enrichment of a water body from man-induced changes to the catchment and inclusion of effluents from point sources, e.g. sewage or factory outlets.

The level of macrophytic growth is underestimated by the use of chlorophyll concentrations and this can be an important consideration in certain waterbody management plans. This appears to have been the situation in Lake Burley Griffin (Cullen & Small 1981) where predicted chlorophyll a levels were double that recorded. This may also be considered a problem with measuring chlorophyll levels in Orielton Lagoon during periods of high macro-algal growth. Although nutrient levels from previous studies indicated that Orielton Lagoon was eutrophic (Buttermore 1977) the chlorophyll levels had never been established. Chlorophyll levels were available for Pittwater for 1985-86 (Hallegraeff et al. 1986.) and were useful for comparisons.

The chlorophyll levels for the lagoon were measured each month from water samples collected at each site as described in the general sampling methods.

In the laboratory a 250 ml sample was filtered through cellulose acetate filters, pore size 0.2 µm (Sartorius Cellulose Acetate Filters). The samples were filtered simultaneously using a set of SARTORIOUS 250ml filters (Model No. SM-16-510) under half an atmosphere of pressure, supplied by a 12 volt DuPont motor.

The filtrate was tested for gilvin, (as above) and 25ml placed in sterile plastic sample bottles (blood sample bottles) which had been rinsed in distilled water. These were frozen at -5°C until nutrient analysis could be undertaken.

The filter papers were analysed for chlorophyll a according to Parsons et al. (1984). As the 250 ml sample was filtered, approximately 1g of calcium chloride was added to the last 50ml to prevent oxidation of the filter paper. Each filter paper was macerated in 5 ml of 90% acetone then a further 8 ml of acetone was added The test tubes were sealed and enclosed in aluminium foil to make them light proof. They were stored at 5°C for 20 to 24 hours and then centrifuged at 4000 rpm for 15 minutes after reaching room temperature. A sample of the supernatant was tested on a Shimadru Spectrophotometer, UV-120-01, against an acetone blank. Absorbance for the samples was read at 750, 664, 647 and 630 nm. The value at 750 nm was read to establish a zero reference point and was subtracted from the other values before they were used. The resulting values were used in the trichromatic equation provided by Parsons et al. (1984) and chlorophyll levels calculated.

4.13 Physical Properties of Sediments

The sediments of a water body are, in many respects, an accumulation of the activities in that water body that have taken place over a long period of time. The use of sediments as a historical document of the past and present state of a water can sometimes even replace "money-consuming water sampling programs extended over several years" (Håkanson & Jansson 1983), with reliable results coming from one substantial sediment survey. The sediments not only reflect the water quality but they also affect the composition and processes of the particular water body.

There are a wide range of physical, chemical and biological processes that take place in the sediments and these have varying impacts on the water column. Each of these processes can overlap. For example, the movement of sediments by burrowing macrofauna can affect the chemical reactions in the sediments.

Sediments can also act as an important source and sink for many of the elements that are implicated in the process of eutrophication.

In the present study the particle size, organic content, total phosphorus and nitrogen levels of selected sediment samples were analysed.

4.13.1 Analysis of sediments

After the sediments were taken back to the laboratory they were sub-sampled manually and about half of the sample, approximately 1kg, was set aside. This sub-sample was placed into a separate plastic bag and formalin was added to make a 10% solution. This was the sample used to examine the macrofauna (an area of the study which has not been presented in this thesis).

The remaining section of the sample was placed in an evaporating dish and dried for 24 to 48 hrs at 80°C. The samples were then broken up using a mortar and pestle. The samples with a high number of mollusc shells were separated at this point and the shells removed and weighed. These were later included in the section of sediment with particle size over 2 mm.

4.13.2 Organic content of sediments

The organic content of sediment samples was determined using loss-on-ignition at 550°C for one hour (Håkanson & Jansson 1983). Oven dried crucibles were weighed and approximately 20 g of oven-dried sediment samples added and weighed to the nearest 0.002 g prior to burning. They were weighed immediately after burning and results calculated as % weight loss during ignition or "LOI".

4.13.3 Particle size analysis.

Most of the sediment samples appeared to be composed of silts, clays and fine sands and analysis using dry sieving techniques was of limited value. A hydrometric technique was therefore used involving mechanical dispersion and a bouyoucos hydrometer (Baver 1948, Hutton 1950). This technique gives values for the mass of silt, clay and sand in the sample. The solution containing the sand section of the sediment was washed until the supernatant was clear. The sand was then oven dried for 24 hrs at 105°C and weighed. Due to lack of expertise with the technique the samples were only divided into sand and combined clay/silt components. This analysis was only undertaken on sediment samples collected in February and March, five sites in May and five sites in September.

4.14 Depth Survey

Concern that the lagoon is silting up is widespread (L.Wall, pers. comm.) so a depth survey was included in this study. The lagoon was surveyed in 1975 by the Department of Lands (ref. Section 3.3) and the resulting data used as the baseline for the present survey. The map produced in 1975 is provided (Map 4).

The depth survey was conducted using a small aluminium dinghy, a compass and a weighted rope which was measured to an accuracy of 0.01 m. A reference siting was taken from Susie Islet, to the western extreme of the causeway, to the middle of the eastern culvert, to the eastern end of the causeway and the sewage treatment plant, this acted as a readily identifiable marker. Following this, bearings were taken at Site 2, Site 5, Site 7 and four other sites around the lagoon and the depth at each of these points was measured. The depth of four points immediately in front of the culverts was also measured. The depth was then related to Australian Height Datum (AHD), using the known level at the outlet culvert sill, and compared to the 1975 survey. The points that were measured have been plotted on Map 4.

4.15 Water Movement in the Lagoon

Prior to the construction of the extended causeway and culverts the water moved in and out of the lagoon through three openings provided by the bridges. The water movement was controlled by tidal movements and at low tide the channel under the bridge closest to Sorell became completely exposed (DMR Files 1952, L. Wall, pers. comm.). An aerial photograph of the area from 1946 clearly shows the three channels and the locations of these channels is still obviouson the Pittwater side of the causeway. Water movement in the lagoon has since been curtailed by the construction of the extended causeway and culverts. The movement of the water body during a period of zero outflow was established using the simple test of following the movement of a floating orange. The day chosen was 30/5/1991 which was very settled, with a slight NNW breeze. Oranges were released at four different points around the lagoon and the distance travelled, direction and time taken were recorded.

4.16 Modelling Water Flow

Water flow out of the lagoon is usually limited to only 3 to 4 months of the year, while water movement into the lagoon is restricted to tidal input at peak high tide, to fresh water input from Orielton Rivulet and input from the sewage treatment plant.

As no accurate data were available to establish the daily depth of the lagoon or water movement from the lagoon, except for the very limited data from 1975 survey by the Lands Department, it was decided to estimate the water movement using a model.

The data available included the rainfall, sewage inflow, flow from Orielton Rivulet and calculated tidal input when the tidal level exceeds sill level. The outflow of seepage through the causeway was estimated using the rate calculated in the 1975 hydrological survey.

The tides at Pittwater lag about 2 hours 40 minutes behind those at Hobart (Harris 1968) but strong winds and unusually high or low barometric pressures can alter the predicted tidal movement. The predicted tidal levels and tide times for the entire year (Tasmanian Tides 1991) were entered on an EXCEL spreadsheet, with the time in minutes from the beginning of the year. The flow of water into the lagoon was then estimated from the predicted tide height assuming the water movement followed a cyclic pattern. It was estimated that, on average, the tide entered the lagoon for half an hour either side of the peak.

The flow rate for Orielton Rivulet has been recorded since 1972 (RWSC 1991) so the average flow rate for each month was calculated and entered in the spreadsheet in the appropriate time segments.

The rainfall for the station at Sorell was available (K. Allen pers. comm.) and it was assumed to fall 100% on the area of the lagoon.

Sewage input was considered to be a constant value of 475 000 L/day (DEP 1986).

Water movement from the lagoon takes place through the culverts when the lagoon is sufficiently full, and is lost to evaporation and seepage through the embankment. Evaporation has been measured at the Hobart Airport since 1986 and the mean daily average for each month was added to the spreadsheet, factored down by multiplying by 70% to convert "pan" evaporation to real pond evaporation conditions (Bureau of Meteorology 1991, pers. comm.). Seepage through the embankment was calculated at 161.614×10^3 m^3 for 20 days in 1975 (Steane 1975). Using this information the daily seepage rate was estimated but, as this would vary depending upon the head of water, a factor relating the predicted level in the lagoon and the seepage rate was added.

The outflow through the culverts was considered to continue until the lagoon level was the same as the sill level.

Using the above information and the EXCEL spreadsheet a program was set up to calculate the predicted inflow and outflow through the culverts for each month. This information was tabulated and also presented as a series of graphs for the existing sill levels. At the same time the total inflow and total outflow for each month was calculated and hence the net turnover of water in the lagoon was available. The level of the lagoon relative to the culverts was also calculated and tabulated.

Different scenarios could be readily calculated using the above information and the inflow and outflow was calculated for various sill levels and initial lagoon depths. The information for a reduced sill level of 1.5 m (AHD) was calculated and graphs and other details recorded. Lowering the sill level to 1.2 m (AHD) (average mean sea level) did not result in an improvement in turnover as the size of the culverts became a restricting factor. Graphs and other information for this sill level were not printed.

4.18 Water Analysis

In an aquatic environment the productivity of the system has been shown to be directly related to the available nutrients (Rosich & Cullen 1981, OECD 1982 , Lee & Jones 1984, Ferris & Tyler 1985, Hillman et al. 1990). The nutrients most readily associated with productivity are nitrogen and phosphorus. Both these are essential to the growth of organisms and either can be the nutrient that limits the primary productivity (Hillman et al. 1990).

Phosphorus occurs in natural waters and wastewaters as soluble phosphates or bound to particulate matter (organic or inorganic), (Franson 1990). Phosphates in a water body arise from a variety of sources including waste-water from commercial cleansing processes, and agricultural and residential run-off carrying particulate matter and soluble phosphates from fertilisers and sewage. The organic phosphates in sewage are largely wastes resulting from biological processes and food residues. Phosphates in the bottom sediments and biological sludges may be incorporated into organic compounds or bound to particulate matter, e.g. clay particles (Håkanson & Jansson 1983, Franson 1990).

Although it is desirable to differentiate the various groups of phosphorus compounds when assessing the nutrient status of a water body (Fresenius et al. 1988) in this study it was not possible to separate these due to lack of time and financial constraints. Also the broad nature of the study did not warrant such an intensive examination of one aspect.

Soluble phosphorus in water samples collected from Orielton Lagoon was converted to dissolved orthophosphate and measured colorimetrically. Initially phosphate in the filtered water samples (filtered using 22 µm cellulose acetate filters used for chlorophyll measurements) was analysed using the stannous chloride method method outlined in the Hach Spectrophotometer Handbook (Franson 1990). However, strong interference from the high level of chloride ions made the low results unreliable as they were generally below detection limits. The rest of the samples were analysed by the DEP analytical laboratories at the University of Tasmania. The total soluble phosphorus, as phosphates in the filtered water, was analysed manually following the Abscorbic Acid Method, 4500PE, (Franson 1990) and measured on a spectrophotometer.

Nitrogen in the water column was analysed as nitrite and nitrate ions using an autoanalyser at the DEP Laboratory. They were analysed colorimetrically after reduction by a cadmium column incorporated in the auto-analyser.

Evidence from a study in Western Australia indicated that phosphorus was the limiting nutrient in the growth of a *Cladophora* species (Gordon et al. 1981) and as the main macrophytic algae in the lagoon was described as a filamentous green algae, later identified as a species of *Cladophora* (G. Edgar, pers. comm.) it seemed likely that phosphorus would also be the limiting nutrient at Orielton Lagoon. Hence phosphorus was chosen as the main nutrient to be investigated.

The total phosphorus in the unfiltered water was analysed colorimetrically after digestion using sulphuric acid and hydrogen peroxide (Fresenius et al. 1988). The resulting hydrogen phosphate ions were then determined colorimetrically using the abscorbic acid method. The absorbence from the Hach Spectrophotometer was read from a standard curve. The samples in sea water were read from a calibration curve produced using standard phosphorus solutions in standard artificial sea water. Fresh water samples were read from a different calibration curve.

Total nitrogen in the water column was not analysed due to time constraints and the broad nature of the study. Nitrogen exchange with the atmosphere can be a complicating factor in any nutrient balance relating to this nutrient and such estimations were well beyond the scope of the present study. Furthermore, the new sewage treatment plant has been designed to reduce the total nitrogen input into the lagoon to 5 mg/L by 1992 (Chong 1987), thus reducing the likely impact of this nutrient.

4.19 Analysis of Sediment Nutrients

4.19.1 Phosphorus

Sediments can act as a sink for excess phosphorus entering a system and this source can then release these nutrients when the level in the water column decreases.

The importance of the nutrient levels in the sediments came to the attention of workers in Sweden when the external nutrient load of a lake was reduced but there was no corresponding decrease in the phosphorus in the water. This caused problems associated with eutrophication, to persist despite the reduced load (Cullen 1986). The release of nutrients from the sediment is important in the development of algal blooms in the Harvey Inlet (Hillman et al. 1989), particularly phosphorus as it is regarded as the limiting nutrient in that system.

The total phosphorus in the sediments was analysed using the perchloric acid method for total elemental phosphorus, which is briefly outlined below (Jackson 1964).

The oven dried sediment was passed through a 0.5 mm sieve. Approximately 2 g of the sieved sediment was placed in a round-bottomed flask with a few anti-bumping granules. Then 10 mL of concentrated nitric acid and 20 mL of hyperchlorite were added to the digestion flask. This was boiled until the sediment was clear, taking approximately 24 hr. The cool sample was diluted with distilled water, filtered, and the filtrate made up to 200 mL with distilled water. Then 10 mL of the solution was added to 50 mL flasks with distilled water and 10 mL of vanadomolybdophosphoric acid. The sample was made up to 50 mL and tested against blanks using a Hach Spectrophotometer. Values were read on the stored program and converted to µg/g dried sediment.

4.19.2 Total Nitrogen

Nitrogen in the sediments, in the form of nitrates, is utilised by a range of organisms including bacteria and undergoes denitrification to be released as free nitrogen.

Total nitrogen in the sediments was analysed after digestion using the Kjeldahl digestion and distillation method (Jackson 1964). Values were converted to µg/g dried sediment.

4.20 Collection of Biological Data

Phytoplankton represent a major component of the primary production unit of any aquatic system as they utilise the raw materials of nutrients and energy. The abundance of phytoplankton can be estimated using the chlorophyll level but the species composition is not evident from such a level of examination. The abundance and species composition of phytoplankton can be an important tool in water quality management, particularly the management of freshwater impoundments which are a major source of domestic water (Anon. 1990). The sudden appearance of toxic blue-green algae can cause a range of problems, including death of farm animals, and the toxins are suspected to cause liver damage in humans.

Toxin-producing flagellates can also cause a range of problems in marine environments, damaging not only natural fish populations but also having dramatic impacts on aquaculture (Hallegraeff 1991, Underdal et al. 1990).

The species composition in an algal community is important to the consumers in the ecosystem as some species, e.g. diatoms, have a high nutritive value for zooplankton (Granéli et al. 1990) while others, such as filamentous green algae and blue-green algae, are considered undesirable.

Other studies of phytoplankton populations in Australian waters (Dakin & Colefax 1940, Jeffrey 1980) have shown clear changes in the dominant genera of phytoplankton throughout the year with cycles of diatom and dinoflagellate abundance. Such patterns have been observed in other parts of the world in water not considered to be affected by humanity.

In this study the phytoplankton and zooplankton were sampled to determine the main species present and to examine the changes in these populations throughout the year. The presence or absence of blue-green algae in the lagoon was also considered, as blue-green algal blooms may have been responsible for the odour problems in the past. Some reports associated with odour described a green scum on the surface of the lagoon and the blooms of *Nodularia spumigena* Mert. reported in the Harvey Estuary have "a distinctive and nauseating smell" (Hillman et al. 1990, p. 45). The odours produced by the blue-green algae have also been described as "earthy, musty, fishy, grassy or rotten smells" (CSIRO 1991, p.1). As the species composition can be affected by the balance of nitrogen and phosphorus (Granéli et al. 1990) the relationship between species composition and nutrient status was of some interest.

The plankton samples were collected each month at each site using the appropriate plankton nets. The net used for the phytoplankton had a mesh of 20 μm and the mesh size for the zooplankton net was 200 μm. The samples were collected from the sites described in the general sampling methods. The net was thrown as far as possible, allowed to sink slightly and then dragged obliquely through the water from the bottom layers to the surface. Samples with sediment were discarded and re-collected. The samples were transferred to small, labelled sample bottles and formalin was added to make a weak solution. Although the material collected was to be used mainly in a qualitative analysis an attempt was made to make the collection of the material as uniform as possible.

The preserved samples were then examined using a phase contrast microscope with a camera-lucida attached. Examples of the plankton were drawn and some photographed. The drawings and photographs (ref.Appendix B) were identified to class and order and identifications confirmed with the help of G. Hallegraeff (CSIRO, Sea Fisheries Division, Tasmania).

The zooplankton species were identified to class or order depending upon the specimen. The larval stages of crustaceans were difficult to identify but the Class CIRRIPEDIA (barnacle) were readily distinguished by fronto-lateral horns on the carapace of the naupli. Brachyuran larvae were distinguished by the presence of a large dorsal spine and compound eyes. These identifications were confirmed by Dr D. Ritz (Zoology Department, University of Tasmania) who also provided identification for the most abundant calanoid copepod (*Acartia tranteri*). Other copepods were listed as cyclopoid or harpacticoid. The tintinnids, Class CILIATEA, Order TINTINNIDA were readily distinguished and three distinct species were identified as species 1, 2, and 3. Other zooplankton were identified in as much detail as possible based on the understanding that the taxonomy of such groups is a specialised task beyond the scope of the present study. Most identifications were confirmed by Dr D. Ritz and a detailed study of the zooplankton is to be undertaken in 1992 as a postgraduate project in the Zoology Department, University of Tasmania.

As the samples were examined a quantitative estimate of the relative abundance of the dominant diatom species was made. There were three categories used as follows :

absent	no individuals noted
present	at least one individual noted
abundant	many individuals noted

The presence of microflagellates is best indicated in fresh samples as they are delicate and frequently destroyed by preservation (Hallegraeff 1990). Samples collected in the last part of the study were examined shortly after they were collected and the presence of microflagellates was easily detected. This was confirmed by examination of fresh material which showed these specimens moving independently through the sample.

Zooplankton were not as easy to quantify due to their larger size, but relative abundance was noted when one group appeared to dominate.

4.21 Diurnal Variation

Throughout this study data were collected in the same order, with sampling of the body of the lagoon usually taking place in the morning and samples from the banks collected in the afternoon. As the time of day was obviously an important factor in the ambient temperature, other factors may also have been directly affected by the time of sampling. A 24 hour study was undertaken on 9-10 October 1991, to examine the diurnal variation at three of the sites in the study.

The aim was to examine the diurnal variation within the lagoon and relate it to monthly data collected, to determine whether the variation in the monthly data reflected the time of sampling or variation due to other causes.

The parameters selected for examination included those physico-chemical factors usually measured in the water column, although soluble phosphorus and nitrogen were only measured for one site due to the costs of the tests. Total phosphorus was not measured for any of the samples collected. Again cost and time were the main considerations, also the value of such information would not justify the expenses involved.

The sites selected for the diurnal study were sites easily reached from the bank and were Site 4, Site 8 and the Inflow Site on Orielton Rivulet.

Parameters measured were:

1) ambient temperature,
2) water temperature,
3) pH,
4) conductivity,
5) dissolved oxygen.

Each water sample was returned to base where a 25 mL sub-sample was placed in a small sample tube and 250 mL was immediately filtered, through 22 µm cellulose acetate filters in millipore filter holders, using a 12 volt portable pump and a heavy duty bus battery. Twenty five mL of the filtered sample was placed in small sample tube, labelled and stored in an insulated container before being returned to the laboratory. The filter papers were placed in clean plastic petri dishes, labelled and also placed in the insulated container prior to analysis in the laboratory.

The diurnal study was started at 2.30 pm and samples were collected every two hours until 2.30 pm the next day. Due to problems with the millipore filters, the 4.30 pm sample for the first day was only collected from the Inflow Site. The collection of the samples, measurements and filtering took about two hours, by which time it was time for the next sampling event.

On return to the laboratory the unfiltered samples were tested for turbidity on the Hach Spectrophotometer described earlier. The filter papers were used to measure the chlorophyll levels and the samples of filtered water were stored in a freezer until nutrient analysis could be undertaken. The chlorophyll levels and nutrient analysis were done in the same way as described elsewhere. The dissolved nutrient levels were only analysed for Site 4 due principally to time constraints.

4.22 Nutrient Balance

Although the trophic status of a water body is frequently estimated from a single water sample, a balance of nutrients entering and leaving a system can act as an important management tool. Such a nutrient balance can indicate the dominant sources of nutrients in a system and can give some indication of the retention of nutrients in the sediments. In this study the source of nutrient enrichment was a prime consideration, particularly following the contradictory reports by Spratt (1984) and the DEP (1986) (ref. Section 3.3). The proposal to dredge the sediments as a means of reducing nutrient input angered bird-watchers (Abbott 1991) so it was important to determine the importance of other nutrients sources before such a remedy was undertaken.

The basis for the nutrient balance study included water samples collected throughout the months June to October, for which total phosphorus was analysed.

To enable an assessment of nutrient input and output for the lagoon, water samples were collected from the main rivulet during each wet period and simultaneously samples were collected from the outflow point on the culverts. Frequent sampling of streams at periods of high flow is more relevant in the collection of data to establish a nutrient balance than regular sampling during periods of low flow (Cullen & Smalls 1981). It is also important to realise that the simple grab sample which may be appropriate under low flow conditions may not accurately assess the load carried by the larger particulate matter that can be moved under high flow conditions (Cullen & Smalls 1981). Despite these issues, time constraints and financial considerations limited sampling during the periods of high flow to one sample at the inflow point (the gauging weir) and one at the outflow point on each high rainfall occasion. Rainfall events which appeared quite heavy in Hobart were frequently very low in the catchment area only 30 km away as the area lies in a rain shadow.

Samples of sewage effluent discharged during the study period were only collected on two occasions as access to the effluent was restricted and earlier work by the DEP (DEP 1986) gave a wide range of values for this effluent. Similarly the values for sewage effluent have been documented by a range of authors (Cordery 1977, Cohen 1972).

The total phosphorus in the water was analysed in the manner described earlier and the daily flow rates of Orielton Rivulet were available from RWSC. The flow rates through the culverts were calculated from depth measurements made on each sampling occasion. Measurements of turbidity, pH, conductivity and temperature were made when samples were collected and general field notes were also recorded. These results were used to calculate the nutrient balance for the lagoon on the particular days when measurements were taken. To extend these data for the inflow of nutrients from Orielton Rivulet the concentration of phosphorus was considered the same for the days immediately following a sampling if the flow rate was the same. For other days an average of 0.05 ppm total phosphorus, was used with the flow rates to estimate the monthly input from the rivulet. Although the average for the samples collected was only 0.035 ppm total phosphorus, it was considered that an overstatement rather than an understatement of the contribution from agriculture would be preferable in any comparison with the sewage contribution.

To estimate the loss of phosphorus, the depth of water over the culverts was considered constant for the entire day of sampling and the average depth for each month was used for the monthly outputs. The outflow concentration of phosphorus was taken as 0.152 ppm (µg/L), which was an average for the samples taken at the outflow.

At one point the water sampled was flowing into the lagoon at the outlet culverts and a sample was collected and analysed.

The concentration of phosphorus from the sewage treatment plant was taken as constant and the inflow from the plant was also considered constant.

Using the above information an estimation of the movement of phosphorus through the lagoon was established.

CHAPTER 5

Results - Physical Parameters

A full set of data on physical parameters collected for this study is presented in Appendix A. Summarised results are presented in tabular and graphical form in the following sections.

5.1 Water Movement in the Lagoon

The results of the work to show water movement in the lagoon are shown on Map 5 which shows the points of release, the distance travelled by the orange, the direction of the movement and the direction of the wind. Although there was a recorded flow rate of 1.8 L/s in Orielton Rivulet the oranges did not show any rapid movement even in the upper reaches of the lagoon(Pt. 1). This indicated that there was very little water movement in the lagoon, even in the upper reaches, which was not controlled by the wind.

5.2 Modelling Program

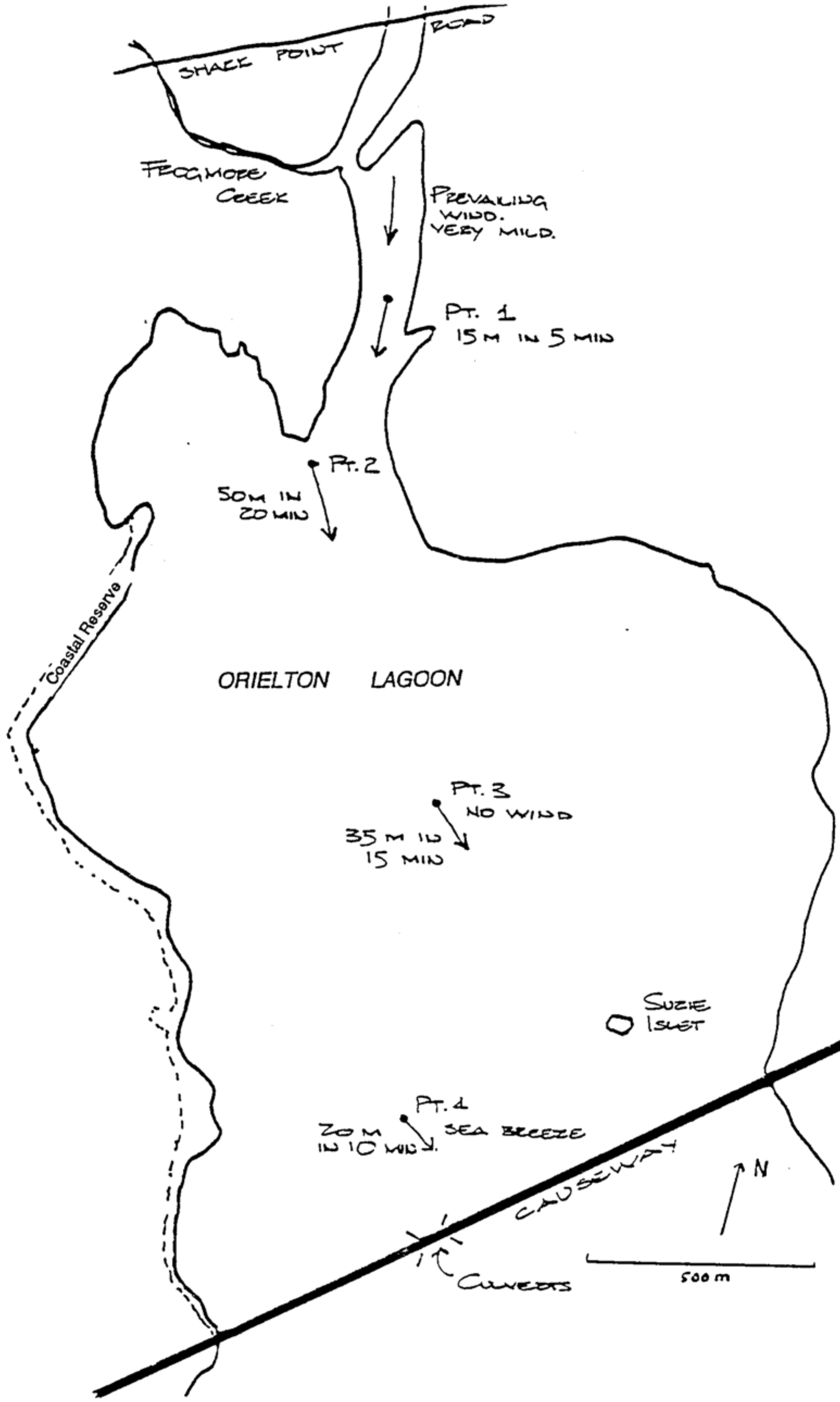
5.2.1 Capabilities of the Model

Using the computer program to model water flows, to and from the lagoon, enabled different scenarios to be examined quickly.

Altering factors such as culvert sill height and lagoon depth at the beginning of the hypothetical year meant these could be manipulated to indicate the effect on water turnover. For the current study the only dimension of the culverts that was altered was the height of the sill, as this is the controlling factor for the incoming tide. The width of the culverts was not altered but the program could easily be adapted to include different culvert widths at a later stage.

5.2.2 Results of the Model

The program produced data in a graphical form as well as an extensive set of tables showing calculations, column by column. The tables are not presented in this thesis but the information is summarised graphically, in Figures 5-1 to 5-25, and in Tables 5-1 and 5-2, indicating the water levels in the lagoon and the turnover of the water for each month.



Map 5 Location, direction and distance travelled by oranges released in Orielton Lagoon, 30/5/1991.

The program was first used to model water movement using the actual conditions expected during the year. This included setting the sill height at the current level, equivalent to a tide of 1.8 m, and allowing average monthly rainfall and tides as predicted by tide charts. A start level of 0.3 m below sill level on 1st January was chosen on the basis of the observed condition in 1991.

The resulting graphs are shown in Figures 5-1 to 5-12

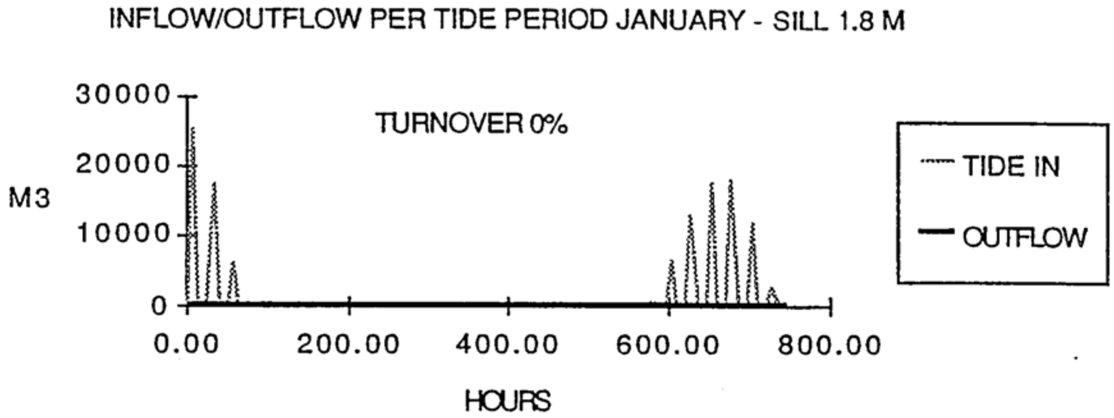
The peaks for tidal inflow represent the exceptionally high tides that occur infrequently through the year. These were evident during 1991 in January, June, July and August with one peak in late December. These high tides are those that exceed the mean high tide level of 1.8 m and they do not occur on a regular basis.

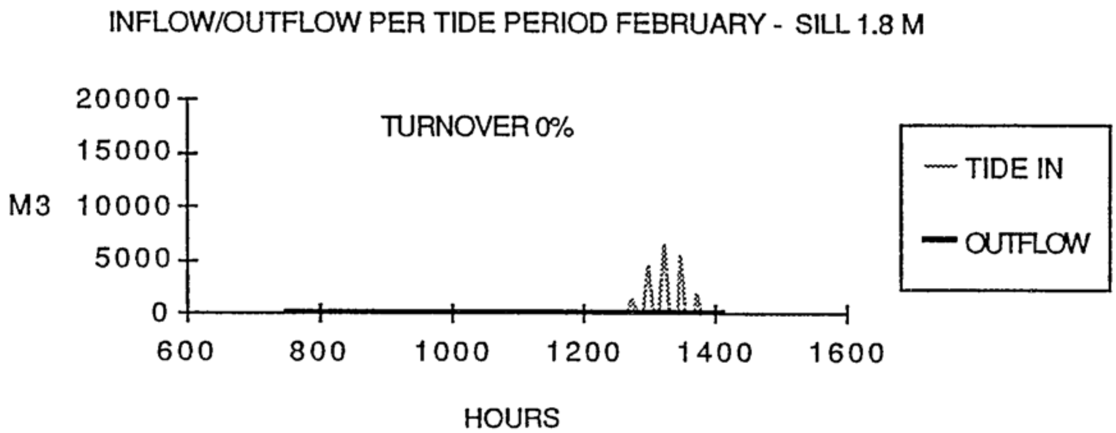
The computer model for the existing sill levels and a starting level 0.3 m below the sill predicted that there would be no outflow from the lagoon until August. The outflow is predicted to cease at the end of September and not to recommence, despite significant tidal inputs, in November and December.

The inflow to the lagoon, as shown on the graphs, is the combination of tide and stream flows. The inflow is a maximum in August, as this is the wettest month, on average, and also the month with the highest tide levels; neap tide or king tides.

The inflow for March is extremely low, with only two days of tidal inflow, which is quickly negated by seepage and evaporation. This is also the month with the lowest average flow rate from the rivulet.

The program was then modified so that the depth of the lagoon at the beginning of January was 20cm below the sill level. This would model the case when the previous winter had been wetter than average. The resulting graphs were not plotted but the water exchange rate for these conditions was recorded (Table 5.1). Using this model the outflow of water from the lagoon began in July and continued until the last weeks of September with a maximum exchange of water in August of 23%. There was also a small exchange of water in July and September but no further water exchange for the next nine months, although there is some tidal input.





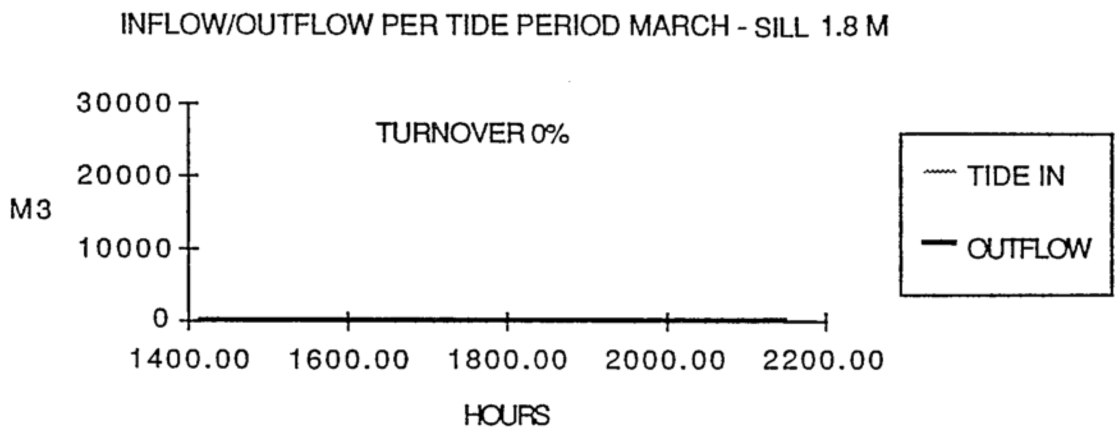
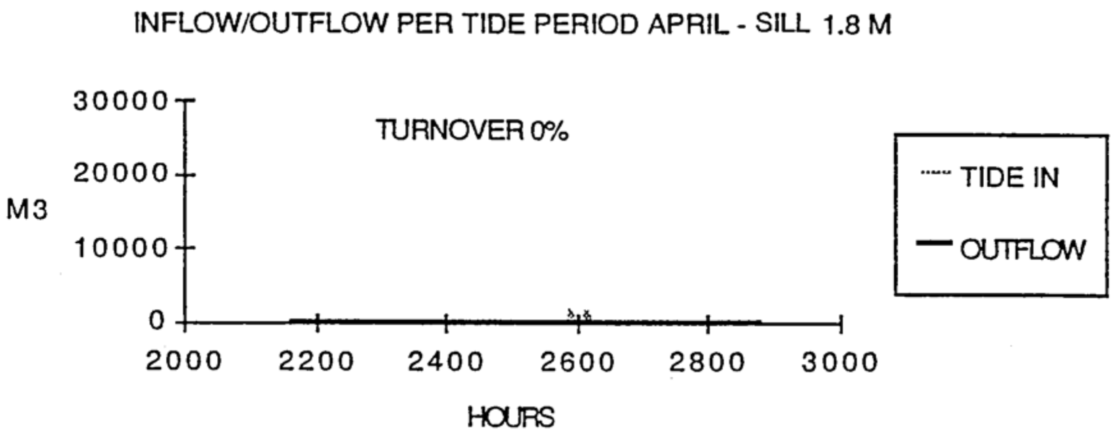
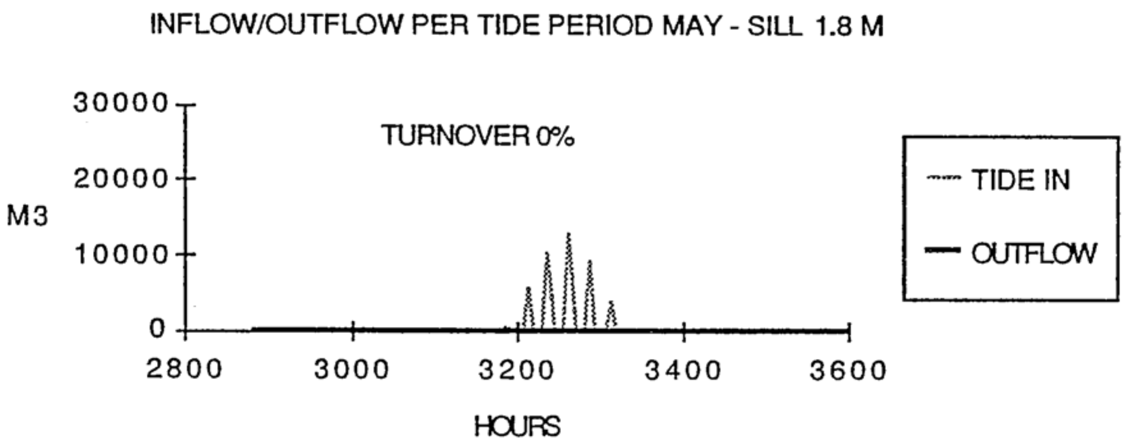


Fig. 5.1- 5.3 **Predicted Inflow/Outflow, January, February, March, for sill level 1.8 m, Orielton Lagoon**





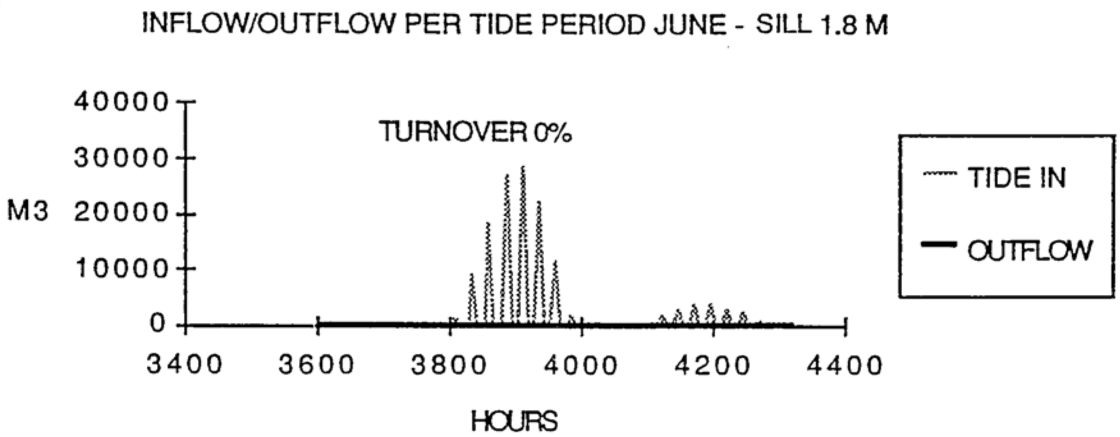
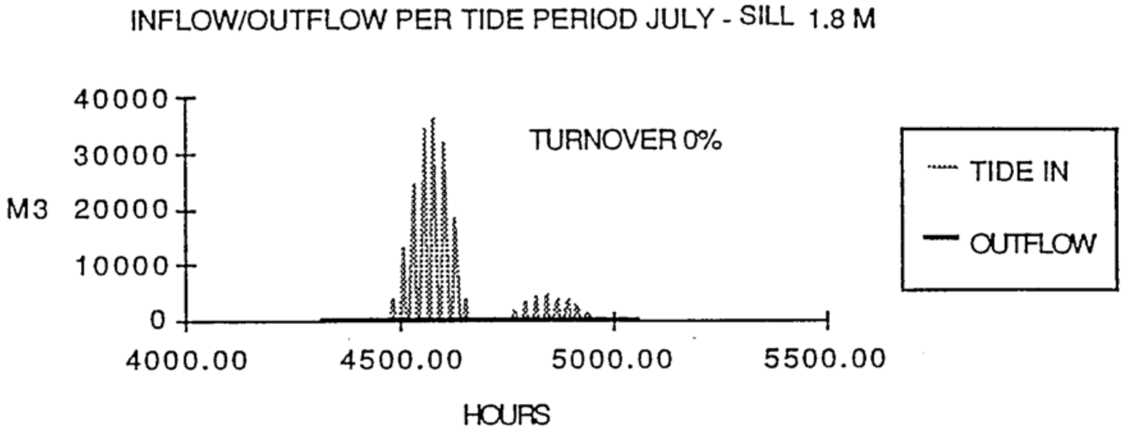
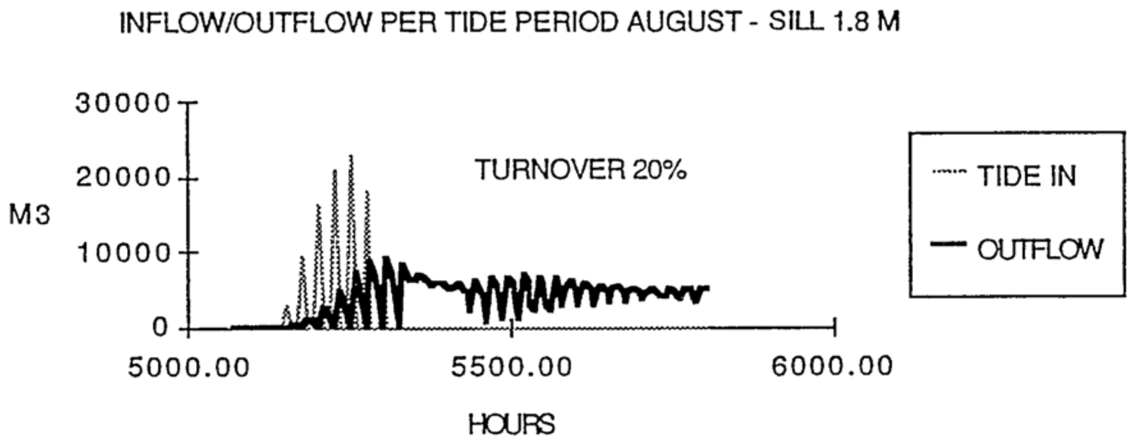


Fig. 5.4- 5.6 Predicted Inflow/Outflow, April, May June, for sill level 1.8 m, Orielton Lagoon





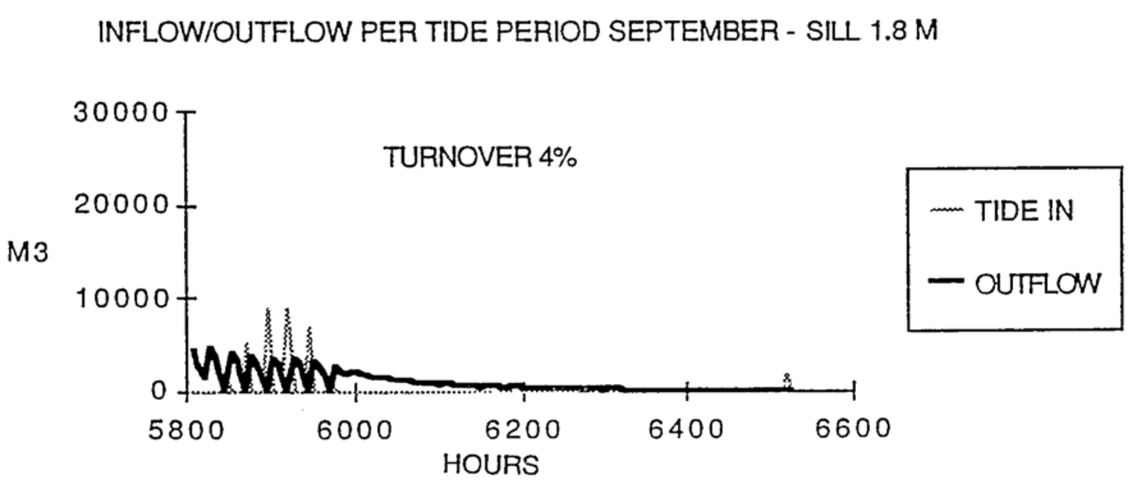
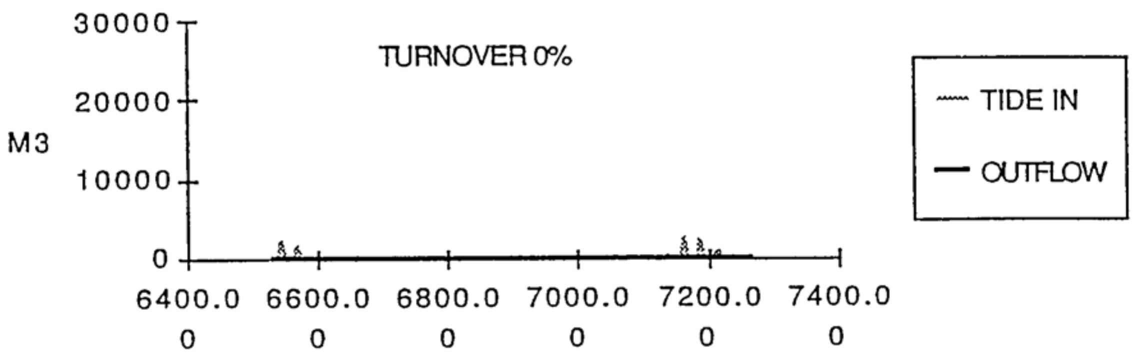
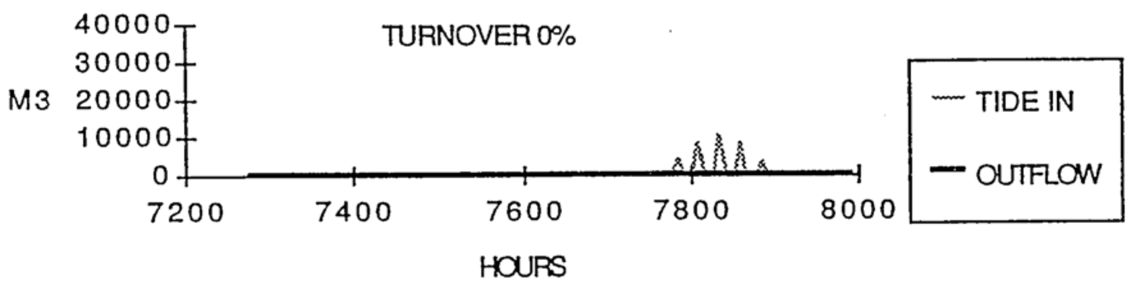


Fig. 5.7- 5.9 **Predicted Inflow/Outflow, July, August, September, for sill level 1.8 m, Orielton Lagoon**

INFLOW/OUTFLOW PER TIDE PERIOD OCTOBER - SILL 1.8 M



INFLOW/OUTFLOW PER TIDE PERIOD NOVEMBER - SILL 1.8 M



INFLOW/OUTFLOW PER TIDE PERIOD DECEMBER - SILL 1.8 M

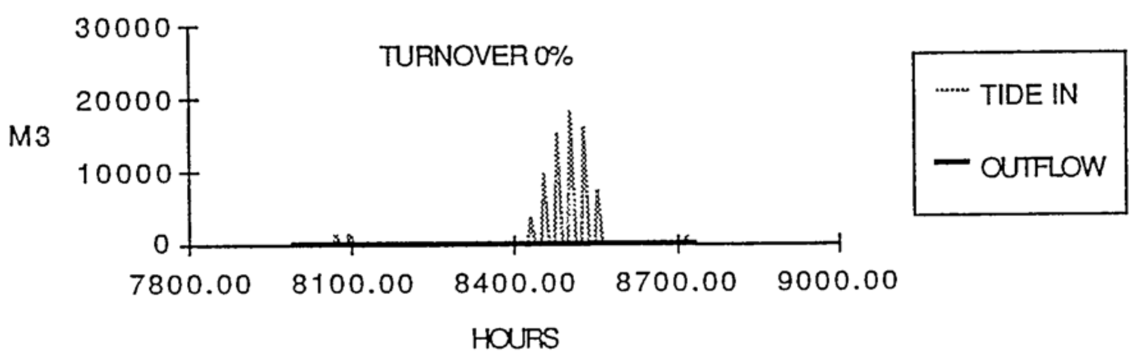


Fig. 5.9- 5.12 **Predicted Inflow/Outflow, October, November, December, for sill level 1.8 m, Orielton Lagoon**

The water level in the lagoon is shown relative to the culvert height and ranges from 1.84 m in August to a low of 1.42 m in March (Table 5.1). The water level in the lagoon thus varies by 0.4 m which would mean exposure of some of the mudflats during summer due to the shallow nature of the northern end of the lagoon.

SILL LEVEL - 1.8m (tide)		
MONTH	WATER LEVEL	TURNOVER (%)
January	1.6	0
February	1.50	0
March	1.42	0
April	1.45	0
May	1.49	0
June	1.59	0
July	1.83	2
August	1.84	23
September	1.80	4
October	1.68	0
November	1.67	0
December	1.64	0

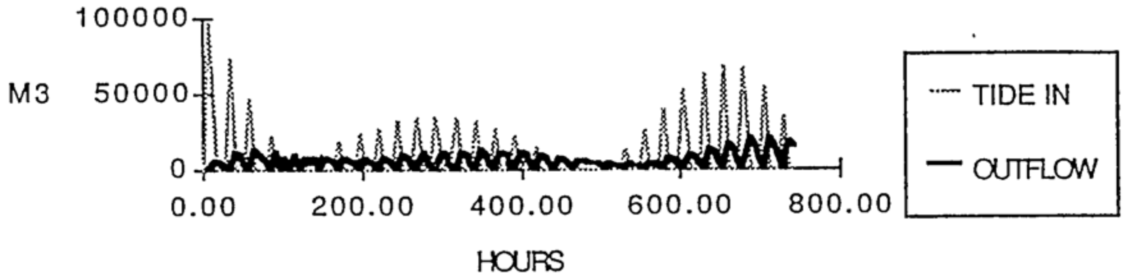
Table 5.1 Lagoon depth relative to the culvert depth of 1.8 m and the % of water turnover in Orielton Lagoon calculated using the hydraulic model, with initial lagoon depth at 1.6 m and culvert sill height at 1.8 m.

From field observations in 1991 the model for the inflow and outflow appears to be satisfactory, with outflow from the lagoon commencing in early July and ceasing during the last week of September. From the model, the predicted starting date was the end of July with an average depth over the culverts of 30 mm. Measurements during 1991 at the culverts gave an average depth of 80 mm. The difference between the predicted and the actual outflow depths may have been caused by the very high tide levels experienced during the late winter and early spring. Higher than predicted tides and strong wind conditions were responsible for minor flooding in the Derwent estuary.

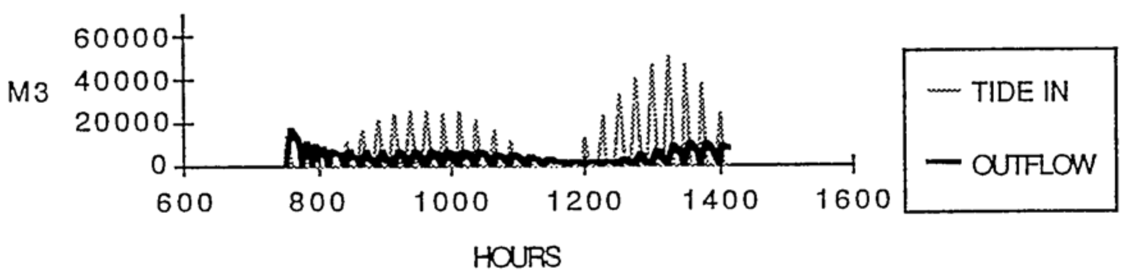
The program was next run using different culvert sill heights. The first run allowed the sill level to be lowered by 30 cm to a height of 1.5 m RL. The graphs for this program are shown in Figures 5-13 to 5-24 and the water level and turnover rate are shown in

Table 5.2. The start water level was selected as 1.56 m which was found by trial running of the program to give a balanced annual model. In fact the results for this case were insensitive to the selected start level as tidal inflow or outflow soon returned to the 1.56 m level in the first few days of January.

INFLOW/OUTFLOW PER TIDE PERIOD JANUARY - SILL 1.5 M



INFLOW/OUTFLOW PER TIDE PERIOD, FEBRUARY - SILL 1.5 M



INFLOW/OUTFLOW PER TIDE PERIOD, MARCH - SILL 1.5 M

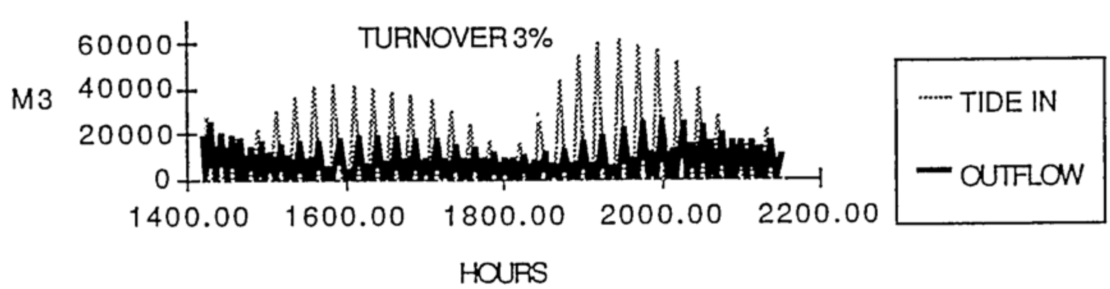
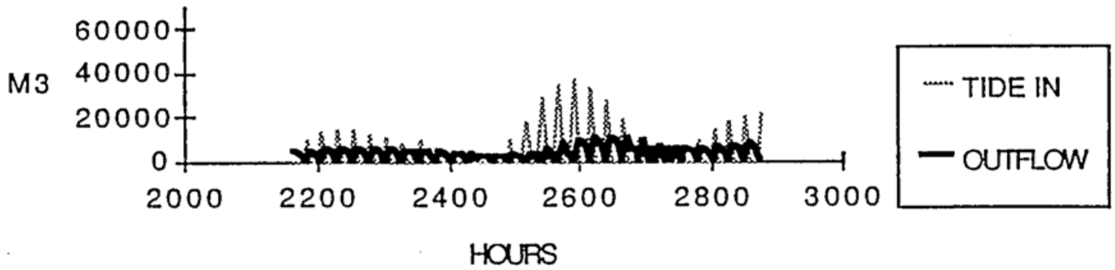
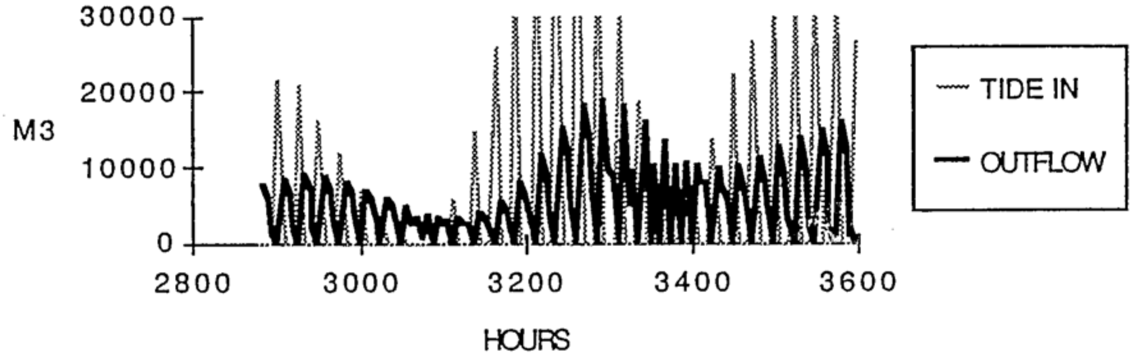


Fig. 5.13- 5.15 **Predicted Inflow/Outflow, January, February, March, for sill level 1.5 m, Orielton Lagoon**

INFLOW/OUTFLOW PER TIDE PERIOD, APRIL - SILL 1.5 M



INFLOW/OUTFLOW PER TIDE PERIOD MAY - SILL 1.5 M



INFLOW/OUTFLOW PER TIDE PERIOD, JUNE - SILL 1.5 M

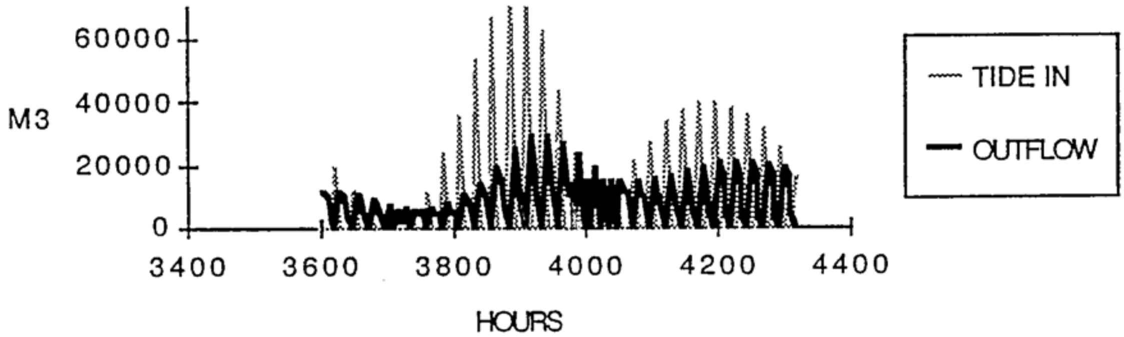
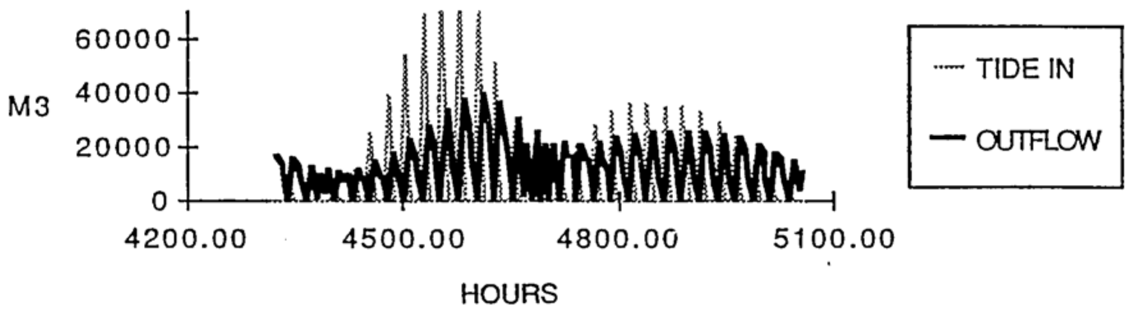
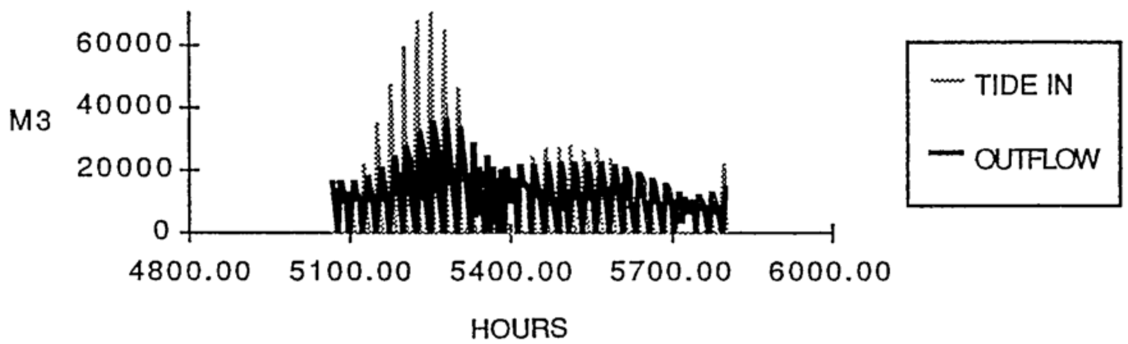


Fig. 5.16- 5.18 **Predicted Inflow/Outflow, April, May, June, for sill level 1.5 m, Orielton Lagoon**

INFLOW/OUTFLOW PER TIDE PERIOD, JULY - SILL 1.5 M



INFLOW/OUTFLOW PER TIDE PERIOD, AUGUST - SILL 1.5 M



INFLOW/OUTFLOW PER TIDE PERIOD, SEPTEMBER - SILL 1.5 M

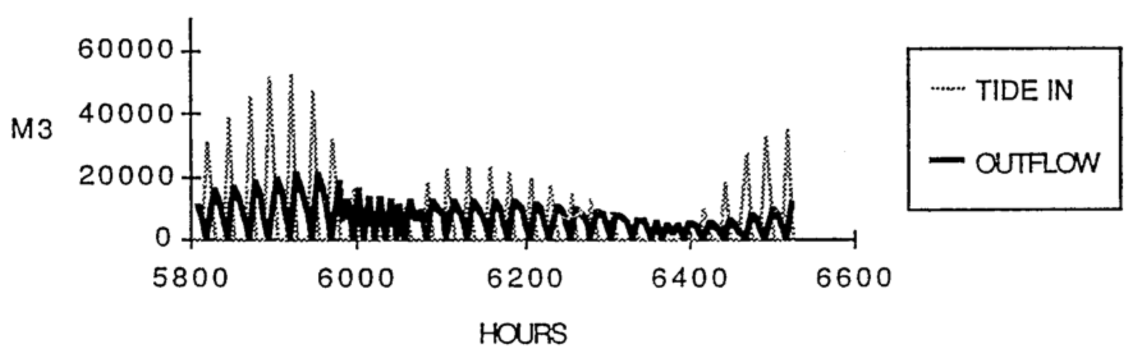
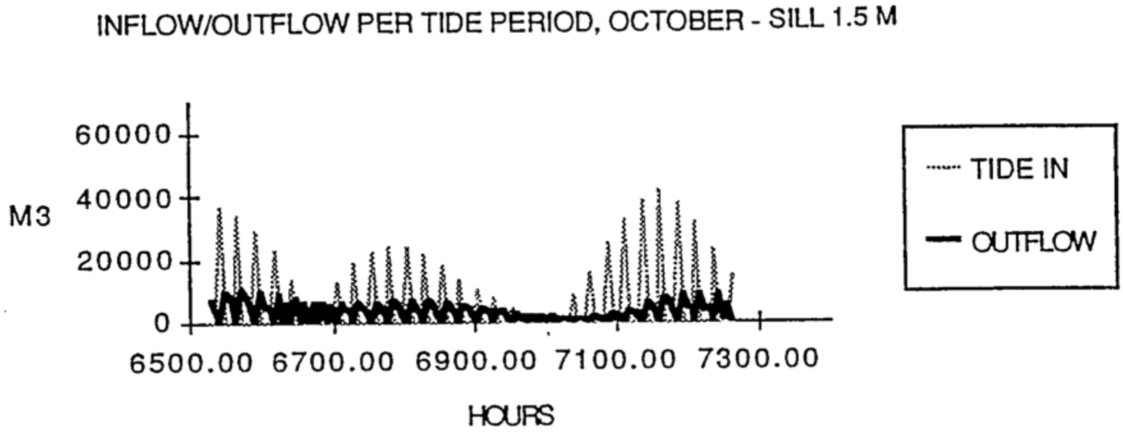
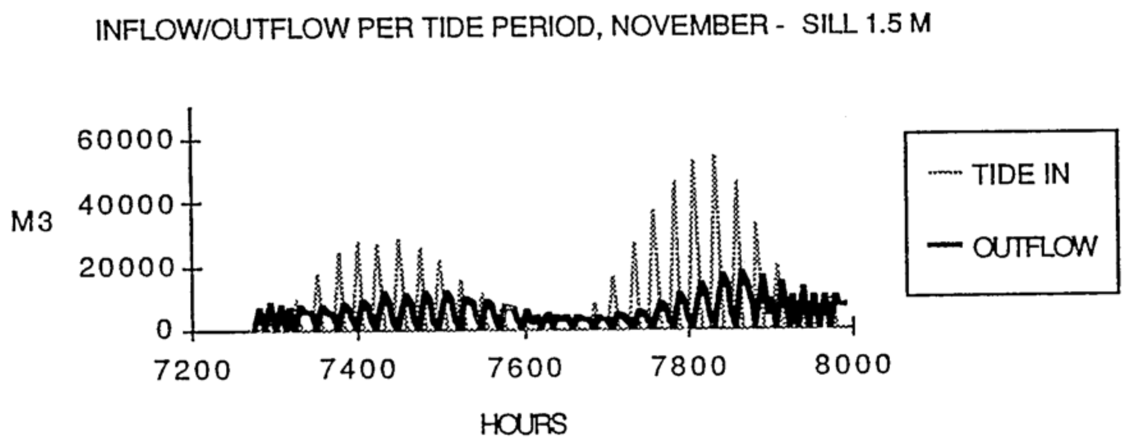


Fig. 5.19- 5.21 **Predicted Inflow/Outflow, July, August, September, for sill level 1.5 m, Orielton Lagoon**





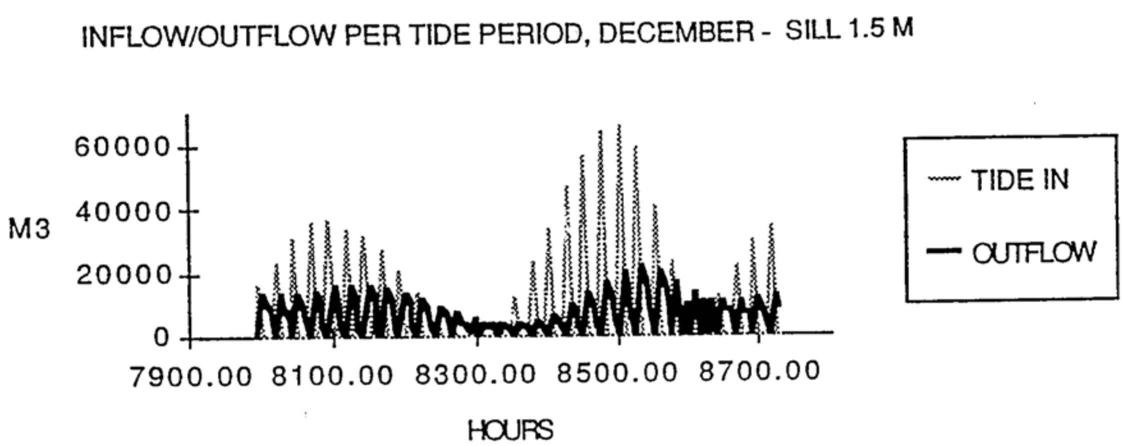


Fig. 5.22- 5.24 **Predicted Inflow/Outflow, October, November, December, for sill level 1.5 m, Orielton Lagoon**

SILL LEVEL - 1.5m (tide)		
MONTH	WATER LEVEL	TURNOVER (%)
January	1.58	26
February	1.55	16
March	1.52	9
April	1.55	17
May	1.57	26
June	1.58	42
July	1.57	61
August	1.58	58
September	1.56	31
October	1.55	14
November	1.56	23
December	1.56	30

Table 5.2 Lagoon depth relative to the culvert depth of 1.8 m and the % of water turnover in Orielton Lagoon calculated using the hydraulic model, with initial lagoon depth at 1.6 m and culvert sill height at 1.5 m.

This program showed a significant increase in the tidal inflow, particularly during the summer months. This compensated for seepage and evaporation and resulted in some outflow even during summer. Inflows shown on the graphs are clearly greater than those modelling the current sill height, with an obvious outflow throughout the year. The water movement is similar for July and August with a minimum outflow in March matching the lower tidal inflow. The water level and turnover rate also showed an increase with a minimum turnover of 9% in March to a maximum turnover of 61% in August. The water level in the lagoon would remain fairly constant around RL 1.6 m with only a variation of 0.05 m throughout the year. This would result in less exposure of mudflat during the summer than is currently the case.

5.3 Depth Survey

The test points of the depth survey are shown in Map 4 with the depths of the 1991 survey compared with those of the 1975 survey in Table 5.3. The seven points surveyed in 1991 indicate that the depth of the lagoon has changed very little at these points.

At Site 2 the depth of the lagoon appears to have increased by 0.13 m while the depth at Site 5 appears to have decreased by 0.08 m in the last 16 years. The other points indicate similar small variations with the points measured immediately in front of the culverts measuring 0.1 m to 0.02 m deeper than in 1975.

Date	Site 2	Pt.2	Site 5	Pt.3	Pt.4	Pt.5	Site 7
1975	1.09	1.27	1.19	1.29	0.75	0.69	0.43
1991	1.22	1.28	1.23	1.24	0.73	0.77	0.45

Table 5.3 Depths of water (m) at seven points in Orielton Lagoon in 1975 and 1991.

Given the accuracy of the measurements it seems reasonable to conclude that the depth has remained essentially constant and that there is no evidence of major silting of the lagoon.

5.4 Temperature Variations in the Lagoon

The ambient and water temperature were measured as part of the core data collected for this study. They are presented with other basic parameters in a summarised form in Appendix A, with the depth of each site and notes on prevailing weather conditions for each month.

The water temperatures closely reflected the ambient temperatures and showed the expected seasonal fluctuations. The water temperatures are shown in Fig 5.25 and clearly show a seasonal variation with peaks in March and December and then a steady decrease through to a low in July.

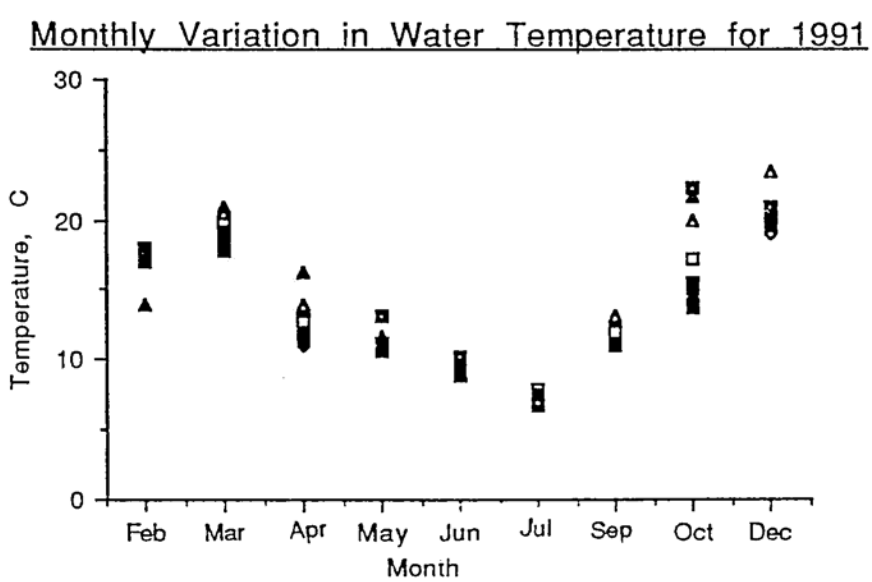


Fig 5.25 **Monthly Variation in Water Temperatures for 9 sites, Orielton Lagoon, 1991.**

The highest water temperatures were recorded in March, average 19.32°C, on a very calm day, and the coolest month was July, average 7.34°C. The temperature variation within the lagoon reflected the depth of the site, the prevailing wind conditions and the time of measurement. Diurnal variation within the system was investigated in October with 24 hr sampling at two sites in the lagoon and at the inflow. The diurnal variation in the water temperature again reflected the same factors. Thermal stratification was not noted in the study.

5.5 Turbidity

Turbidity values measured on the Hach Spectrophotometer in FTU (Formazin Turbidity Units), while equivalent to NTU (Nephelometric Turbidity Units) (Hach Spect. Handbook, 1990) could not be compared with values obtained on a nephelometric turbidity meter. However any variation within the system could be accurately measured. The variation in the turbidity is shown in Fig 5.26 which gives the mean monthly turbidity with standard error bars.

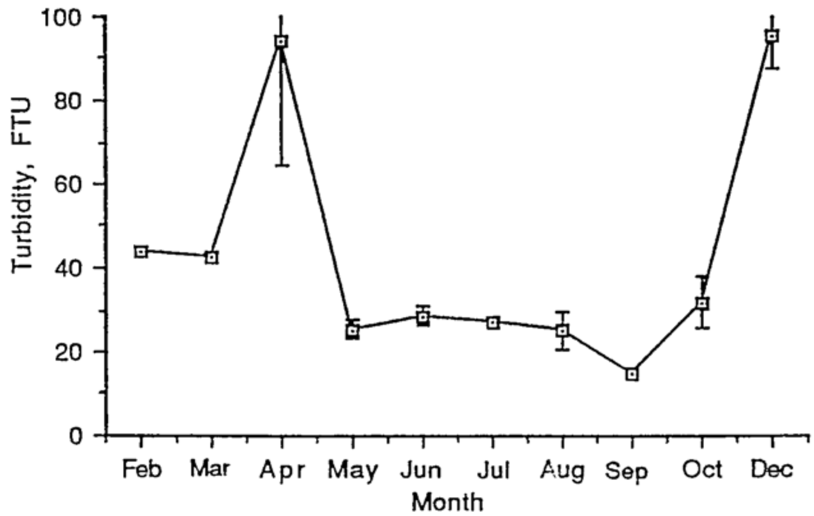


Fig 5.26. Mean Monthly Turbidity with Standard Error Bars for 9 sites, Orielton Lagoon, 1991

The turbidity peaked in April (94.11 FTU, mean) with a sharp decline through to September (14.33 FTU, mean) when it started to rise. There was another similar peak in December with a mean of 94.6 FTU.

Site by site variation is presented in a series of graphs, Figures 5.27 to 5.29 .

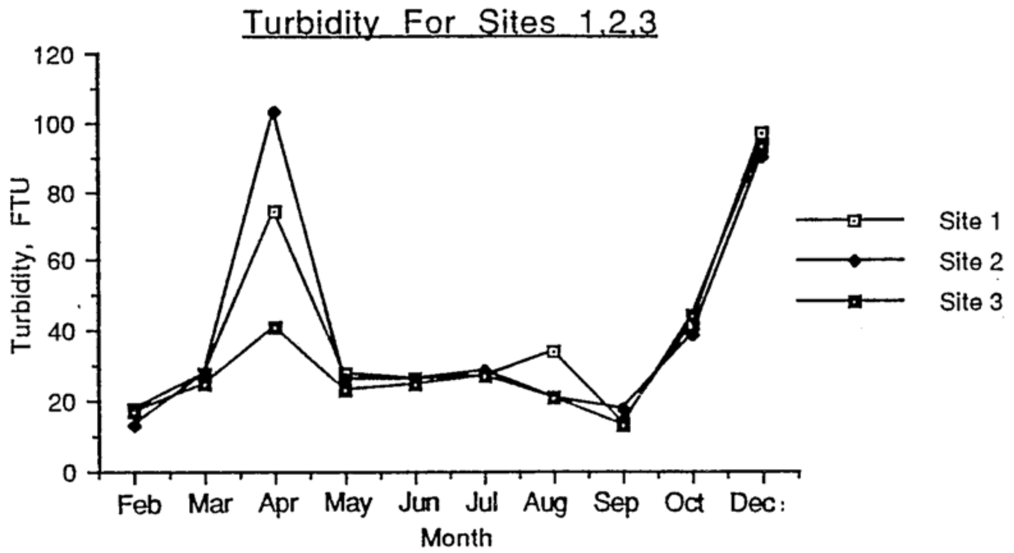


Fig. 5.27 **Turbidity For Sites 1,2,3, Orielton Lagoon, 1991**

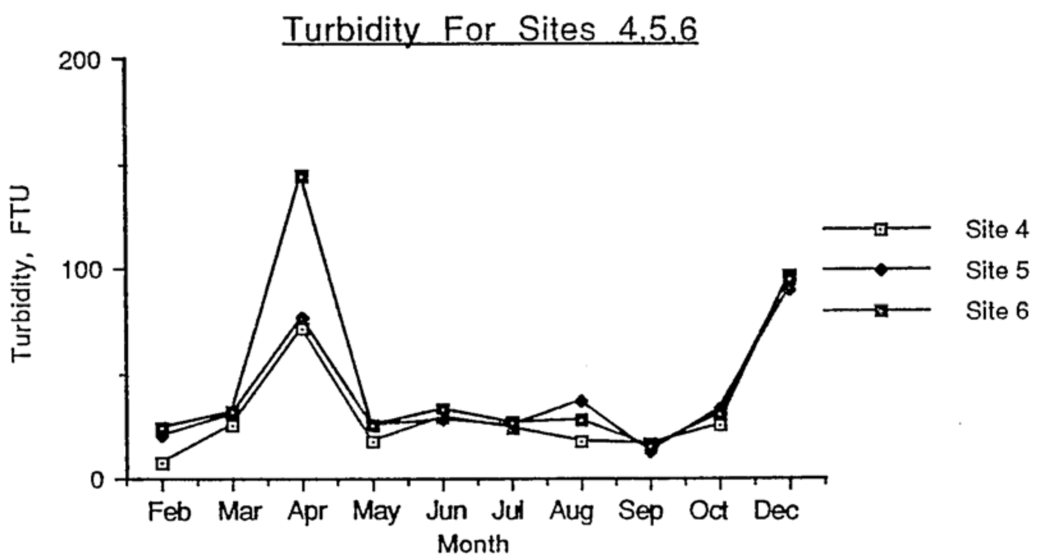


Fig. 5.28 **Turbidity For Sites 4,5,6, Orielton Lagoon, 1991**

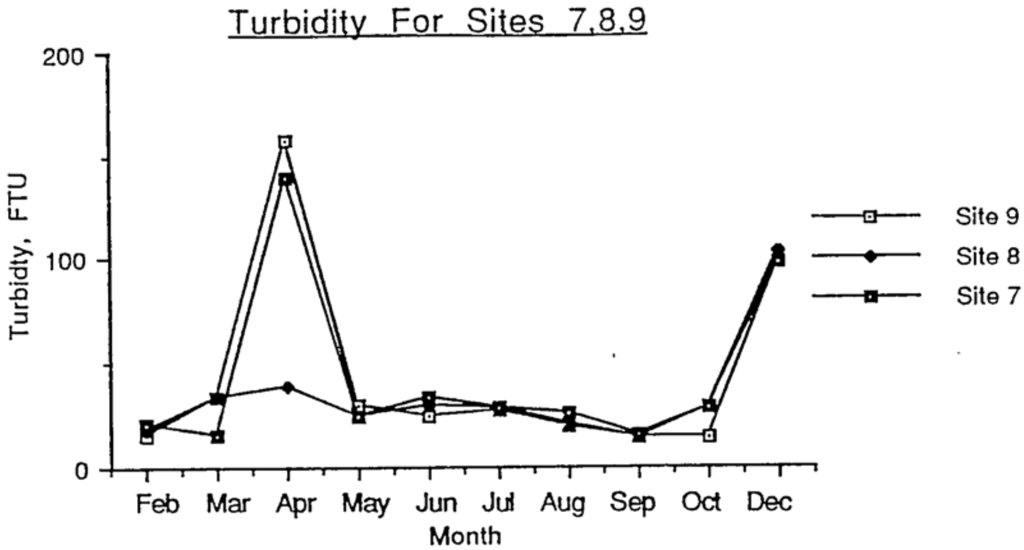


Fig. 5.29 **Turbidity For Sites 7,8,9, Orielton Lagoon, 1991**

The variation between the sites was not very marked except in April, when turbidity varied between 39 FTU and 157 FTU. This variation was not evident in December when turbidity was again high but sampling in April was on a windy day while the sampling day in December had only a light wind. The turbidity each month was similar for all sites, particularly between May and December with the sites following the variation described for the average values.

The turbidity of the site sampled at Pittwater was much lower than than the values obtained from the lagoon, with values ranging from 2 to 5 FTU.

5.6 Secchi Disc

The Secchi Disc values for the last four months averaged 41 cm, except for September, which had an average value of 67 cm. For some points in the lagoon the Secchi disc hit the bottom of the lagoon before it disappeared from view and there were no values obtained when the sampling was done from the bank. This limited the number of readings for this apparatus.

5.7 Physical Properties of the Sediment

5.7.1 Organic Matter

The percentage of organic matter in the sediment samples is shown in Table 5.4. This table shows that Sites 5 and 9 consistently had an organic matter content above 12 % while Sites 1 and 8 occasionally had values at that level. The other sites showed consistently low levels of organic matter.

Site No.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1	11.5	3.5	2.8	2.6	12.5	6.7	NC	7.1	15.3
2	3.7	6.9	2.8	3.2	2.7	2.5	NC	2.8	3.1
3	2.8	8.1	1.9	2.1	1.8	1.9	NC	2.2	1.4
4	3.6	1.6	1.5	1.7	2.1	1.7	NC	NC	UF
5	15.9	20.9	18.8	15.7	14.9	15.9	NC	17.5	UF
6	2.8	4.9	5.1	1.7	2.0	UF	NC	2.3	1.8
7	3.1	2.4	1.8	2.8	2.5	1.7	NC	2.8	1.8
8	9.5	3.5	7.0	6.1	15.6	3.3	NC	NC	UF
9	16.1	17.1	14.7	12.4	14.2	UF	NC	18.8	UF

Table 5.4 **Organic matter as % of material lost on ignition at 550°C, for samples of sediment from Orielton Lagoon NC - Not Collected, UF - Unfinished.**

The higher values for Sites 5 and 9 concur with field observations. Sediments from Site 5 were odorous with a strong smell of hydrogen sulphide while Site 9 sediments often included plant roots from *Juncus* species and other plant material including seeds and fine root-hairs.

5.7.2 Particle Size Distribution

The particle size distribution for the sediments analysed has been divided into percentage of fine sand (0.5 to 0.063 mm) and a clay and silt component combined to give the percentage of particles less than 0.063 mm. The particle size distribution was initially only carried out for the first two months but, as variation in total phosphorus in the sediment was shown in September samples, the particle size distribution was carried out for selected sites for September. The sites chosen corresponded to those sites where total phosphorus in the sediment was analysed, except for Site 5, where there had been insufficient sediment left after LOI tests and the material set aside for benthic macrofauna. The sites selected also corresponded as closely as possible to those points sampled by the DEP in 1986 (DEP 1986).

The percentages of sand and silt/clay are summarised in Table 5.5 and selected results are presented graphically in Figure 5.30 to 5.34. The particle size distribution generally shows a substrate which has a high percentage of sand at most sites sampled.

Site No	Feb		Mar		May		Sep	
	% silt & clay	%sand & shell	% silt & clay	%sand & shell	% silt & clay	%sand & shell	% silt & clay	%sand & shell
1	34	66	16	84	12	88	26	74
2	26	74	41	59	25	75	16	84
3	15	85	42	58	14	86	13	87
4	8	92	7	93	2	98	ND	ND
5	88	12	96	4	97	3	ND	ND
6	17	83	32	68	13	87	12	88
7	54*	46*	15	85	ND	ND	16	84
8	51	49	14	86	ND	ND	ND	ND
9	85	15	88	12	ND	ND	ND	ND

Table 5.5 Particle Size Distribution, for samples of sediment from Orielton Lagoon, 1991. * indicates a sample divided into >0.5 mm and < 0.5mm, ND - not done.

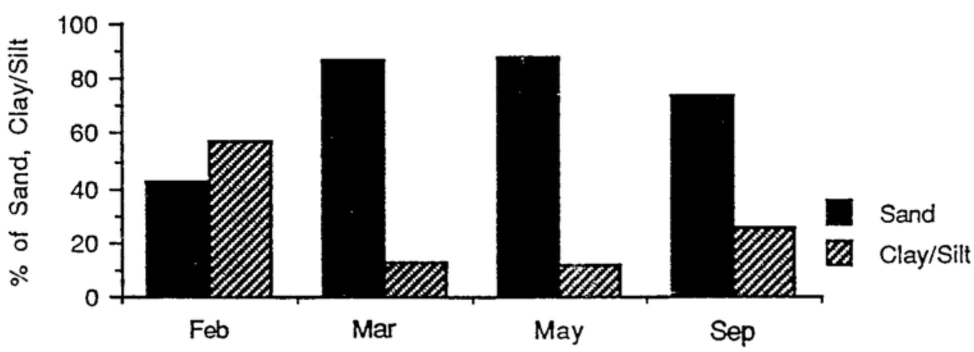


Fig. 5.30 Site 1, % sand and clay/silt in sediments. Orielton Lagoon, 1991

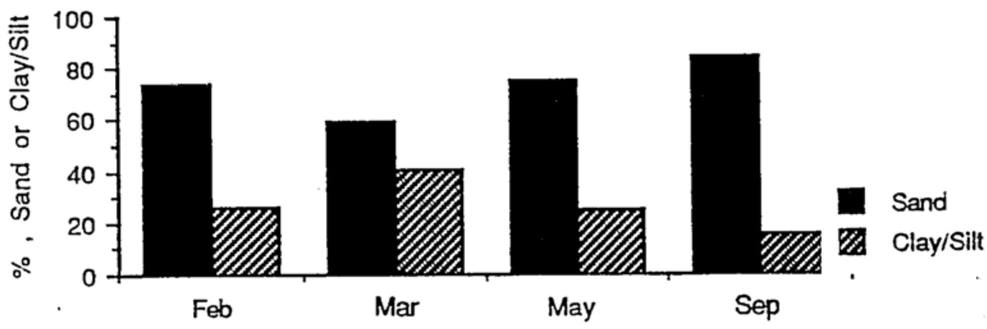


Fig. 5.31 Site 2, % sand and clay/silt in sediments, Orielton Lagoon, 1991

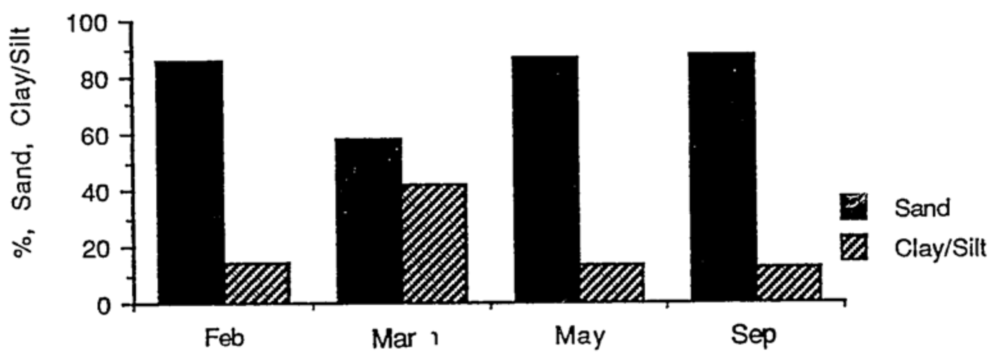


Fig. 5.32 Site 3, % sand and clay/silt in sediments, Orielton Lagoon, 1991

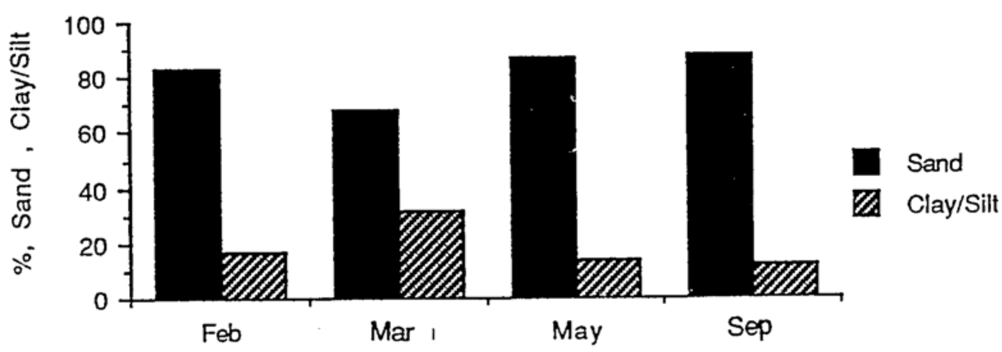


Fig. 5.33 Site 6, % sand and clay/silt in sediments, Orielton Lagoon, 1991

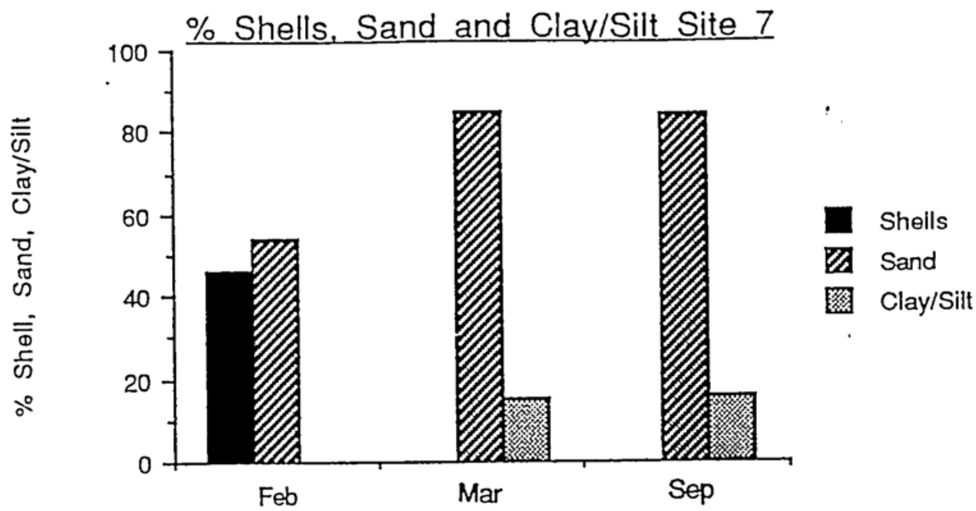


Fig. 5.34 Site 7, % sand and clay/silt in sediments, Orielton Lagoon, 1991

At Sites 4 and 7 the level of mollusc shells in the samples precluded the normal analysis for February and the particle size was only divided into material >0.5 mm and material less than 0.5 mm. Field notes indicated that the substrate at these points was shelly (Site 7) and very rocky (Site 4).

Sites 5 and 9 had the lowest percentages of sand, less than 20%, while Sites 1 and 8 showed only 40 to 50% sand on one occasion.

The variation between the sediments sampled in the first two months and the sediments sampled in September was not consistent, with the sand fraction slightly higher in September at Sites 2, 3 and 6. The sand fraction at Sites 1 and 7 were within the range measured for February and March.

The fine, brown-grey sediment observed on the floor of the lagoon was not collected efficiently using the simple dredge but sampling with a corer did not give better results. Removing the samples broke up any fine layers on the surface of the sample. Some of this fine sludge may have been representative of organic matter in samples or may have been the result of very high diatom populations which can form such a surface (Anon. 1990). However it is unclear exactly how much of this material was present in each sample. The depth of this fine layer could be estimated by skin-diving and/or sedimentology techniques.

Chapter 6

Results - Chemical Parameters

A full set of data on chemical parameters, collected for this study, is given in Appendix A. Summarised results are presented in tabular and graphical form in the following sections.

6.1 Salinity

The salinities for all the sites, throughout the year, are shown in Fig 6.1. The general trend to a decrease in salinity during winter and early spring can be seen.

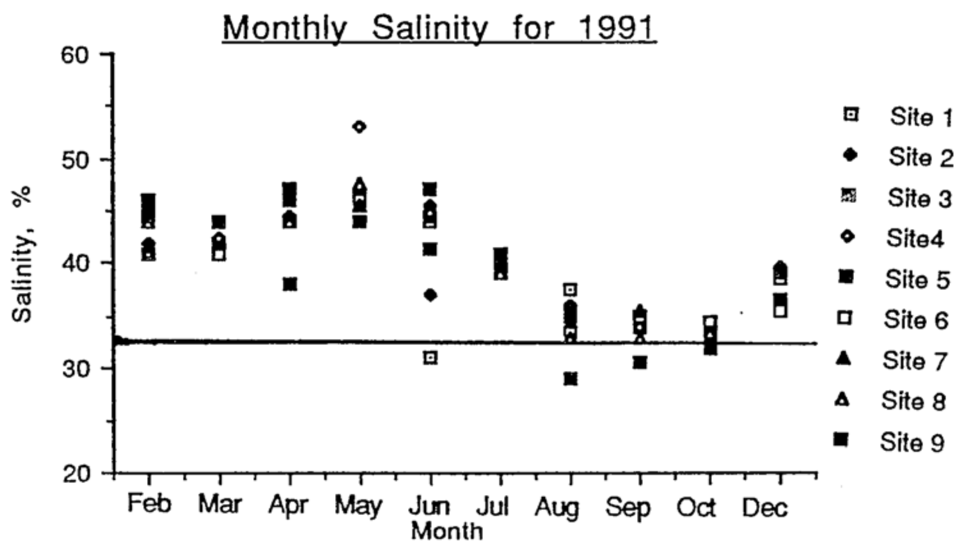


Fig. 6.1 **Monthly Salinity, Orielton Lagoon, 1991. The horizontal bar represents normal sea water salinity.**

The salinity for the first four months was up to 25% higher than normal sea water, with initial drops in June being recorded at Sites 1 and 2 which are closest to the culverts, areas most likely to be affected by any incoming tide. This is represented by the outliers on the graph for June. There was an inflow of sea water during the third week of May which may have lowered the hypersaline conditions. Continued input from the sea during July and August reduced the salinity to standard sea water in August. There was a slight drop in salinity, to below that of sea water, at Site 9 in August and September, which would be the result of fresh water inflow throughout those months. October results show a salinity comparable to that of sea water, and by December salinity had increased again, but not to the levels for February through July.

As fresh water entered the system, during the winter months, it was expected that a halocline would develop, with the formation of a freshwater layer on the surface. At sites measured within the lagoon, there was no evidence of stratification but measurements at the very top end of the lagoon, about 200 m below the gauging weir (ref. Map 3, Brinktop Road Bridge) showed some stratification in the water column. This occurred on 15/7/1991 and 15/8/1991, after heavy rainfall the nights before, resulting in flow rates of 0.03 cumecs on the 13/7/1991 and 0.138 cumecs on the 15/8/1991.

Date	15/7/1991	15/8/1991
Flow Rate	0.03 cumecs	0.138 cumecs
Surface Salinity ‰	6	2
Bottom Salinity ‰	42	35

Table 6.1 Salinity variations in surface and bottom water at Brinktop Road Bridge during spring 1991, at Orielton Lagoon. Salinities are expressed as ‰.

These were the only times when there was any stratification in the water column and was clearly related to the less dense fresh water input. The stratification had disappeared by the time the water reached the northern end of the lagoon, at the Shark Point Road Bridge (ref. Map 3).

The salinity of water leaving the lagoon, during the winter, was similar to that in the body of the lagoon and was not unmixed water with a surface layer of fresh water.

Salinity variation in the diurnal study, discussed in Section 6.11, was reduced because the study was undertaken when there was no daily tidal influence and no water movement from the lagoon.

6.2 Acidity

Acidity fluctuated between pH 7.82 and 8.64 with the highest pH value in July and the lowest in April. This fluctuation was approximately the same as that in the diurnal study and there were no trends or dramatic variations in the rest of the results. The fluctuation in the diurnal study, discussed in Section 6.11, was one pH unit, but the variation during the sampling period was lower.

6.3 Dissolved Oxygen

Dissolved oxygen was near saturation point at most sites for most of the year, with the lowest levels recorded in May and higher values in March and October. Both sampling days for the latter months were fine, sunny, calm days so photosynthetic activity would have been at a maximum. The level in December was also very high reflecting a high level of photosynthetic activity. The chlorophyll values and very green appearance of the lagoon at this time indicated a high level of phytoplankton.

There was evidence of stratification observed in December and the variation in dissolved oxygen in the surface and bottom water at the deeper sites is shown in Table 6.2 .

Site	Surface DO %	Bottom DO %	Surf.DO, mg/L	Bot. DO, mg/L
2	113	55	9.2	3.8
3	112	93	10.1	9.4
5	94	35	7.4	2.9
6	101	33	8.6	4.4

Table 6.2 **Levels of dissolved oxygen at four sites in December,1991 in Orielton Lagoon.**

The dissolved oxygen showed the greatest variation at Sites 2, 5 and 6 with the variation in dissolved oxygen between the surface and the bottom at Site 3 not as noticeable. The variation at the other sites indicated the presence of stratification with an anoxic layer of water above the sediments.

Surface dissolved oxygen variation in the dirunal study, discussed in Section 6.11, ranged between 77 to 127 % but the range during normal sampling times was only 100 to 127 %.

6.4 Dissolved Organic Matter

The dissolved organic matter or gilvin content, measured as g440, is given for each site in Figs 6.2 to 6.4. Monthly means are shown in Fig 6.5, which shows the variation during the year. Values were obtained by combining data from all sites each month.

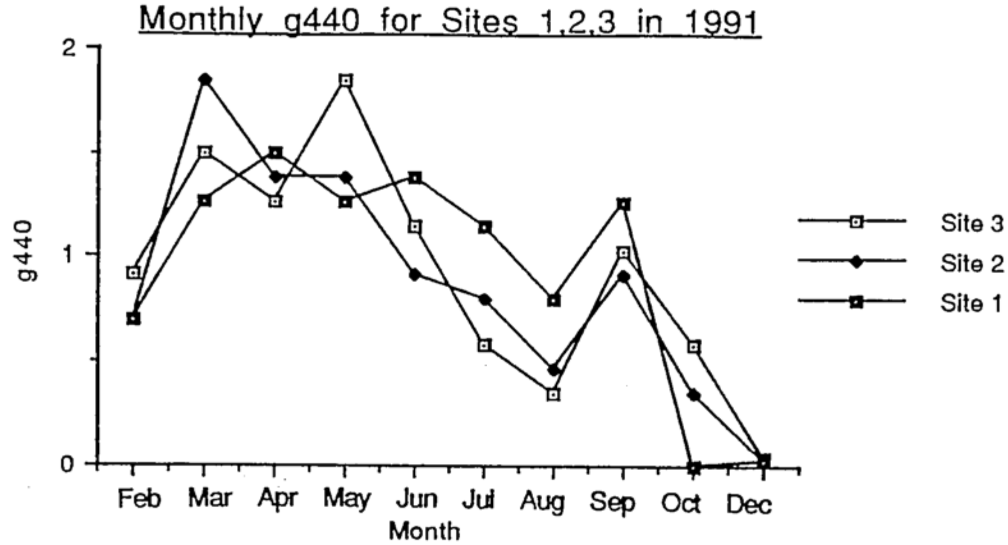


Fig. 6.2 **Monthly g440 for sites 1,2,3, Orielton Lagoon, 1991.**

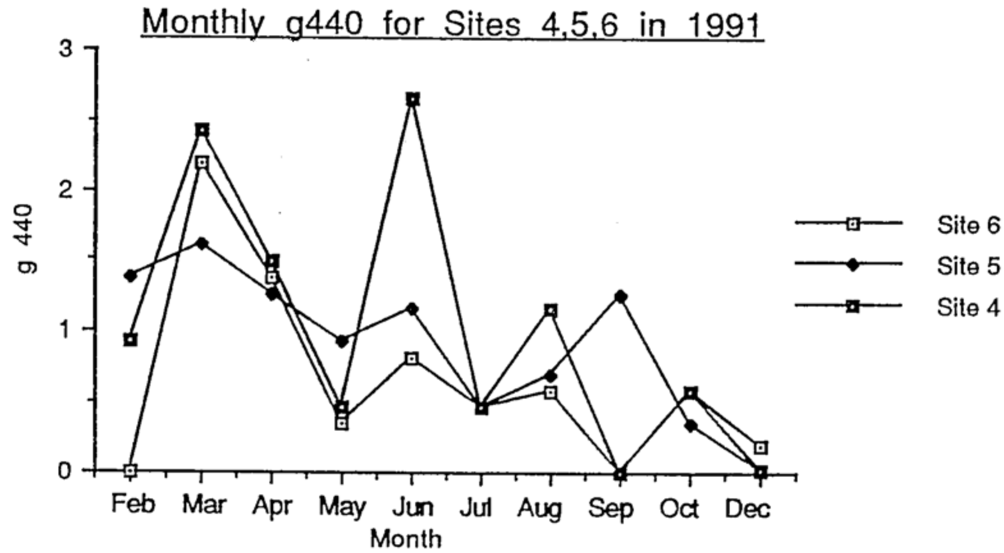


Fig. 6.3 **Monthly g440 for sites 4,5,6, Orielton Lagoon, 1991.**

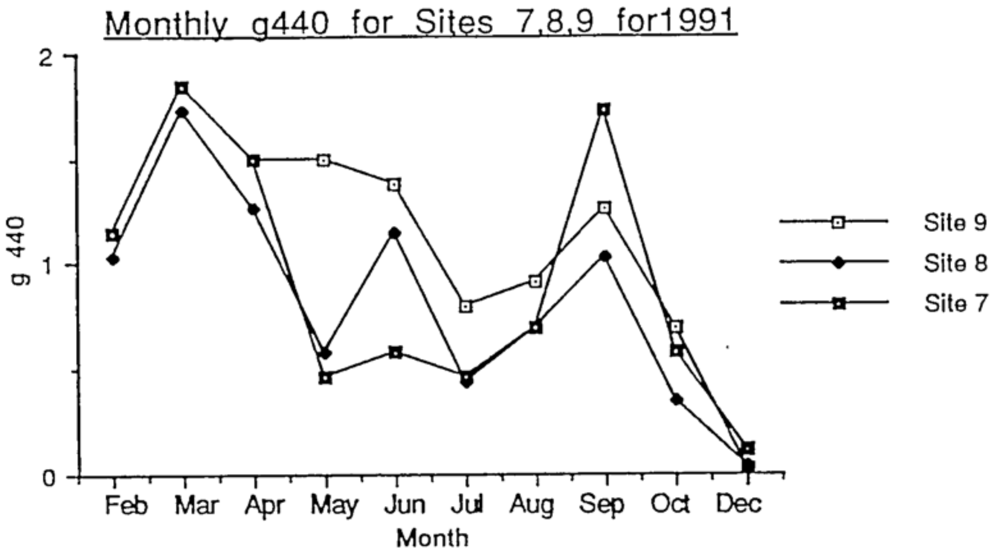


Fig. 6.4 Monthly g440 for Sites 7,8,9, Orielton Lagoon, 1991.

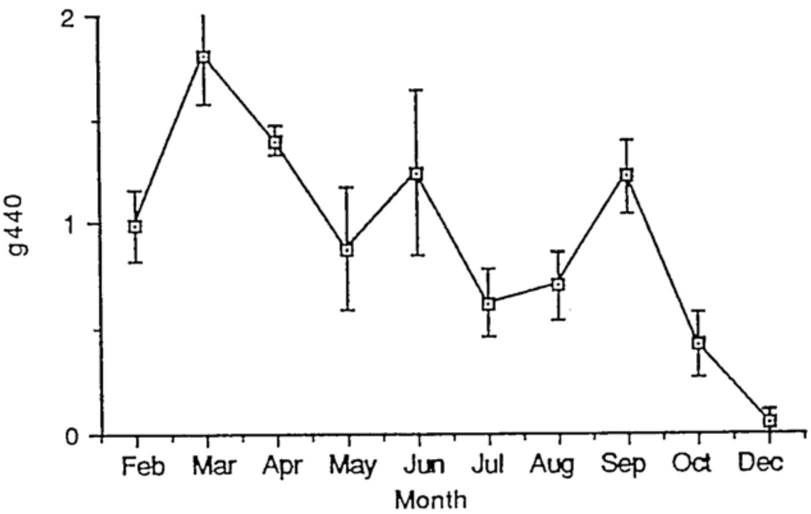


Fig. 6.5 Mean Monthly g440 for 9 sites, with standard error bars, Orielton Lagoon, 1991.

The values of g440 in this study ranged from 0.052 in December to 1.80 in March. After the peak in March, the values showed a steady decline throughout the year, with the exception of September.

The g440 value for the inflow water was higher, for four out of five months, than the value found in the lagoon. Input from the rivulet during August and September may have increased the level of dissolved organic matter during those months.

Variation between the sites was not constant throughout the year with variation in some months being very low. Values for April and December showed little difference and corresponded to the months with the highest chlorophyll levels, although the average levels for these two months was very different.

6.5 Chlorophyll Levels

The chlorophyll levels in the lagoon were used to measure phytoplankton biomass and give an indication of the productivity of the lagoon. Chlorophyll levels measured in the lagoon varied widely and this is shown in the scatter graph Fig 6.6.

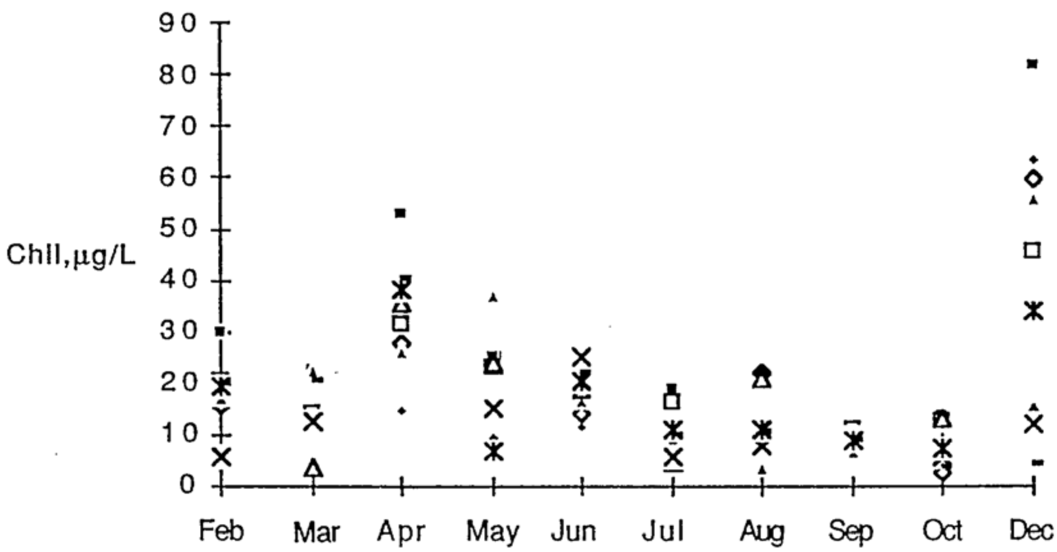


Fig. 6.6 Monthly Chlorophyll levels for 9 sites, Orielton Lagoon, 1991.

The variation between the sites is more clearly shown in the series of graphs represented in Figs 6.7 to 6.9. Due to a range of technical and field difficulties, not all the samples collected were successfully analysed for chlorophyll levels.

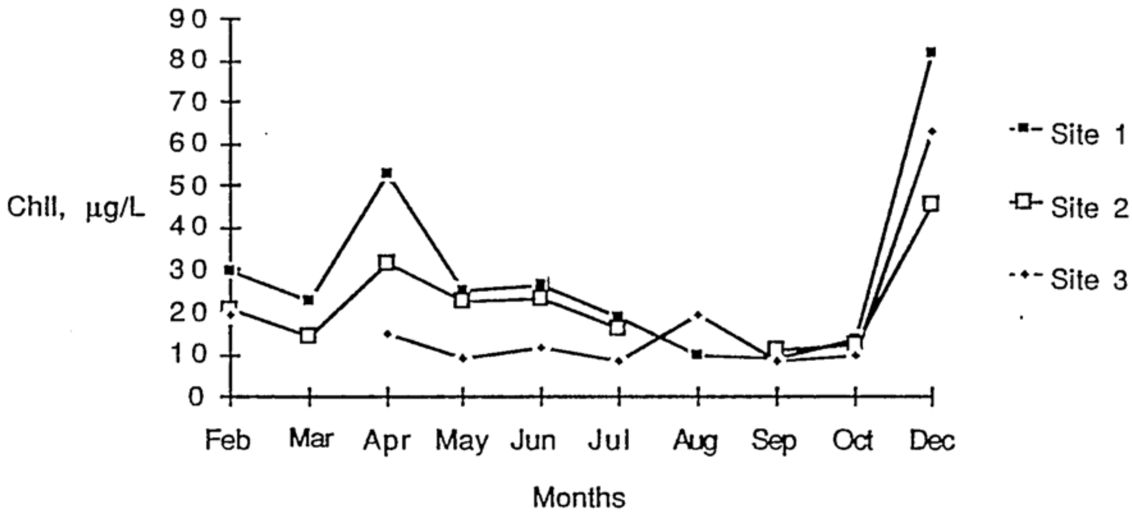


Fig. 6.7 **Monthly Chlorophyll levels, Sites 1,2,3, Orielton Lagoon, 1991.**

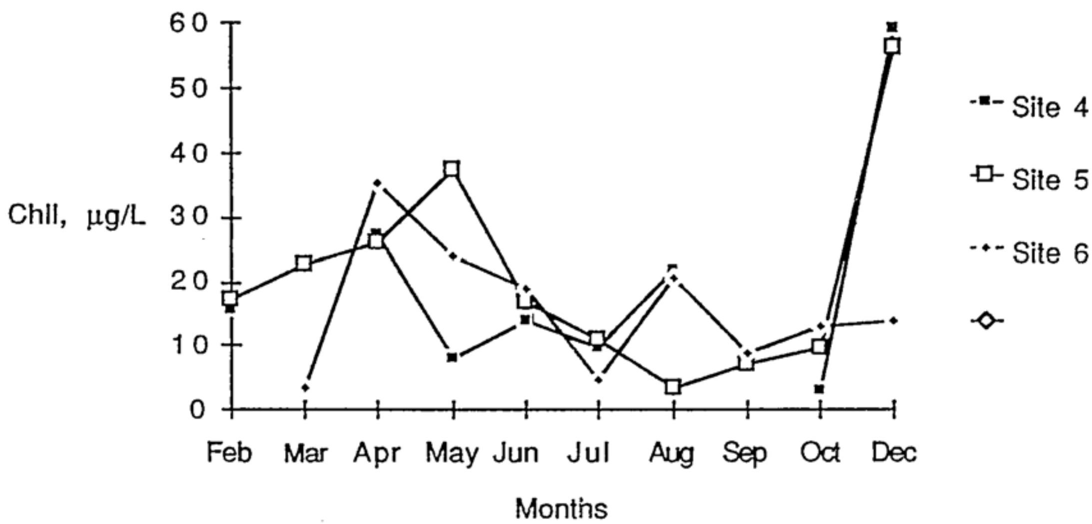


Fig. 6.8 **Monthly Chlorophyll levels, Sites 4,5,6, Orielton Lagoon, 1991.**

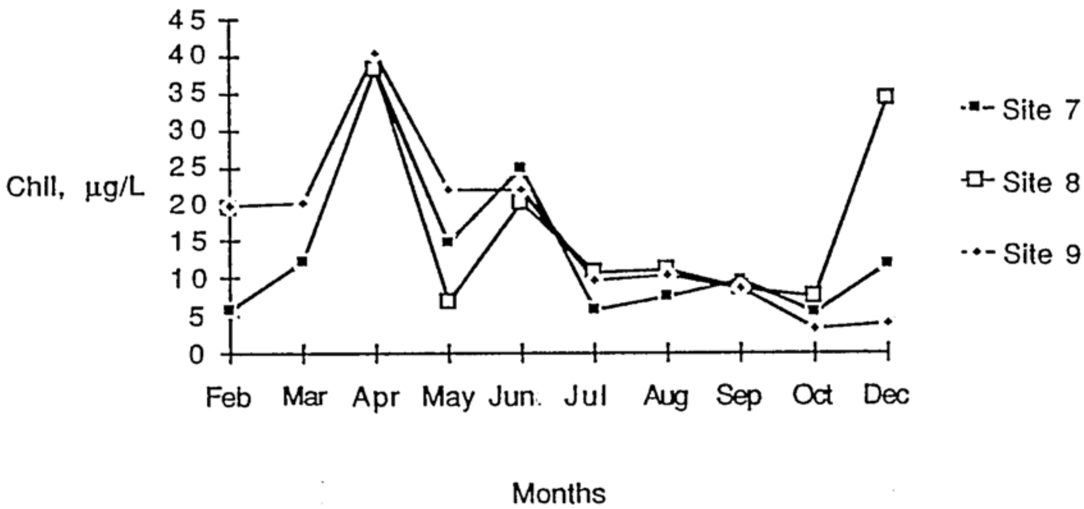


Fig. 6.9 Monthly Chlorophyll levels, Sites 7,8,9, Orielton Lagoon, 1991.

Average chlorophyll levels for each month were calculated and are presented in Fig 6.10.

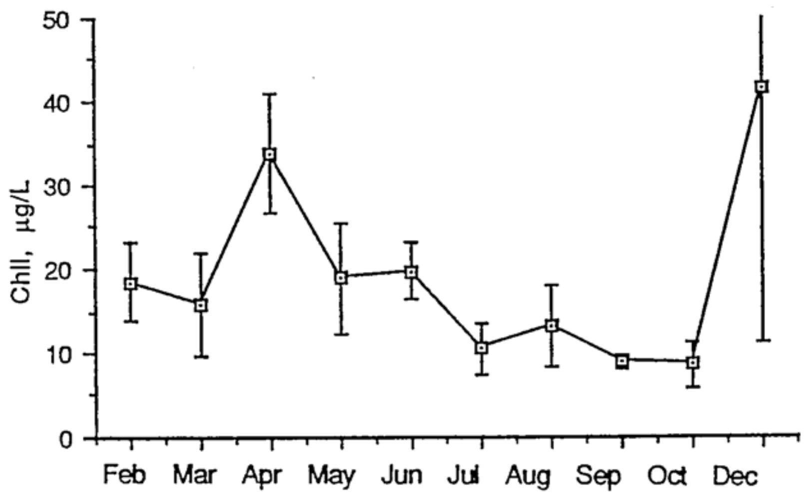


Fig. 6.10 Average Monthly Chlorophyll Levels, for 9 sites, with Standard Error Bars, Orielton Lagoon, 1991.

Fig. 6.10 shows a peak of 33.82 µg/L in April with a gradual decrease in the next six months to a low of 8.67 µg/L in October. There was a further peak in December of 41.76 µg/L, corresponding to reports by the public that the lagoon was very green. Values for this period were the highest recorded with a maximum of 81 µg/L at Site 1 but a relatively low value of 4.09 µg/L at Site 9. Field notes indicate that this particular point was very clear and the bottom of the lagoon was readily seen. However, the sample of water collected was taken with some difficulty, with the result that there was an unusual amount of mud stirred up. This resulted in a very high reading of turbidity which did not reflect the clarity of the area. The values for Sites 6 and 7 in December are lower due to filter paper damage during filtration but both samples had characteristics similar to other sites in that month.

Chlorophyll levels for nearby Pittwater were measured on three ocassions in the latter part of the study and values ranged between 0.01 µg/L to 1.6 µg/L.

The diurnal study in Orielton Lagoon revealed a fluctuation of 7 µg/L, at the two sites within the lagoon indicating the variable nature of chlorophyll levels. Normally samples were collected during the daytime when the variation in chlorophyll levels was not as great as it was during the night. This is discussed further in Section 6.11.

Even accounting for the variation within a day there is still a definite trend to lower chlorophyll levels in the early months of spring followed by a dramatic increase in December.

6.6 Phosphates and Nitrates in the Water

Soluble nutrients were recorded in ppb equivalent to µg/L.

The values for the dissolved phosphorus as phosphates for Sites 1 to 9 are shown in Fig 6.11. Fig 6.12 shows the phosphate values for Orielton Rivulet.

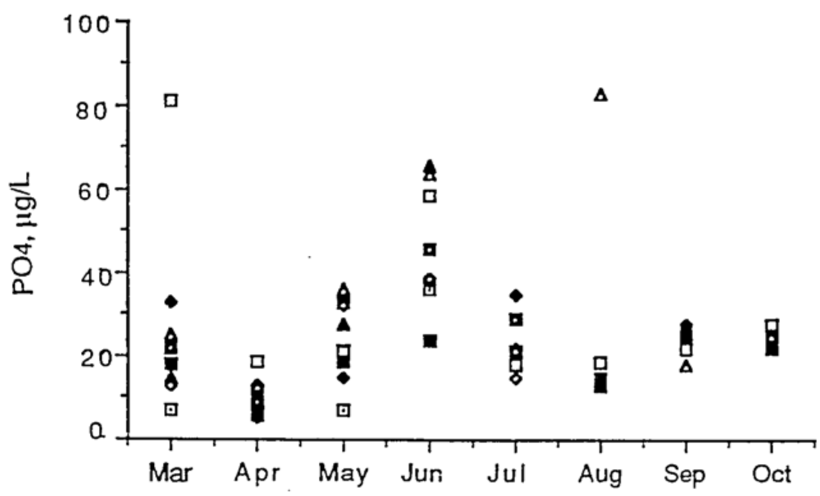


Fig. 6.11 **Monthly Dissolved Phosphate Levels, Sites 1 to 9, Orielton Lagoon, 1991.**

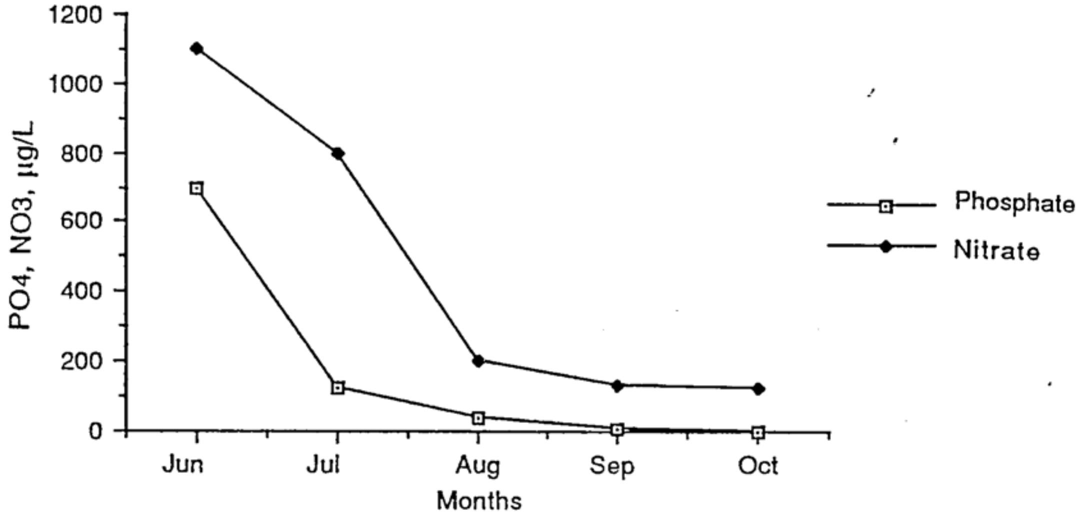


Fig. 6.12 **Monthly Dissolved Phosphate and Nitrate Levels, Orielton Rivulet, 1991.**

Phosphates ranged between 6 µg/L and 83 µg/L in the body of the lagoon with a peak in June corresponding to a similar high level of total phosphorus. The lowest phosphate concentrations occurred in April at which time the average chlorophyll levels were highest. Soluble phosphates for December were not available at the time of writing.

Soluble phosphates were measured in Pittwater for the last four months of the study and values ranged from 9 to 23 µg/L, with three of the four values below 12 µg/L.

The values for the dissolved nitrogen as nitrate and nitrites for Sites 1 to 9 are shown in Fig 6.13. Levels are relatively low with all values below 50 µg/L and generally below 30 µg/L. The values show no definite trends although there was a slight increase in July.

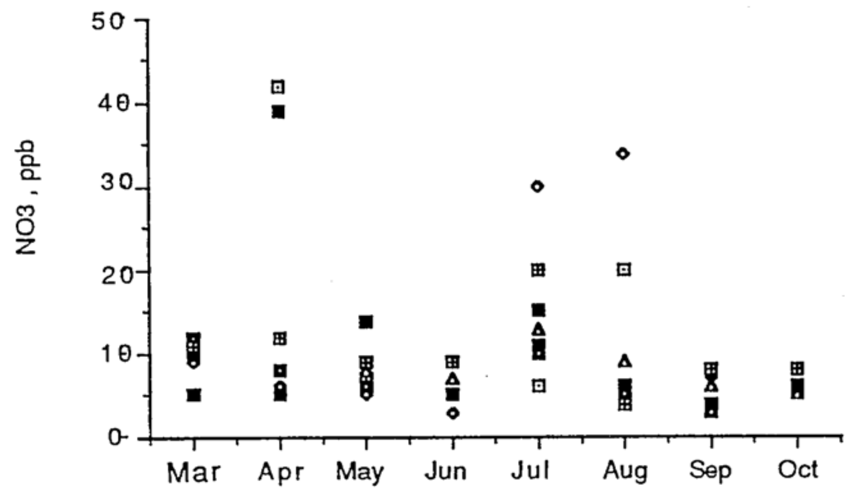


Fig. 6.13 **Monthly Dissolved Nitrogen Levels, Sites 1 to 9, Orielton Lagoon, 1991.**

Phosphate and nitrate concentrations in the freshwater samples obtained from the rivulet were much higher than those obtained in the body of the lagoon when sampling commenced in June, but decreased dramatically between June and October, as shown on Fig 6.12. Phosphate levels in the rivulet decreased to very low levels whilst nitrate remained relatively high compared to levels within the body of the lagoon.

6.7 Nitrogen/ Phosphorus Ratios

As total nitrogen values for the water column were not determined, the ratio between nitrogen and phosphorus is based on the soluble forms of these nutrients. The average nitrate/nitrite and orthophosphate levels for the body of the lagoon are presented in Table 6. 3. This includes the relative ratios of these nutrients over the months of the study.

The N:P ratio for the system varies between 3.09:1 and 0.40:1 with a peak in April. This is noted to correspond with the time of the highest chlorophyll level, as shown on Fig 6.1.

The annual average N:P ratio was calculated from monthly averages at 1.13:1.

Month	N Nitrate/Nitrite, µg/L	P Orthophosphateµg /L	N/P Ratio
Mar	9.3	25.4	0.81:1
Apr	15.8	11.3	3.09:1
May	7	24.1	0.71:1
Jun	9	41.8	0.44:1
Jul	16.3	23.3	1.55:1
Aug	13	20.5	1.40:1
Sep	5.6	24	0.52:1
Oct	5	23	0.48:1

Table 6.3 Nitrogen-to-phosphorus ratios for 9 sites in Orielton Lagoon, 1991. Data are calculated by atom for inorganic forms of phosphorus and nitrogen, and are mean monthly values.

6.8 Total Phosphorus

Values for total phosphorus in the water column were measured as part of the nutrient balance study and ranged between 37 µg/L and 261 µg/L as shown in Fig 6.14. The relationship between total phosphorus and flow rate in the rivulet ranged between 0.078 ppm and <0.005 ppm. There was no apparent relationship between the variables.

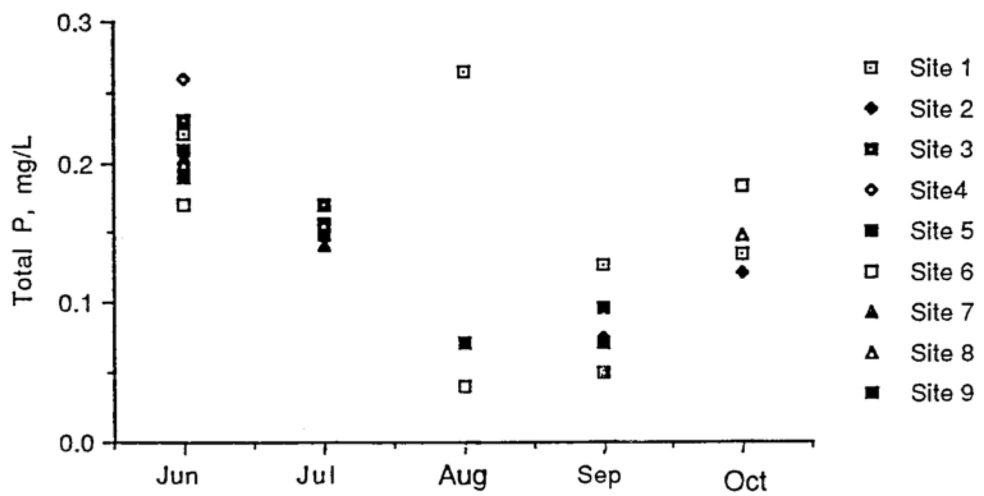


Fig. 6.14 Monthly Total Phosphorus Levels, Sites 1 to 9, Orielton Lagoon, 1991.

As mentioned earlier, there was a definite trend towards lower total phosphorus values in August followed by a gradual increase in the levels to October. Although values for total phosphorus were not measured during the first four months of the study, similar trends between the orthophosphates and total phosphorus over the last five months suggest that the increase in total phosphorus would continue for the rest of the year. Thus total phosphorus levels would be expected to build up during the period of no outflow, culminating in a peak in early winter, depending on rainfall events in any particular year.

The outlier for total phosphorus in August was at Site 1, close to the sewage outlet. The high level may be related to malfunction of the new sewage treatment plant which resulted in the discharge of poorly treated sewage for a short time during this month (Personal observation).

6.9 Relationships between Parameters

Correlation coefficients were used to examine the relationship between the different parameters measured in the body of the lagoon over the ten month study period.

The data were first tested for normality using the Kolmogorov-Smirnov Goodness of Fit test and the data proved to be non-parametric. When data were non-parametric, normal correlation coefficients are generally not applicable (Zar 1974). Also the lack of complete sets of data for some parameters precluded the use of the normal analysis of variance and correlation analysis. So, correlations were examined using a Spearman Rank correlation test. Table 6.4 shows the correlations between the various parameters measured in the lagoon body.

Significant correlations are indicated in 9 out of 28 combinations.

Water temperature shows a positive correlation with turbidity, phosphorus as orthophosphate and nitrogen as nitrate.

The relationship between temperature and turbidity may directly reflect the prevailing weather conditions although some degree of seasonality must also be a factor, particularly as there is also a correlation between turbidity and chlorophyll levels.

The other factors that were correlated significantly to chlorophyll levels were the turbidity, salinity and pH.

Salinity was correlated significantly with turbidity, g440 and chlorophyll, while g440 was correlated significantly with the nitrate level.

	pH	Salinity	Turbidity	g440	Chll	PO_4	NO_3
Water Temp	0.033, NS n=72	-0.04, NS n=72	0.288, ** n=72	-0.108, NS n=72	0.123, NS n=72	-0.327, ** n=72	-0.243, * n=72
pH		0.131, NS n=94	0.088, NS n=94	0.055, NS n=94	0.215, * n=94	0.14, NS n=72	0.015, NS n=72
Salinity			0.251, ** n=92	0.291, ** n=94	0.532, *** n=94	0.013, NS n=72	0.035, NS n=72
Turbidity				0.108, NS n=94	0.513, *** n=94	-0.141, NS n=72	0.105, NS n=72
g440					0.105, NS n=90	0.009, NS n=72	0.243, * n=72
Chll						-0.043, NS n=72	-0.048, NS n=72
PO_4							0.043, NS n=72

Table 6.4 Spearman Rank Correlations for Data from Orielton Lagoon, 1991.
NS denotes "not significant", *denotes $p<0.05$, **denotes $p<0.01$, *** denotes $p<0.001$.

Graphs relating the natural log of chlorophyll against different nutrients were drawn up; lines of best fit, equations and probabilities calculated. There was no significant relationship, in terms of correlation coefficient, found between chlorophyll and phosphates (n=81, $p>0.1$) and chlorophyll and nitrates (n=81, $p>0.1$).

A significant relationship (n=19, $p<0.001$) was noted between total phosphorus and chlorophyll during the months when there was no outflow from the lagoon. A plot of these data is presented in Fig. 6.15.

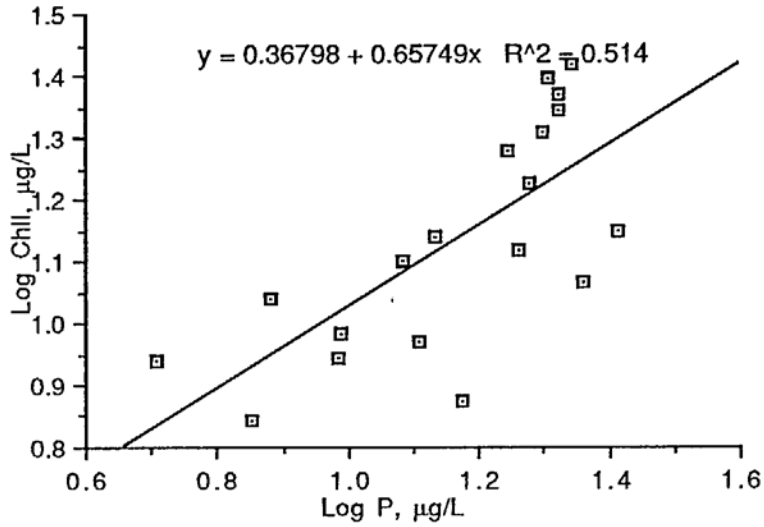


Fig. 6.15 Total Phosphorus/Chlorophyll Relationship, zero outflow condition, for 19 samples over 3 months at Orielton Lagoon, 1991.

When the results for the winter period, with tidal inflows and some outflow, were included, the relationship was no longer significant (n=27, $p>0.1$) as shown on Fig. 6.16.

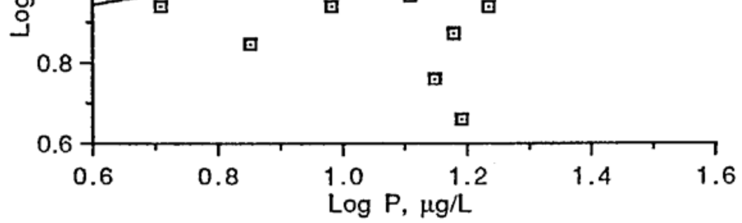


Fig. 6.16 Total Phosphorus/Chlorophyll Relationship, including all outflow conditions, for 27 samples over 5 months, Orielton Lagoon, 1991.

6.10 Phosphorus Loading, Predicted versus Actual Chlorophyll Levels

Using the equations developed for freshwater systems in the OECD eutrophication study (OECD 1982), the phosphorus loading for the lagoon was calculated. As the lagoon is a semi-marine environment the predicted outcomes from changes in the loading may not be as reliable. There are two assumptions made; namely that phosphorus can be made the controlling nutrient, and that the sewage treatment plant is the only source of this nutrient.

The phosphorus loading term is given by the formula

$$\frac{L(P)/q_s}{1 + \sqrt{T(W)}}$$

where L(P) - specific loading of total phosphorus per unit lake surface area per year (mg $P/m^2/yr$)

q_s - hydraulic loading (m/yr) = z/T(W)

T(W) - hydraulic residence time (yr)
= water volume(m^3)/annual inflow volume (m^3/yr)

z - mean depth (m)
= water volume (m^3)/ surface area (m^2)

L(P) = 1072.5 mg $P/m^2/yr$

q_s = 3.25 (m/yr)

T(W) = 0.407 yr

This gives a phosphorus loading term of 202.2 $mg/m^3/yr$, and using this in conjunction with Fig 8.5 (OECD 1982, p. 81) the predicted maximum chlorophyll level would be 85 μg/L; Fig 8.4 (OECD 1982, p. 81) gives a predicted annual mean chlorophyll level of 25 μg/L.

This information was used to predict the phosphorus load that would be required to change the average and maximum chlorophyll levels in the system. The average chlorophyll level for the Pittwater is 0.5 to 2 μg/L (Hallegraeff et al. 1986).

If the mean average chlorophyll levels in Orielton Lagoon are to be this low, say 1 μg/L, the phosphorus loading term would be 3.5 $mg/m^3/yr$ (Estimated from Fig 8.4, OECD, 1982, p. 81).

From Fig 8.4 (OECD, 1982, p. 81):

$Pi/(1+\sqrt{T(W)}) = 3.5$ (where Pi equals L(P)/qs)
This gives a permissible average phosphorus concentration which should not exceed $Pi = 3.5(1+\sqrt{0.407}) = 5.712$ mg/m^3

Thus the permissible average phosphorus concentration for the inflow would be 0.0057 mg/L for a mean chlorophyll level of 1 µg/L.

The permissible average phosphorus concentration for the inflow would be 0.045 mg/L for a peak chlorophyll level of 5 µg/L (assumed to be acceptable).

The permissible load, L(P), for a chlorophyll level of 1 µg/L would be 18.6 mg P/m^2/yr or 18.6 x 2 x 10^6 mg/yr = 37 kg/yr. (For Orielton Lagoon with a surface area of 2 x 10^6 m^2).

If the water residence time is decreased to 0.1 yr (inflow volume would then exceed the volume of the lagoon, a turnover of 1000%) the Pi value decreases to 4.6 mg/m^3, but the total permissible phosphorus entering the system increases from 37 kg to 119 kg. These calculations are based on an average chlorophyll level of 1 µg/L which is similar to that in nearby Pittwater.

Using the predicted increase in water movement in the lagoon, if the culvert sills are lowered 30cm, an annual turnover of 353% would produce an inflow of 9.17 x 10^6 m^3 which would give a water residence time, T(W), of 0.283 yr. If the desired chlorophyll level is to be the same as the average for Pittwater of 1 µg/L the maximum permissible average phosphorus concentration can be calculated as follows:-
From Fig 8.4 (OECD, 1982, p. 81):

$$Pi/(1+\sqrt{T(W)}) = 3.5 \quad \text{(where Pi equals L(P)/qs)}$$

$$Pi = 3.5(1+\sqrt{0.283}) = 5.35 \text{ mg/m}^3$$

The total permissible phosphorus load can be estimated from the fact that Pi equals L(P)/qs.

$$L(P) = 5.35 \times 4.642 = 24.84 \text{ mg P/m}^2\text{/yr} = 49.66 \text{ kg/yr.}$$

If a mean chlorophyll level of 5 µg/L is acceptable and the water residence time is lowered to 0.283 yr, a phosphorus loading of 28 mg/m^3 (Estimated from Fig 8.4, OECD, 1982, p. 81) gives a permissible inflow concentration of Pi = 42.9 mg/m^3 .
So L(P) = Pi qs = 42.9 x 4.642 x 2 x 10^6 = 397.9 kg/yr.

With the 1991 phosphorus load for the lagoon (1072.5 mg P/m^2/yr) and a decreased water residence time (0.283 yr), as a result of the lower culvert sills, the predicted phosphorus loading term is 150.89 mg/m^3/yr, and the predicted average chlorophyll level is 15 µg/L (Estimated from Fig 8.4, OECD, 1982, p. 81).

6.10 Diurnal Variation

The diurnal variation study reflected variations within a closed system as there was no tidal influence during that period. The results indicated a range in air temperature from 9.8 to 19.4 ^{0}C with water temperature only varying between 10.6 and 14 ^{0}C.

The variation in pH is shown in Figure 6.17 with a clear trend in all three sites particularly Sites 4 and 8.

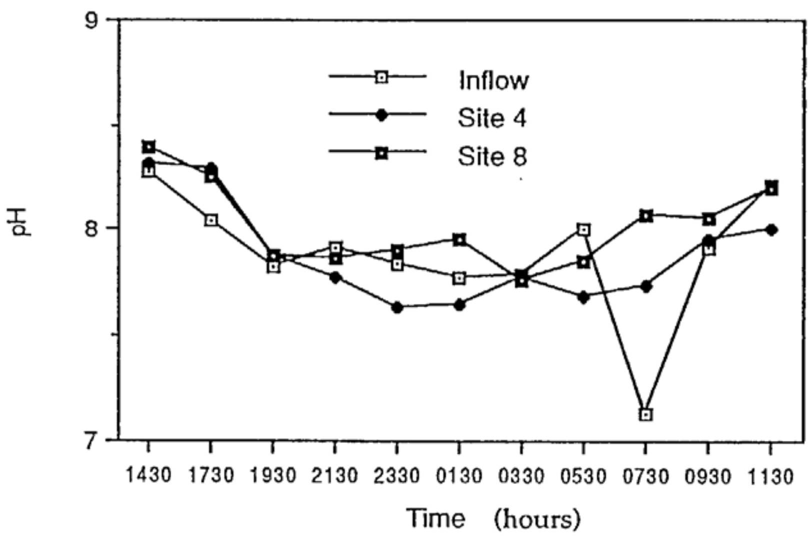


Fig. 6.17 pH Variation Over 24 Hrs, at three sample points, Orielton Lagoon, 1991.

At both these sites there was a distinct trend to a lower pH in the early morning hours followed by a gradual rise to the value that was initially measured. The variation in pH was approximately one unit for all sites with the lowest level during early morning hours and the highest levels during the afternoons.

Chlorophyll levels also showed the same trends at all sites with the highest levels being recorded in the very early morning, approximately 5.30 am, followed by a general decline back to the levels initially measured. The variation of values for chlorophyll levels was shown at Site 4 with a range between 3.3 and 11.89 µg/L and the lowest range between 2.9 and 6.86 µg/L at the inflow. This variation is shown clearly in Fig. 6.18.

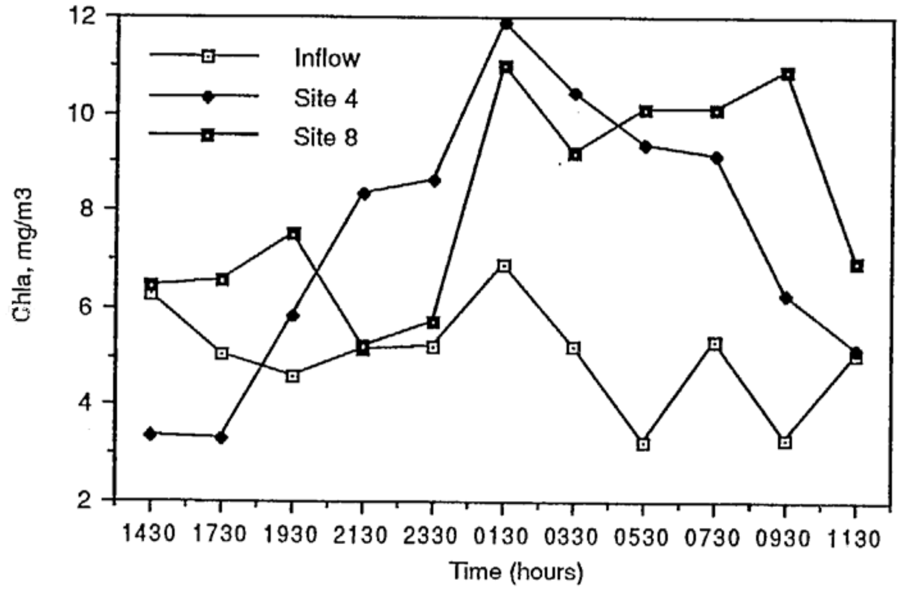


Fig. 6.18 **Chlorophyll Variation Over 24 Hrs, at three sample points, Orielton Lagoon, 1991.**

Simultaneously the dissolved oxygen showed a decrease at about the time that the chlorophyll levels rose and the pH dropped at the three sites measured as shown in Fig 6.19.

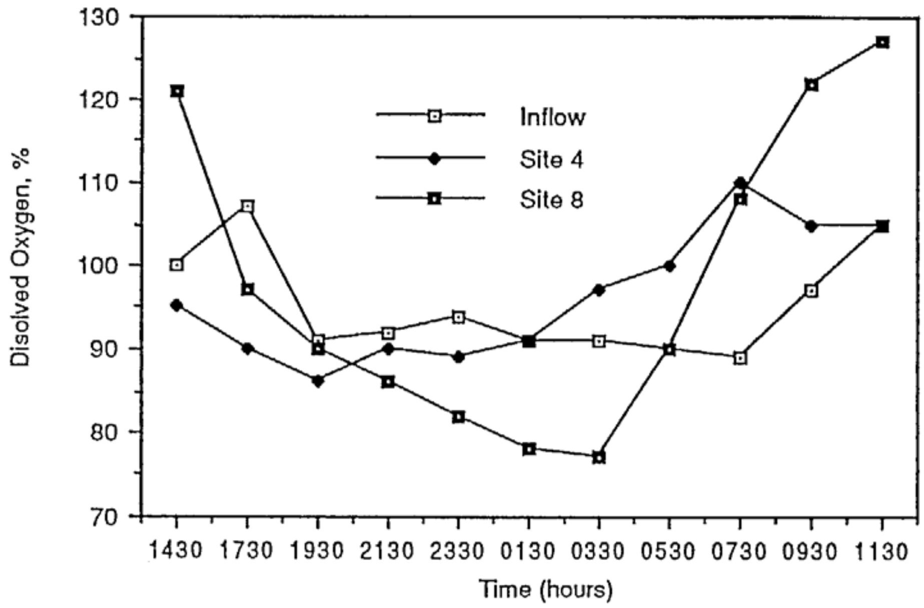


Fig. 6.19 **Dissolved Oxygen Variation Over 24 Hrs, at three sample points, Orielton Lagoon, 1991.**

The drop in dissolved oxygen was greatest at Site 8 and least at the Inflow Site, the latter also showing the lowest values for chlorophyll.

These variations correlate well with each other as increased respiration results in increased carbonic acid and this causes a subsequent decrease in pH. The increase in chlorophyll levels in the early hours of the morning correlate with the decreased dissolved oxygen levels at about the same time. The increase in chlorophyll a levels at this particular time of the day was not expected but may reflect diurnal movement in the phytoplankton populations through the water column.

Variations in turbidity with time are shown in Fig. 6.20.

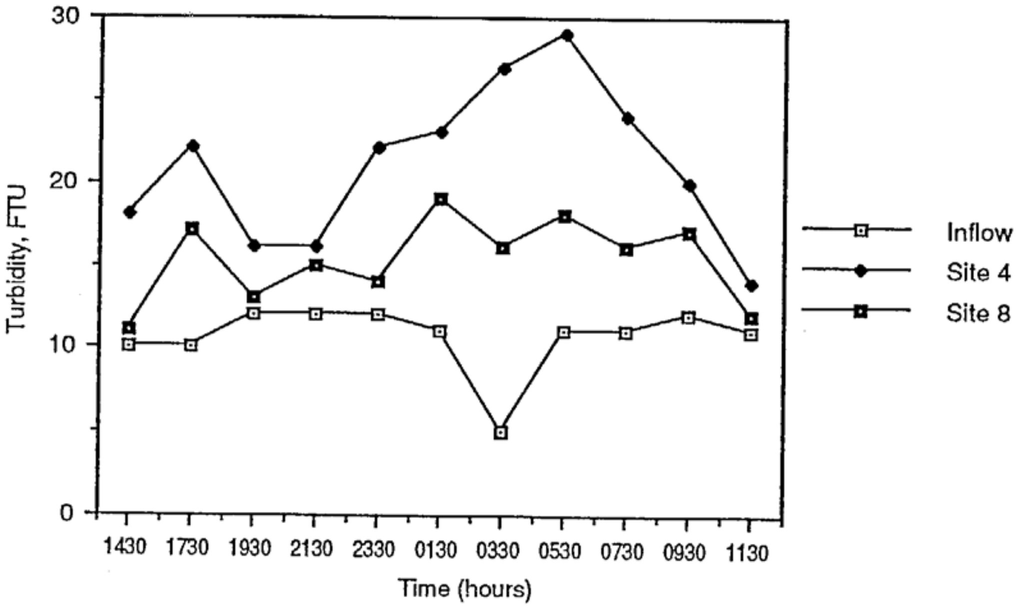


Fig. 6.20 **Turbidity Variation Over 24 Hrs, at three sample points, Orielton Lagoon, 1991.**

The turbidity of the samples showed the greatest range at Site 4, reaching a peak prior to a wind change which left the site in a sheltered position. The variation in turbidity at Site 8 was not as regular, although there was a general trend to highest values during the early hours of the morning, when chlorophyll levels where highest. Site 8 did not appear to be as affected by the wind direction while the inflow was very sheltered and was not subject to the influence of wind. This is shown in Fig 6.20 where the turbidity of the inflow is constant, except for one point, where the turbidity drops to half the previous value. This could be related to the observed movement of filamentous algae through the water column. A similar drop of one unit in pH occurred at the Inflow at 0930 (9.30 am) when the dissolved oxygen was lowest and the chlorophyll level was moving up, but not at a peak.

Due to financial constraints the variation in soluble nutrient content in the water column was only analysed for Site 4; the results are shown in Figs 6.29 and 6.30 .

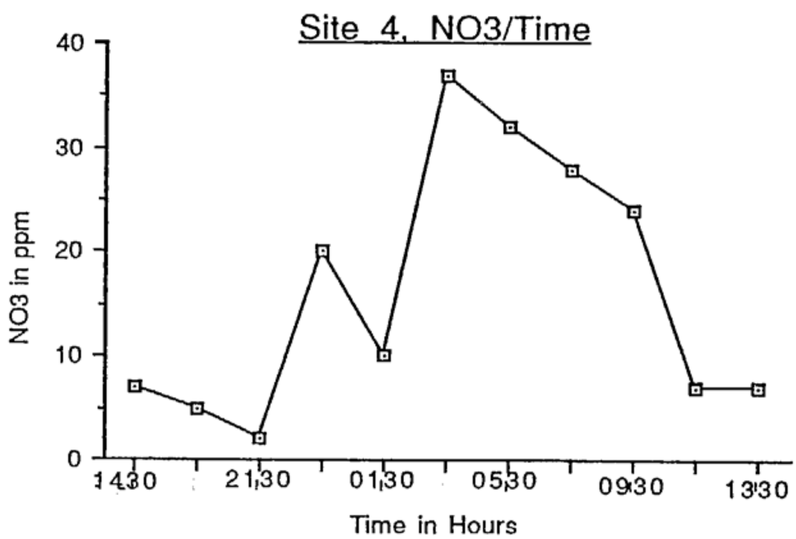


Fig. 6.29 **Nitrate Variation Over 24 Hrs, Site 4, Orielton Lagoon, 1991.**

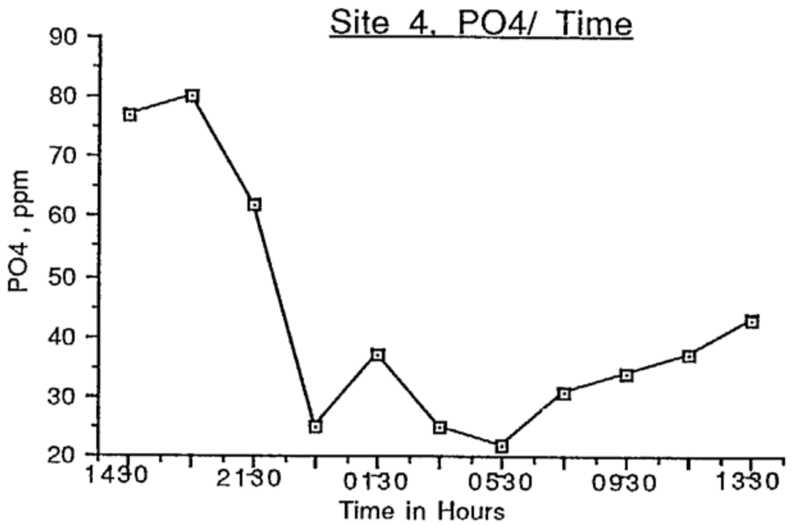


Fig. 6.30 **Phosphate Variation Over 24 Hrs, Site 4, Orielton Lagoon, 1991.**

There is wide variation in the nutrient content over the 24 hr period with the highest levels for nitrates during the early hours of the morning, the same period for lowest phosphate concentrations. The decrease in phosphate levels corresponded to the increase in chlorophyll levels, decrease in dissolved oxygen and the decrease in pH. This suggests that there is an increase in the uptake of phosphate by the increased level of phytoplankton during the night. This again may relate to movement of the phytoplankton through the water column.

The measurement of diurnal variation is important to ensure that the samples collected in the rest of the study are representative of the system and that variation between the monthly samples represents true seasonal variation rather than variation due to sampling time. As a result of this study, the variation that could be expected to occur during any sampling trip was estimated.

The sampling for all the sites was carried out in the same order each month. The variation that would occur during the daytime when monthly sampling took place is shown in Table 6.5. The range of values obtained for the study period (i.e. the ten months) and the inter-site variation is also recorded.

Parameter	Diurnal Range 24 hr Range 9th to 10th Oct, 1991	Diurnal Range Sampling Period Range 9.30am to 4pm	Seasonal Range 9 sites, Feb-Dec 1991
Water Temperature, °C	10.4 to 14.7	11.5 to 14.2	6.7 to 23.5
pH	7.63 to 8.4	7.74 to 8.3	8.04 to 8.68
Turbidity, FTU	14 to 29	12 to 20	8 to 103
Dissolved Oxygen, surface, %	77 to 127	100 to 127	66 to 190
Salinity, ‰	34 to 36	36 to 36.5	29 to 53
Chll, mg/m^3	3.3 to 10.9	3.3 to 6.2 (4) 6.4 to 10.9 (8)	4.5 to 81.7
PO_4, µg/L	22 to 80	34 to 43	<5 to 83
NO_3, µg/L	2 to 37	7 to 7	3 to 42

Table 6.5 Variation in Selected Parameters for Diurnal Study shown against seasonal ranges for 9 sites, Orielton Lagoon, October 1991

The table only includes the values obtained from the sites in the body of the lagoon, Sites 4 and 8, and excludes the information collected for the inflow, as this was only sampled for the last six months of the study. It shows a wider range of values occurring in the seasonal data than in the diurnal range, particularly for the hours when the monthly sampling took place. pH is an exception and shows the same range in the seasonal variation as it does for the diurnal variation. The range for nitrates also is as great over the 24 hours as it is for the seasonal variation. The range in nitrate levels is reduced during the daylight hours used for sampling. The chlorophyll variation for the two sites during the sampling period, is 3 to 4 µg/L, although the level was lower for Site 4 than Site 8.

6.11 Nutrient Balance for the Lagoon.

The daily nutrient balance for the lagoon is shown in Table 6. 6. This indicates a net loss of phosphorus from the system on each sampling event except on the 15/8/1991 when the sample taken was collected from water moving into the lagoon. On that sampling trip the water flowed into the lagoon for about 15 minutes although the predicted tide height for that day was only 1.78 m and sea water would not normally have entered the lagoon.

	Inflow Data			Outflow Data		
Date	Flow Rate cumecs	Total P ppm	Total P kg/day	Depth of Outflow (m)	Total P ppm	Total P kg/day
7 Jul	0.0039	0.05	0.0168	0.03	0.21	6.244
12 Jul	0.0087	0.04	0.03	0.075	0.20	23.507
15 Jul	0.0143	0.037	0.0457	0.075	0.076	8.933
24 Jul	0.002	0.055	0.0095	0.07	0.139	14.733
30 Jul	0.002	0.05	0.0086	0.03	0.20	5.947
6 Aug	0.0032	<0.005	<0.0013	0.08	0.295	38.202
8 Aug	0.0062	0.052	0.0278			
9 Aug				0.145	0.122	38.551
13 Aug	0.0086	0.01	0.0074			
15 Aug	0.1382	0.041	0.489	0.09	0.081	12.516*
16 Aug	0.0668	0.078	0.45	0.055	0.106	7.823
18 Aug	0.0262	0.024	0.0543			
26 Aug	0.0062	<0.005	<0.002	0.04	0.098	4.486
26 Sep	0.0072	<0.005	<0.002	0.03	0.074	2.2
23 Oct	0.00165	0.031	0.004			
	Sewage	Input				
3 Dec	475000 L/d	12.66	5.985			

Table 6.6 Phosphorus Measurements For Orielton Lagoon, 1991. * sample from water moving into the lagoon.

The total phosphorus entering the lagoon from agricultural sources was very low with the highest contribution of 0.5 kg on 15/9/1991, while the daily contribution from the sewage treatment works was considered a steady 5.9 kg. The total phosphorus lost from the system during outflow was up to 38 kg for one day which is equivalent to approximately one week of input from the sewage treatment plant. The phosphorus lost from the system may be slightly overestimated as there is obviously some return of lagoon water on each flood tide. Observations at the outflow culverts indicated an initial movement of dirty water into the lagoon followed by movement of clean water, presumably without a high level of phosphorus.

The estimated annual balance for nutrients for 1991 is shown in Table 6.7. This shows a net retention of 51% for phosphorus.

Month	Agricultural Input (kg)	Sewage Input (kg)	Output (kg)	Retention Rate
Jan	0.0267	179.55	0	100%
Feb	0	179.55	0	100%
Mar	0.041	179.55	0	100%
Apr	0.038	179.55	0	100%
May	0.0937	179.55	0	100%
Jun	0.2074	179.55	0	100%
Jul	0.6839	179.55	357.35	-198%
Aug	2.797	179.55	610.2	-352%
Sep	2.448	179.55	140	33%
Oct	23.4*	179.55	0	100%
Nov	15.19*	179.55	0	100%
Dec	13.91*	179.55	0	100%
TOTAL	58.8	2154.6	1107.4	51%

Table 6.7 Estimated Nutrient Balance For Orielton Lagoon. * Average flow rates for the last three months, others calculated.

The input from the agricultural source for the last three months was much higher than that obtained for the previous months. This was due to the use of historical average flow rates as actual results were not available at the time of writing. The results indicated that 1991 was a dry year, at least until mid October. Despite this there was still a much greater input of phosphorus, in comparative terms (2 orders of magnitude) from the sewage treatment works for these months. This result is obtained even after deliberately overestimating the total phosphorus levels from the Inflow Site.

6.12 Nutrients in Sediments

Total phosphorus and nitrogen in the sediments were measured for the first two months of the study. Later work concentrated on phosphorus.

The results are recorded in Table 6.8

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
	Total P								
Feb	280.8	137.8	108.1	235.9	467.6	115.1	120.2	289.8	298
Mar	166.6	140.2	282.2	111.9	357.2	125.2	197.4	75.1	174
Apr	238.8	142.4	116.7	208.9	375.4	224.4	120.1	195.3	237.9
Sep	318.8	84.7	16.8	ND	341.6	24.8	69.9	ND	ND
Oct	564	506	63	ND	278	80	98	ND	ND
	Total N								
Feb	549	2371	660*	F	F	1737	521	2590	3351
Mar	1015.9	1658	2056.9	1036	675*	F	1002.5	1004.5	F

Table 6.8 The levels of Total P and Total N for sediments from Orielton Lagoon, 1991: µg/ g of dried sediment: *indicates sample overflowed so result is underestimated, ND -Not done, F-Failed.

The values of total phosphorus in the sediment over the year, for six sites, is shown in Fig. 6.31.

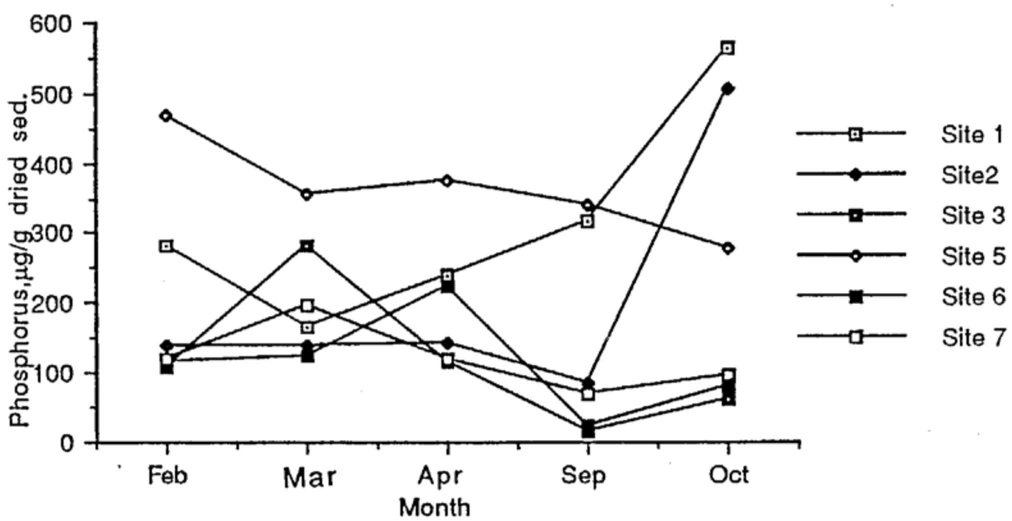


Fig. 6.31 **Total Phosphorus Values in Sediments Collected at 6 Sample Sites, Orielton Lagoon, 1991.**

The levels of total phosphorus at the various sites was relatively constant over the first three months of the study but became quite variable later in the year. There was a dramatic drop in the total phosphorus at Sites 3 and 6, by a factor of ten, between April and September. Sites 2 and 7 also dropped in the corresponding time, but only by 50%, and Site 5 showed a very slight drop. The total phosphorus in the sediments at Site 1 increased slightly in September but values obtained from the samples collected at the end of October all showed an increase, particularly at Sites 1 and 2. October samples were collected after water movement from the lagoon had ceased.

Chapter 7

Results of Biological Study

7.1 Phytoplankton

The population of phytoplankton was recorded throughout the study period and although the sites were treated separately for each month, there did not appear to be any site specific variation, so the results for each month were pooled. This improved presentation of the data, shown in Table 7.1. The main species present were drawn and some photographed, and this pictorial survey is presented in Appendix B.

Phytoplankton	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
BACILLARIACEAE									
DIATOMS									
Chaetoceros spp.	xx	XX	x			x		xx	x
Pleurosigma spp.	x	x	xx	x	xx	xx	xx	x	x
Gyrosigma spp.	x	x	xx	x		xx	xx	x	x
Nitzschia spp.	x	x	xx	x	x	xx	xx	xx	x
Nitzschia closterium	x	x	x						x
Rhizosolenia setigera	x	x	x	x			xx	x	
Rhizosolenia styliformis		x	x					x	xx
Entomoneis sp.	x	x	x	xx	xx	xx	xx	x	x
Naviculoid	x	x	x	x		x	x	x	x
Biddulphia sp.						x	x		x
Thalassiosira sp.							x		
cf. *Leptocylindrus*			x	xx		x	xx	xx	
Berkeleya sp.					X				
Grammatophora sp.					X				
Microflagellates						x	xx	xx	xx
Silicoflagellate, *Ebria*								x	xx
Blue-Green Algae									
Oscillatoria sp.	x	x	x		x	x	x	x	x

Table 7.1 **The dominant species of phytoplankton in Orielton Lagoon, Tasmania, 1991. Relative abundance:- absent , x - present, xx - abundant.**

The main group in the phytoplankton was diatoms but there were changes in species composition throughout the year. During February and March samples were dominated by small chains of *Chaetoceros* spp., a widely distributed centric species (Newell & Newell 1963). There were at least three different species of *Chaetoceros* but they were grouped together for the purpose of the study.

Other species present in February included *Pleurosigma* sp. , *Gyrosigma* sp., *Nitzschia* sp. (at least 3 species), *Entomoneis* sp. (Amphiprora), *Rhizosolenia* sp., and a naviculoid diatom. Some of the common species present are not truly planktonic but are bottom dwellers; e.g. *Pleurosigma, Gyrosigma* and *Nitzschia* which can creep about and are often found in inshore plankton samples (Newell & Newell, 1963). The very shallow nature of the lagoon and the frequent wind activity would account for the presence of these bottom dwellers in the plankton samples.

The blue-green algae *Oscillatoria* sp. was also present in short strands in all samples collected in February but the *Aphanizomenon* sp. reported in February 1986 (G.Hallegraeff, pers. comm.) was not present in 1991.

A similar diatom dominance was observed in the March with *Chaetoceros* sp. most abundant.

The micro-flora changed in April, with the pennate, non-colonial diatoms becoming dominant. *Chaetoceros* spp. were still present but *Pleurosigma* and *Gyrosigma* were most numerous in these samples. *Oscillatoria* was still present in some of the samples examined for April but only as small strands and not dominant.

By May the diatom population had markedly decreased and *Chaetoceros* spp. were not present at all. The phytoplankton was dominated by *Pleurosigma, Gyrosigma,* and an Amphiprora, *Entomoneis* sp. The blue-green *Oscillatoria* was not present in these samples.

In June phytoplankton were relatively low with a pattern similar to that for May, but by July the population had increased and was dominated by *Entomoneis* sp. with *Nitzschia* and *Pleurosigma* also abundant. The large single-celled cf.*Chaetoceros peruvianum* was found in these samples with two species of colonial diatoms, cf. *Berkeleya* sp.

and *Grammatophora* sp.. These colonial diatoms are benthic species not normally found in plankton samples.

August populations were again dominated by *Entomoneis* sp. with *Pleurosigma*, *Gyrosigma* and *Nitzschia* also abundant. A range of other diatoms also became more common including cf.*Leptocylindrus*, a colonial strand forming diatom, *Rhizosolenia* spp. (at least two sp.), *Biddulphia* sp., *Thalassiosira* sp. and a Naviculoid diatom. Smaller plankton species were also present and represented the Silicoflagellates, *Ebria sp.* (a colourless chrysophyte) and cf. *Scripsiella*.

Spring growth in the phytoplankton was dominated by *Chaetoceros* spp., *Leptocylindrus*, *Rhizosolenia*, *Nitzschia*, *Pleurosigma* and *Gyrosigma*. *Entomoneis* was no longer the dominant species but was still present in most samples examined. There was also a large background population of microflagellates present in all samples.

The October micro-fauna showed a dramatic change in species composition with total domination of all samples by cf. *Rhizosolenia styliformis* distinguished by intercalary bands and short, pointed spines on either end of the cell. These formed chains or occurred singly. Previously present species were also apparent but not as abundant as before. Microflagellates were also quite common.

Samples were not collected in November. Mid-December samples (6 weeks after October sampling) did not indicate a dominance by any particular species but showed a mixed population of diatoms with an abundance of microflagellates again. These samples had not been examined in detail at the time of writing.

7.2 Zooplankton

Identification of the zooplankton populations was difficult. The resulting data are incomplete but the information collected is presented in Table 7.2.

ZOOPLANKTON	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Dinoflagellates									
cf *Scrippsiella* sp.	xx	x	x	x		x	x	x	xx
Oval Dinoflagellate	x	x	x					x	x
Copepods									
Acartia tranteri	x	x		xx	x	xx	xx	x	x
Paracalanus indicus							x		x
Harpactacoid		x							x
Tintinnids									
Sp. 1	xx	x		x		x	x		x
Sp. 2	x	x				x	x		
Sp. 3	x						xx		
Encapsulated amoeba	x	x				x	x		
Ciliated flatworm							xx	x	
Ciliated amoeba							x		x
Crab Zoea									xx
Barnacle naupli	x	x		x		x		x	
Naupli	x	x	x	xx	x	x	x	x	

Table 7.2 **The dominant species of Zooplankton in Orielton Lagoon, Tasmania, 1991. Relative abundance:- absent, x - present, xx - abundant.**

Population changes that were noted are described below.

Overall there were no large populations of dinoflagellates in any of the samples collected, but small cf.*Scripsiella* and oval-shaped dinoflagellate (which appeared to be connected to an extra shell in some specimens) collected in October. Both these had cellulose plates enclosing the cell and have been mentioned in the phytoplankton section. Throughout the study there were many crab antennae noted in the samples.

February samples were dominated by tintinnids with three different species present. There were also encapsulated amoeba (P. Tyler, pers. comm.), barnacle naupli, unidentified naupli and the calanoid copepod, *Acartia tranteri*. Harpacticoid copepods were also present as was cf. *Scrippsiella* in most samples.

Tintinnids were less abundant in March and not present by April. Naupli were the dominant zooplankton in April but, as sampling for that month used a phytoplankton net, the high level of phytoplankton recovered may have reduced the collection of zooplankton. However, cf.*Scrippsiella* was present again. An inspection of the water samples taken at the same time did not reveal copepods which were readily seen in samples collected later in the year. This supports the observation that levels of zooplankton were reduced during April.

By May copepod, *Acartia tranteri* was abundant as were naupli. Populations had declined in June but in July the abundance of *Acartia* was again obvious with cf.*Scrippsiella* and other single-cell flagellates present. August populations were similar with an increase in naupli and tintinnids reappearing; ciliated flatworms and ciliated amoebas were also present.

In September *Acartia* had been replaced by abundant crab zoea, with microflagellates, cf. *Scripsiella* and *Ebria* also present. There was also a small oval-shaped organism present but it was difficult to establish the presence of flagella. Material collected live in September for photography showed tintinnids eating diatoms and the presence of a substaintial background population of microflagellates.

The October zooplankton fauna was similar to that in September but copepods and tintinnids were also present. Samples for December have not been examined but there were *Macrobrachium* shrimps present in some samples collected that were readily visible to the naked eye.

Chapter 8

Discussion

8.1 Physical Model

8.1.1 Water Movement in the Lagoon

The results of a current measurement test carried out (ref. Section 5.1) on a day when there was no net outflow, showed a slow, gentle movement of water towards the causeway. This would be expected in view of the small inflow from the rivulet and the direction of the light prevailing breeze. No water movement, independent of that related to wind was observed.

Obvious factors controlling water movement in the lagoon are inflow and outflow, but there is very little inflow for most of the year and no outflow for 8 to 9 months. Water movement in an enclosed waterbody can be controlled by the wind and this will have direct impact on certain physical characteristics such as resuspension of sediment. During the study it was noted that change of wind direction visibly altered the exposed shore and, within one sampling day, the level of water at the northern end of the lagoon changed as the wind pushed it in that direction.

Although waves generated in shallow waters are smaller than waves generated in deep waters, the ratio of surface area to mean depth is a critical factor in the impact that waves have on many aspects of limnological character (e.g. transparency) (Håkanson & Jansson 1983). When the value of $\sqrt{a}/D$ (where a is surface area in km^2, D is mean depth in m) is larger than 3.8 and the lake is larger than 1 km^2, then the resuspension activity due to wind/wave activity will dominate aspects of the limnological character of the water. This value for Orielton Lagoon is 1.114 which indicates that resuspension will be important but not the critical factor.

Resuspension of sediment in the Harvey Estuary is wind-induced as the "estuary lies parallel and exposed to the prevailing winds (SSW and NNW)" (Hillman et al. 1990, p. 45). This has an important impact on the lack of growth of the macro-algae *Cladophora* sp. which is found in the adjacent Peel Inlet. At Orielton, the lagoon is protected to some degree by the existence of shallow marginal platforms similar to those in the Peel Inlet, although the lagoon lies parallel to the prevailing winds (NW in the mornings to SE sea breezes). Resuspension of benthic microalgae in autumn has been significantly correlated with the maximum mean hourly wind speed measured 12 hr prior to sampling in the Harvey Estuary (Lukatelich & McComb 1986) indicating the importance of wind activity in shallow water bodies. High winds present during the April sampling trip could have resulted in resuspension of benthic species. This may have influenced the chlorophyll levels for that month.

It is suggested that wind is the most significant factor affecting water movement at Orielton Lagoon during much of the year and has a significant but not critical impact on the limnological characteristics of the lagoon.

8.1.2 Inflow and Outflow

The results of the modelling program reported in Section 5.2 give some idea of the likely impact of altering the culvert sill level. The exchange rate of water with the existing sill levels is 0% for most of the year with a maximum estimated exchange rate of 23% in August. This gives an average annual exchange rate for the lagoon of 2.4% which is far lower than the 1% exchange rate per tide experienced by Tuggerah Lakes, NSW (Spratt 1991). The enclosed nature of Orielton Lagoon for much of the year reduces the effect of tidal influences in contrast to the tidal range of 10 to 20 cm in the Peel-Harvey System, WA. Both these systems mentioned above have been subject to problems which are the result of cultural eutrophication and both have had important fisheries affected (Hillman et al. 1990, Jackson 1991). In these instances part of the solutions proposed have involved an increase in the flushing rate of the water bodies (Hillman et al. 1990, Jackson 1991) and lowering of the sill level in Orielton Lagoon would have the same effect.

Altering the sill level to 1.5 m (0.3 RL) would lower the existing sills by only 30 cm but would have a dramatic impact on water exchange and retention time. This should lower the levels of nutrients in the system, having a considerable influence on chlorophyll levels and subsequent clarity of the lagoon. The inter-relationship between these factors will be discussed later, after considering the chemical characteristics of the system.

The impact of lower sill levels on the water level of Orielton Lagoon would be to maintain a relatively constant depth, slightly above the sill level of 1.5 m. Tidal influence would reflect the tidal conditions of the day, with some degree of tidal input on most days and a subsequent movement of water to and from the lagoon. The restricted size of the existing culverts would probably prevent any significant daily variation in water depth as the average water depth for each month would vary by only 0.05 m. This would prevent large areas of the mudflats becoming exposed at low tide.

Mudflats have not been considered to be aesthetically valuable and have also been blamed for unpleasant odours at Orielton Lagoon (D.M.R. Files 1982, DEP Files 1990). Using the depth survey produced in 1975 (Steane 1975), the area of mudflats that would be constantly exposed should the sill be lowered has been predicted (Map 6). This area is slightly more than presently exposed when the lagoon is full but significantly less than the area exposed when the lagoon is at a seasonally low level. The current seasonal low level, particularly in March, results in the lagoon level being around 38 cm below the existing sill level.

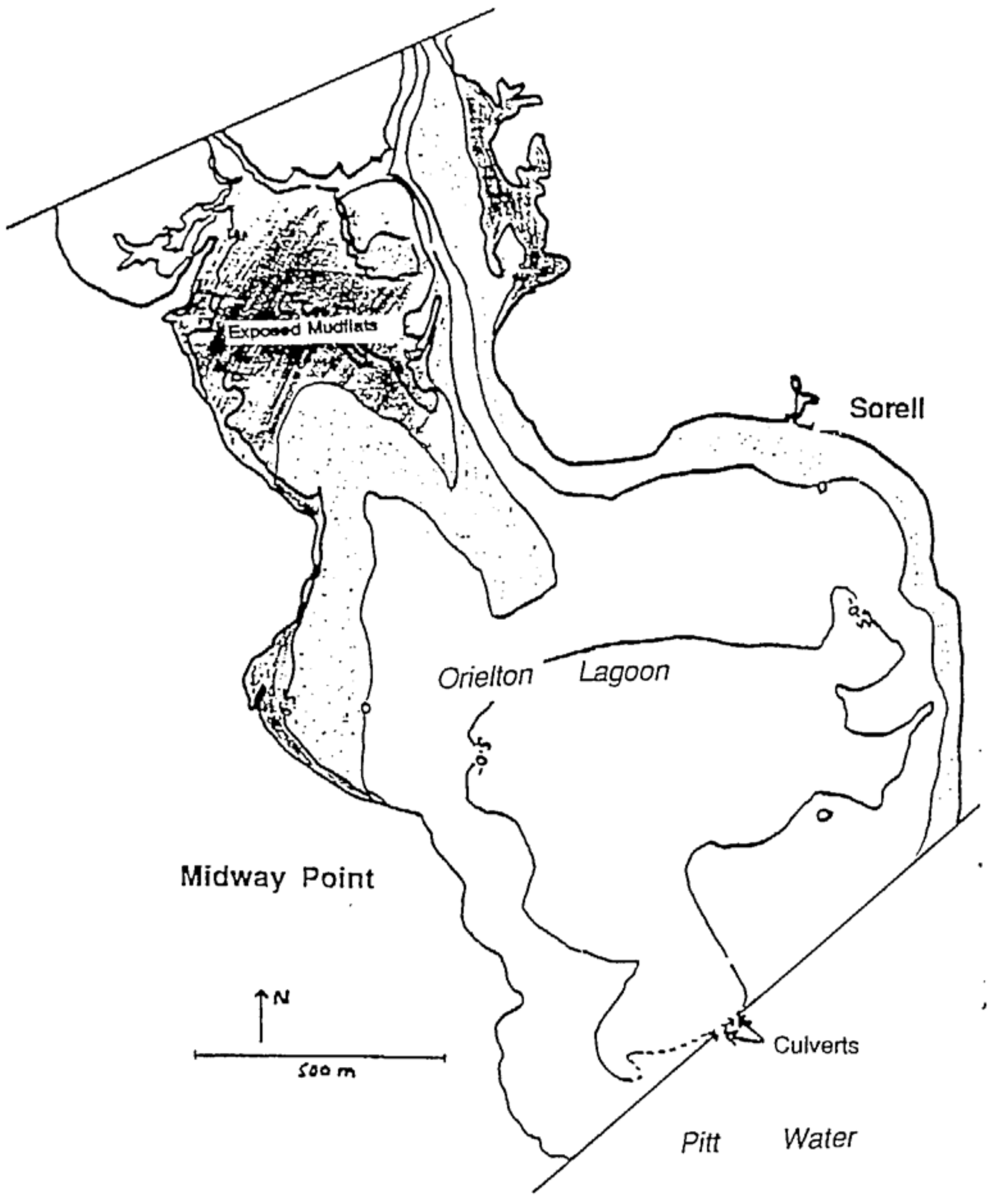
A constant area of exposed mudflats would eventually be colonised by saltbush. Areas in the north of the lagoon charcterised by the remains of *Sclerostegia arbuscula* may be re-established, as this area would no longer be inundated for long periods during the winter months.

Another physical impact of a lower lagoon level would be larger areas of shallow water, favoured by feeding birds, being available during summer and autumn. Prior to impoundment a large spit of land, the "Samphire flats", was exposed as the tide moved in and out and this was described as an important feeding area for the birds (Abbott 1991).

Water movement at the periphery of the lagoon would be difficult to predict if the sill levels were lowered. There is a strong feeling among some locals that a further channel in the SW corner is necessary to encourage water movement in that area (J Reynolds, pers. comm.). However, the shallow nature of the lagoon and frequent winds may be sufficient to provide circulation in the areas not directly influenced by water movement in the existing channels.

8.1.3 Lagoon Depth

Estuaries can be defined as transition zones between inland fresh water and coastal marine waters (McComb & Lukatelich 1982) and are transient in geological terms. In the Pittwater estuary large and dramatic changes have occurred in recent geological time as the Coal River graben was filled with "estuarine and lacustrine sediments throughout the late Mesozoic and Tertiary time" (Harris 1968, p.6).



Map 6 Contour map of Orielton Lagoon form depth survey of 1975. Shading indicates areas predicted as exposed with a sill height on the culverts of 1.5 m. The stippled area shows parts of the lagoon which would only be 30 cm deep. Datum of all RL's is MSL derived from Tide Gauge at Hobart (State Datum).

Harris (1968) also found mottled sands overlying thick shell beds, which occurred at a depth of 30 to 50 cm below the surface.The shell beds were "typically lagoon or estuarine oyster facies" (Harris 1968, p.71) and indicated that the area was subject to a natural degree of sedimentation.

In periods of high flow, i.e. during flood periods, larger particles in the suspended load may be released in the upper reaches of the lagoon. However, the fine clay soils through which the rivulet passes will produce clay particles as the dominant form in the suspended load and these would generally settle more rapidly in water than individual particles of the same size. Clay particles have surface electric charges and form flocs (Håkanson & Jansson 1983) and this flocculation is enhanced by increased salinity and high algal concentration. The salinity in the upper reaches of the lagoon between Shark Point Road Bridge and Brinktop Road Bridge is the same as the salinity in the body of the lagoon. There was evidence of a salt wedge at the bottom of the stream near Brinktop Road Bridge during one sampling trip in winter but the tidal influence in these upper reaches would normally ensure saline conditions in the area. This supports the idea that most of the material carried by the stream would, in most circumstances, be deposited in the upper reaches, before reaching the main body of the lagoon in normal flow conditions.

There would still be some deposition of finer material in the main body of the lagoon as flood water velocity further decreased and as salinity and algal concentration changes had effect. The change in flow rate through the lagoon would depend on the existing lagoon depth and the height of the tide on the Pittwater side of the causeway. The capacity of the culverts should not be limiting as they have been designed to cope with the maximum predicted flood (DMR Files 1953).

The results of the depth survey reported in Section 5.3, while not conclusive, present strong evidence that the lagoon is not silting up. This work indicated that there were at least seven well spaced areas where there has been little change in depth in the past 16 years. There were several areas where there had been a slight increase in the depth in the channels which may still be undergoing redefinition after the impoundment in 1953. This evidence also supports the idea that there is limited sedimentation in the lagoon and that some of the material brought into the lagoon during floods may pass through before sedimentation can take place (DEP, 1986). The lack of change in depth may be insignificant in geological terms but should reduce concerns that the lagoon will silt up in the short term.

8.1.4 Organic Matter in the Sediments

Nitrogen in organic matter in the sediments is broken down by nitrification and this is more important in shallow zones where oxygen is constant and where the pH is less than 9 (Håkanson & Jansson 1983). These conditions exist for large areas of the lagoon. In most areas, the level of organic matter is below 5%. Only Site 5 and Site 9 had a significant level of organic matter. In the case of Site 5 this related to a higher clay whilst samples from Site 9 consistently included vegetation which accounted for the higher organic level. Organic content reported in Baltic Sea sediments ranged between 14 and 25 % (Josson et al. 1990) but values between 4.9 to 10% were reported in Lake Burley Griffin (Rosich & Cullen 1980a), where the amount of organic matter in the sediments, was considered an important factor in relation to phosphorus release from the sediments, in this fresh water lake.

In a study on the absorption and release of phosphorus from sediments in a stream receiving effluent, the level of organic matter was found to be related to the absorption rate of phosphorus in the sediment. This could be related to the formation of clay-humic acid-phosphate complexes (Fox et al. 1989). Site 5 had high clay and organic contents and consistently high phosphorus levels. Cosser (1989) found high organic content (12 to 14%) and fine clay were associated with the dead-end locations in residential canals and these locations were associated with high sulphur levels. Similar characteristics were again found at Site 5 which had a strong hydrogen sulphide smell associated with sediments collected there throughout the year.

8.1.5 Particle Size Distribution

The test results described in Section 5.7.2 show that particle size distribution in the lagoon sediments, ranges from predominantly sand through to sediments dominated by silt and clay. The samples showing higher silt content are limited to Sites 5, within the main body of the lagoon, and 9, in the upper reaches of the lagoon. These areas, particularly the latter, would be expected to be zones of siltation from sediment settling from inflow during flooding.

Other sites showed a consistently high sand content suggesting limited siltation.

There was some significant variation in the particle size distribution noted at Site 1, near the south-west corner of the lagoon, where the percentage of sand increased between February and March samplings. This suggests a movement of silt, most likely due to wind induced waves. A limited reduction in silt content was noted at Site 2, near the outlet culvert, between the May and September samplings. This was considered to be associated with water movement in the channels of the lagoon in net outflow periods during July, August and September.

Harris (1968, p 36) described sand as the dominant grain size in Pittwater with clay fractions becoming important in the "upstreams, backwaters, tidal weed banks and saltmarshes". The current study has confirmed a similar sediment distribution with no obvious change during the intervening 22 year period.

The level of clay in the sediments at a particular site is important in that phosphorus can bond to the clay lattice (Fox et al. 1989) and as such, is important in determining the absorption and release of phosphorus from the sediments. However, it appears that there is limited clay sediment at Orielton Lagoon and hence the sediment loading of phosphorus would be similarly limited. This supports the findings of sections 8.1.3 and 8.1.4.

8.1.6 Water Temperature Variations

During the 1991 study water temperatures varied from 7 °C to 23 °C as reported in Section 5.4. This was a similar range to that described by Harris (1968), Buttermore (1977) and Hallegraeff et al. (1986). Historical data indicated variability in the temperature of the water in Pittwater from 1949 to 1956 with summer temperatures reaching 23°C in 1950 (Hallegraeff et al. 1986). Similar high temperatures were recorded in parts of Orielton Lagoon during December 1991 but there was no odour as predicted by earlier reports which claimed 18°C as the critical temperature at which hydrogen sulphide odours are released (Spratt 1984).

However, the high temperatures recorded during 1991 may have been responsible for the observed death of a large number of crabs and the death of at least one eel. The piles of dead crabs are shown in Plate 3. There was a slight odour associated with the decomposing crabs but it was not offensive enough to be reported to the DEP by local residents. Inspection of the crabs confirmed that the shells were not simply moults and contained decomposing tissue.

Plate 3. Piles of dead crabs littering the shoreline of Orielton Lagoon, December 1991, following a series of hot days.

Although thermal stratification was not recorded in Orielton Lagoon the presence of an anoxic layer following a series of warm, still days suggests thermal stratification may occur. Daily temperature stratifications in Lake Alexandrina a shallow freshwater lake, in South Australia, were recorded on very calm days but were absent when the lake surface was rough (Geddes, 1984). These variations in water temperature were reflected in the variation in the oxygen concentrations in the lake. The presence of a shallow anoxic layer over the sediments in a water body can influence the absorption and release of nutrients from the sediments (Rosich & Cullen 1980b).

8.1.7 Turbidity, Secchi Disc Transparency and g440

Turbidity, Secchi Disc Transparency and g440, reported in Sections 5.5, 5.6 and 6.4 give a quantitative estimation of the water clarity, one aspect of water quality which is important for aesthetic reasons as well as being a significant element in controlling productivity in an aquatic system.

The turbidity in the system varied throughout the year with maxima around 90 FTU in April and December which related to chlorophyll peaks.

The Secchi Disc (SD) measurements are recognised as a quick and acceptable means of defining water clarity (OECD 1982) and are useful because comparable values can be found in literature. SD transparencies for Tuggerah Lakes were measured at 1.0 to 1.8 m over 13 months (Kirk 1986), considerably greater than that measured in Orielton Lagoon where the range extended from 0.35 m to 0.65 m. Similar low values for SD transparencies have been recorded in Lake Alexandrina (Geddes 1984) which has recorded SD transparencies of 19 cm, associated with high chlorophyll levels of 32.2 µg/L.

The high turbidity and low SD transparencies for Orielton Lagoon reflect a system in which light may act as the limiting factor in the development of benthic flora on suitable substrate at various times of the year. Beds of *Zostera* and *Ruppia* reported by Buttermore (1977) for 1976 do not appear to be present in the areas previously identified as containing these species. This was confirmed on several of the sampling trips by the use of a simple viewing tube.

The shallow nature of much of the lagoon meant that when turbidity was lowered the sediments may receive sufficient light for photosynthesis and this may be a factor in the development of the *Cladophora* sp. which is initially a benthic species. The thalli of *Cladophora* are usually sessile and attached to the sub-stratum by long rhizoidal branches (Smith 1955) and many are perennials. Reports of marine species of *Cladophora* indicate that liberation of zoospores takes place during the spring tides and that they develop into rhizoids after zoospore swarming ceases (Smith 1955). The lowest mean turbidity for the system was in September which was approximately six weeks prior to the appearance of the mats of *Cladophora* sp. and would be the time when zoospores would settle and develop rhizoids.

Light has been identified as the most important factor controlling productivity changes in seagrass in the Swan-Canning estuary and in the standing crop of *Ruppia megacarpa* in the Blackwood River estuary (McComb & Lukatelich 1986). The development of *Cladophora montagneana* has been found to be light limited under the first 2 cm or so (McComb & Lukatelich 1986), which supports the notion that light could be of considerable importance in the development of the algal mats of *Cladophora* sp. in Orielton.

The poor clarity of the water in the lagoon is obvious to motorists driving over the causeway. Following an anonymous report to the author in December, a water sample was photographed (Plate 4). The chlorophyll level for a water sample collected at that time exceeded 80 μg/L. The correlation between turbidity and chlorophyll levels is discussed later. The relationship between wind induced resuspension of sediments and turbidity is an area for future work.

Plate 4. A bottle of water from Orielton Lagoon in December, 1991, indicating the intense discolouration of the water. The sample was collected on a calm day following a period of calm hot days and does not reflect turbidity due to resuspension of sediments.

The g440 values for Orielton Lagoon reflect a low gilvin level, with filtered water being very clear. This indicates that most light is absorbed or scattered by particulate matter (Geddes 1984). The g440 level dropped in December when turbidity and chlorophyll levels were at a peak, but a similar relationship was not shown in April when the chlorophyll levels were high.

The fresh water from Orielton Rivulet had higher g440 levels than the lagoon waters although the turbidity was usually lower. This higher value in the freshwater input may account for the increase in g440 in the lagoon during September, as this followed the peak freshwater input.

Although turbidity readings and g440 results describe water clarity, the SD transparencies are frequently used to identify the trophic status of a water body. Based on the OECD figures (OECD 1982) an SD transparency between 0.4 and 0.5 m places the water body in the hypertrophic level, with an SD transparency between 1.5 to 4.0 m indicating a eutrophic level. It would appear that Orielton Lagoon lies in the eutrophic to hypertrophic range and tends towards the hypertrophic category for much of the year .

8.2 CHEMICAL MODEL

This section discusses the results of the chemical properties reported in Chapter 6 and the interrelationships between the various parameters.

8.2.1 Salinity

The lagoon was hypersaline for a large part of the year, with salinities ranging between 28‰ and 52‰. There was no drop in the salinity to 2‰ which is close to fresh water, as previously reported (Buttermore 1977). This could reflect the low rainfall that the district received throughout the winter months in 1991. The salinity of Pittwater as recorded in historic CSIRO data ranged from 30 to 38 ‰ (Hallegraeff et al. 1986) and salinity measurements of Orielton Lagoon in 1967 indicated a salinity of 44 ‰ (Harris 1968) which is in the range recorded in the present study.

The salinity of the system is a controlling factor in the development of *Nodularia* akinetes in the Harvey estuary in Western Australia (Hillman et al. 1989) and thus the development of the *Nodularia* blooms. Although the nitrogen to phosphorus ratio appears to be the factor controlling the development of summer blooms of nitrogen-fixing blue-green algae in freshwater systems and in the Baltic Sea Proper, salinity appears to be more important in the Kattegat (Higher salinity) (Graneli et al. 1990). The relationship between salinity and the development of blue-green algae may account for the recorded observation of the blue-green algae *Aphanizomenon* sp. in Orielton Lagoon during February 1986 (G. Hallegraeff, pers. comm.). Rainfall and stream flow records indicate that there was heavy rainfall and a high flow rate in December 1985 and a further large input of fresh water in January 1986. This may have been sufficient to lower the salinity to levels suitable for the development of the algal bloom. Improved tidal exchange in Orielton may prevent the occurrence of the lower salinities that appear to be needed for blue-green algal blooms.

8.2.2 Acidity

The pH in the lagoon, as reported in Section 6.2, showed very little fluctuation in the monthly readings, ranging from 7.82 to 8.64. A variation in the pH from 7.6 to 8.35 was noted during the diurnal study. In both cases the variation is low and probably represents a range of values that could occur throughout the lagoon at any time.

The pH of the lagoon was reported in 1975-6 (Buttermore 1977) and ranged between 6.79 - 8.40 with the lowest value recorded in August. The variation in pH in 1975-6 was higher than the variation measured during 1991 and is possibly a reflection of higher rainfall during the earlier study.

The pH of a water body can affect the rate of release of phosphorus from the sediments (Furumai & Ohgaki 1989) and high pH in calcareous sediments increases the concentration of phosphorus in the solid phase. Thus the high pH, usually above 8.2, found in Orielton Lagoon together with the high calcium content of the sediments would imply that the sediments would absorb, rather than release phosphorus in the given conditions.

8.2.3 Dissolved Oxygen

Consistently high levels of dissolved oxygen have been recorded in this study (ref. Section 6.3) and in the study undertaken in 1975-6 (Buttermore 1977). There was a drop in the dissolved oxygen during the winter months which corresponded to a reduction in the chlorophyll levels. The dissolved oxygen showed marked diurnal variation but this was slightly less than that recorded during sampling throughout the year. The reduction in dissolved oxygen during the middle of the night is related to the respiration of organisms and has implications for the release of nutrients from the sediments. Low oxygen regimes are also important in determining the level of the zone responsible for reduction processes in the mudflats. The sulphur-reducing bacteria responsible for producing hydrogen sulphide move to the surface and extend into the water column as the waters above the sediments become anoxic (Odum 1972). Thus low oxygen regimes during the night may enhance the production of hydrogen sulphide during calm conditions when the waters remain unaerated by wind action. The development of an anoxic layer above the sediments in December, following a series of days of light or nil wind, would enhance the release of phosphorus and contribute to the available phosphorus in the water column, which in turn would increase the chlorophyll levels in the lagoon. Such a layer may also be responsible for the development of the hydrogen sulphide odours that have been reported in the past (ref. Section 3.3). This layer may also develop at other times in the year when conditions are favourable, increasing the contribution from internal loading, but this stratification was not observed at other sampling times.

8.2.4 Chlorophyll Levels

The chlorophyll levels found in Orielton Lagoon, as reported in Section 6.5, are variable with values ranging from 3 μg/L to 81 μg/L. The lowest monthly average of 8.67 μg/L occurred in October, with a peak monthly average of 41.76 μg/L in December.

Previous studies have not measured the chlorophyll levels in the lagoon but a study by the CSIRO, in nearby Pittwater during 1985-86, gave a range of values between 1 and 7.5 μg/L, with peaks in late December and much lower peaks in late autumn. Values obtained from the same area during the present study were below 2 μg/L. These figures highlight the difference between the low levels in the open water and the extremely variable but typically high levels in the lagoon.

In the Peel-Harvey Inlet system chlorophyll levels peaked at values up to 550 μg/L during blooms of the blue-green algae *Nodularia* while peak values between 60 and 80 μg/L occurred with diatom blooms which preceded the blue-green algal blooms. This is the pattern in the Harvey Estuary where high turbidity due to frequent wind-stirring and the occurrence of blooms reduces the macrophytic growth (McComb & Lukatelich 1983). Similar peak values for the diatom bloom in Orielton were recorded in 1991. High levels of chlorophyll have been recorded in Lake Alexandria (Geddes 1984) and have been associated with the development of a filamentous green algae, *Planctonema lauterbornii* Schmidle, which gave peak chlorophyll values up to 70 μg/L, during December.

The chlorophyll levels in a water body have been used extensively as an indication of its trophic level and as a measure of productivity (Lee et al. 1978, Forsberg & Ryding 1980, OECD 1982, Jeffers 1980 , Lee & Jones 1984, Jones & Lee 1986).

As well as the chlorophyll levels, other factors are frequently incorporated when the trophic state is determined (Forsberg & Ryding 1980). These include the phosphorus and nitrogen concentrations and the transparency, usually the Secchi disc transparency. Using the chlorophyll levels and the classification system outlined by OECD (OECD 1982) Orielton Lagoon falls in the eutrophic range, (peak chlorophyll 9.5 to 275 µg/L) but at the lower end of the scale.

8.2.5 Nutrient Levels

When estimating the available nutrients in a water body either the soluble nutrient or the total nutrient is measured. The soluble mineral components (forms of inorganic nitrogen, orthophosphate) are generally assumed to control growth rates (OECD 1982). It is also recognised that, with increasing trophy, a correspondingly high fraction of easily metabolised mineral components become available for algal growth (OECD 1982). In management terms, it is often desirable to determine the limiting nutrient in the system and, as nutrients are required in the inorganic form, the inorganic N to P ratio is often considered more meaningful (OECD 1982, Jeffers 1980). However, when measuring the soluble nutrients, laboratory values may not reflect the actual levels, as there can be rapid recycling of the nutrient, which is not identified in measurements (Harris 1986). The spring growth of algae is based on nutrients accumulated during the winter and so concentration ratios in the winter surface water may be used to indicate the nutrient limiting spring blooms (Granéli et al. 1990). In Orielton Lagoon the winter period is the time when there is a reduced level of nutrients available due to the movement of water from the lagoon. There may also be a seasonal variation in the nutrient that is limiting (Jeffers 1989). This was shown in the Peel-Harvey system where nitrogen was found to be the most likely limiting nutrient during summer and autumn (Lukatelich & McComb 1986).

Reduction of the "limiting" nutrient is a primary means of eutrophication control.

Soluble phosphates and nitrates in the water column were measured as part of this study and results have been reported in Section 6.6. Values for phosphorus as orthophosphate ranged from 6 to 83 µg/L with an average value of 24.2 µg/L.

A report by Buttermore for the DEP in 1975 recorded orthophosphates below 10 µg/L (DEP Files, 1975). Phosphates reported in 1976 (Buttermore 1977) ranged between 10 to 180 µg/L. In 1984, orthophosphates in the water column were all below 30 µg/L (Spratt 1984). Values from the DEP report in 1986 (DEP 1986) recorded values for orthophosphates between 100 to 400 µg/L (av. 330 µg/L), considerably higher than other reported levels. A laboratory report (22 to 23/6/1987)(DEP Files, 1987) presented orthophosphates below 10 µg/L.

This wide range of values for the same water body suggests that either the levels can vary widely under different conditions or that some of the extreme results may be unreliable. Concentrations measured during this study compare with the lower range of results reported by others and are comparable to those found in the Peel-Harvey Inlet. The levels of phosphorus as phosphate reported in the Harvey Estuary were in the range 1 to 210 µg/L (average 20 µg/L) and in the Peel Inlet ranged between 1 to 216 µg/L (average 16 µg/L) (Lukatelich & McComb 1986).

However, values reported in an estuarine system in South Africa ranged from 121 µg/L to 1320 µg/L (Emmerson 1989). The estuary with the high phosphate level was enriched with urban sewage and industrial effluent . The 1986 concentrations in Orielton Lagoon are within this range.

Phosphorus as phosphate, measured in Pittwater, during this study ranged between 9 and 23 µg/L with an average of 14 µg/L. Historic values for phosphates in the same system, measured between 1949 and 1956, were in the range 0 to 40 µg/L with an average of approximately 10 µg/L (Hallegraeff et al. 1986). This indicates been little change in the phosphate levels in the Pittwater area in the last 35 years, although the data for the present study were only available for four months. Longer term monitoring of the Pittwater estuary may give a more accurate estimate of any possible changes to phosphate levels.

The historic and present phosphate levels found in Pittwater are approximately half those found in Orielton Lagoon in 1991.

Nitrate levels in the lagoon ranged from 2 to 40 µg/L, with the lower values being close to the lower level of detection. Values reported from Pittwater between 1949 to 1956 are in the same range (0 to 35 µg/L) (Hallegraeff et al. 1986).

The nitrate levels previously recorded in Orielton Lagoon, are higher than those found in this study, ranging from 10 to 640 µg/L in 1987 (DEP Files 1987). Levels at the lagoon outflow varied from 30 to 780 µg/L (av. 129 µg/L) in 1986 (DEP 1986). Some sampling for the 1986 study took place when there was a high flow rate in the rivulet and the values obtained could reflect the freshwater input. Results from the present study showed a higher level of nitrate in the rivulet (Fig 6.12) which decreased as the study progressed. Nitrate levels reported by Buttermore (1977) were below 100 µg/L.

The report in 1984 (Spratt 1984) recorded a range for nitrate values between 300 to 5800 µg/L, far in excess of any reported elsewhere, suggesting some degree of contamination. Contamination can arise if sample bottles washed in weak nitric acid, are not thoroughly rinsed in distilled water. Acid rinsed bottles are used when water samples are collected for heavy metal analysis (Franson 1990).

Nitrate levels reported in the Peel Inlet varied from 1 to 2506 µg/L (average 115 µg/L), but were substantially lower in the Harvey Estuary; 1 to 490 µg/L (average 53 µg/L). Higher levels of ammonium nitrogen were reported in the Harvey Estuary (Lukatelich & McComb, 1986). Nitrate levels at the higher end of the scale were related to river flow in winter but levels at other times of the year were almost undetectable. High nitrate levels recorded at Orielton Lagoon outlet in 1975, were also associated with high levels in freshwater from Orielton Rivulet (Buttermore 1977). In late summer there was an increase in levels following the collapse and decomposition of blue-green algal blooms (Lukatelich & McComb 1986).

Nitrate/nitrite levels in three South African estuaries were higher than those reported in Orielton Lagoon, ranging from 69 to 723 µg/L (Emmerson 1989). Higher levels in the upper reaches of the estuaries suggested strong nutrient enrichment there.

In common with the phosphate results, nitrate levels reported at Orielton Lagoon vary widely. Relatively low levels were recorded during the current study. It is apparent that nitrate levels are particularly variable and influenced by the conditions in the water column at a particular time. There was no large freshwater input throughout the current study period so there would have been no increase in nitrate levels due to that source. Similarly, low values were measured in the Harvey Estuary during years when there were low flows in the Murray River (the main freshwater source for that system) (Lukatelich & McComb 1986).

Of particular interest was the decrease in levels of phosphate and nitrate in inflow to Orielton Lagoon following initial flow from winter rain. This clearly showed a "first flush" of nutrients from surface water run-off. The inflow from the rivulet in June featured nitrate levels in excess of 1500 μg/L and phosphate levels of around 700 μg/L. By July the phosphate levels had dropped to approximately 100 μg/L whilst nitrates were still around 800 μg/L. This indicates the nature of the freshwater inflow as relatively nitrate rich but phosphate poor in comparison to sewage inflow with a high phosphate to nitrate ratio (Cordery 1972, OECD 1982).

The nitrogen to phosphorus ratio has been used to predict the nutrient whose control would be most advantageous in reducing the symptoms of eutrophication. It has been inferred that nitrogen can limit productivity in marine environments. Investigations into whole ecosystems are rare although there is currently a full scale experiment on marine (brackish-water) nutrient limitation being undertaken at the Himmerfjärd basin in the Baltic Sea Proper. Results of this full scale experiment will indicate whether control of nitrogen input will reduce the symptoms of eutrophication found in that area (Granéli et al. 1990). This clearly will have implications for control of eutrophication in othe marine environments such as Orielton Lagoon. However, reduction of nitrogen input in the Baltic Sea follows reduction of phophorus input by nutrient removal in sewage treatment plants (Granéli et al. 1990).

In theory, the ratio between the nutrients in the external supply should determine which element, ultimately limits production within the ecosystem (Granéli et al. 1990). Granéli et al. (1990) suggest that concentration ratios in the surface winter water may be a better indicator of the nutrient which is most limiting for the spring bloom. In the present study, the ratio between the soluble nutrients was established for the ten months of the study; reported in Section 6.7. The annual variation appeared to be related to changes in the chlorophyll levels. This is despite the lack of a positive correlation between soluble nutrient levels and chlorophyll levels.

The average N:P ratio for the Orielton Lagoon system was calculated at 1.13:1 (Section 6.7) based on the figures from this study. Using values from the DEP report, (DEP 1986) the ratio was 1.64:1. This indicates that, although the actual values may differ in the reports, the relative ratios of the two nutrients being examined are the same. Values for this ratio below 5 to 10 denote a nitrogen-limited system (Jeffers 1989) which is typical of a marine environment (Lee et al. 1978, Rosenberg et al. 1990).

Thus the limiting nutrient at Orielton Lagoon appears to be nitrogen.

However, in some estuarine systems, phosphorus and silicon may be the limiting nutrients (Emmerson 1989) and, in conditions of generally high nutrients concentrations and phytoplankton biomass, light may limit the system (Lukatelich & McComb 1986). Furthermore, "even when another nutrient such as nitrogen is (occasionally or normally) the limiting factor, phosphorus may still be made to play the role of limiting factor through appropriate control" (OECD 1982, p. 10).

For example, despite the fact that nitrogen is usually the limiting factor in marine environments, blooms of diatoms are controlled by the phosphorus levels. Phosphorus was shown to be the limiting nutrient in the growth of the macrophyte *Cladophora* sp. in the Peel Inlet (Gordon et al. 1981). Both diatoms and *Cladophora* sp. are significant symptoms of eutrophication at Orielton Lagoon.

Thus, even in a marine environment such as Orielton Lagoon, where nitrogen may be the limiting nutrient, the control of phosphorus to the system is of critical importance.

At Orielton Lagoon the nitrate levels are not particularly high. During the study period the levels of nitrate in the lagoon were not markedly different to the external waters of Pittwater. This could indicate that a significant source of nitrate input is from freshwater stream flow and there may be a similar level of input from other catchments. The sewage effluent would also be a source of nitrate, but nitrate levels in the sewage would be expected to be relatively low (Cordery 1972, OECD 1982). Control methods to reduce nitrate levels from stream inflow could include the development of shallow wetlands at the upstream end of the lagoon.

The concentrations of phosphorus in the lagoon are significantly higher than in Pittwater. These levels appear to be influencing the development of the major symptoms of eutrophication, namely diatom blooms and macro- algal growth. The major source of phosphate appears to be sewage and some control of eutrophication could be achieved by removal of the source.

8.2.6 Total Phosphorus

Levels of total phosphorus in the water column, of the lagoon were measured. This was part of the work undertaken to establish a nutrient balance and is reported in Section 6.8. Levels ranged from 40 to 250 µg/L, with the maximum value recorded close to the sewage outlet in August. There was a trend to higher values in June.

After June the values decrease, probably as a result of greater influence from the tidal input; movement of water had begun before July samples were collected. Thus the total phosphorus in June should represent a maximum value as there is an accumulation of input over the previous nine months.

The total phosphorus reported in an earlier study (DEP 1986), indicated levels from 300 to 1000 μg/L at the lagoon outlet. These values are much higher than those recorded in the present study and higher than most levels noted in literature. No reason for the discrepancy could be determined.

Values ranged from 8 to 793 μg/L (average 93 μg/L) in the Peel Inlet and 6 to 4178 μg/L (average 163 μg/L) in the Harvey Estuary (Lukatelich & McComb 1986). The higher levels in the Harvey Estuary were associated with high phosphorus loading from the Harvey catchment, the generally larger phytoplankton biomass and the higher resuspension rates. The peak values occurred during the late spring and early summer periods (Lukatelich & McComb 1986).

Total phosphorus levels in Lake Alexandria (Geddes 1984) ranged from 89 to 385 μg/L while the range for three estuaries in South Africa was 208 to 1498 μg/L (Emmerson 1989). The levels reported in South Africa correspond to those from the 1986 report on Orielton Lagoon (DEP 1986).

The total phosphorus in a system is another parameter that can indicate the trophic status of the system. The total phosphorus in a eutrophic system can vary between 16 and 386 μg/L (OECD 1982) and on this basis Orielton Lagoon definitely falls within the eutrophic classification.

8.2.7 Relationships Between Physical, Chemical and Biological Factors

The relationships, reported in Section 6.9, between the physical, chemical and biological parameters measured during the study, indicated several statistically significant correlations.

These included strong relationships between water temperature and turbidity, phosphates and nitrates. The relationship between turbidity and chlorophyll levels was also very strong and this is demonstrated graphically in Figs 5.26 and 6.10. An increase in phytoplankton (chlorophyll levels), which results in an increase in turbidity and a reduced SD transparency, results in a higher use of soluble nutrients and a subsequent decrease in nutrient levels. This relationship can be used to explain the negative relationship between water temperature and nutrient concentration, as phytoplankton concentrations decreased in conjunction with declining water temperatures thus allowing the soluble nutrient concentration to increase.

A statistically significant relationship between salinity and chlorophyll levels was indicated by the Spearman Rank Coefficient. This can be seen by comparing graphs 6.1 and 6.10. A gradual decrease in chlorophyll levels was noted during winter and early spring, increasing again in December due to seasonal changes. Salinity decreased during winter and early spring due to the inflow of fresh water and high spring tides; it increased again during December, due to evaporation and the seasonally lower tidal inflow. Thus the apparent relation between salinity and chlorophyll is not a direct causative relationship but one that has arisen because of the nature of the impoundment.

The correlation between pH and chlorophyll levels is possibly a reflection of the relationship found in the diurnal study, where pH levels dropped as chlorophyll levels increased. The average monthly pH was slightly lower for April and December corresponding to peaks in chlorophyll levels. This also corresponded to higher levels of dissolved oxygen in the surface water. This relationship reflects the increase in photosynthetic activity during these times, resulting in the production of carbonic acid thereby lowering the pH. pH was found to be a contributing factor in the chlorophyll levels at an estuarine station in an Indian river subject to high levels of industrial and domestic effluent (Joy et al. 1989) but, was not considered a controlling factor in the Peel-Harvey Inlet (Lukatelich & McComb 1986).

8.2.8 Nutrient and Chlorophyll Levels

The relationship between nutrient loads and chlorophyll levels in aquatic systems is well documented (Forsberg & Ryding 1980, Cullen & Smalls 1981, OECD 1982, Lee & Jones 1984). However, in the present study there was no clearly defined relationship between the soluble nutrients and the chlorophyll levels (ref. Table 6.4). This may be the result of the changes brought about by the combined influence of cooler winter temperatures, increased water movement and the continuous supply of nutrients from the sewage treatment plant. The peaks of chlorophyll corresponded to lower levels of phosphate, while higher levels of phosphate in June corresponded to lower levels of chlorophyll. Nitrate levels did not vary to the same degree and showed no real trend. There was a slight increase in nitrates during July, as chlorophyll levels continued to decrease. However, a complicating factor at this time of the year is the influx of sea water and the consequent flushing action that must take place. The highest level of water movement took place during August, a month with low chlorophyll levels, low phosphate concentrations and the lowest total phosphorus values for the study period.

Probably the single most important factor controlling relationships in the Orielton system is the influx of sea water during winter. This appears to reduce the level of nutrients in the system rather than providing an influx, as is the case in the Peel-Harvey Inlet, where the winter flow from rivers is the main source of nutrients (Lukatelich & McComb 1986).

The impact of the drainage from agricultural areas in the Orielton system has been estimated and will be discussed later (ref. Section 8.2.10).

After late September 1991, Orielton Lagoon became an enclosed system and the influence of sea water was reduced to a few isolated inflow events. During this period, after water movement from the lagoon had ceased, the level of total phosphorous and phosphate increased slowly but chlorophyll levels remained constant. By mid-December chlorophyll levels had risen to a maximum which indicated a late spring bloom but nutrient levels were not available for that month. The bloom could be related to the build up of available nutrients in the lagoon after outflow had ceased.

8.2.9 Nutrients in the Sediments

The sediments of a system can act as a sink or a source for nitrogen and phosphorus (Håkanson & Jansson 1983). Their importance as a source of nutrients for the eutrophication process has become apparent, as water bodies have failed to respond as predicted following a reduction in external nutrient loads (Ahlgren 1980, Cullen 1986, Jost et al. 1991). As the importance of the internal loading of phosphorus in marine and freshwater systems has become better understood, work on the chemistry involved in phosphorus release from the sediments has increased. The simplified view which regarded the issue as a reduction process has been expanded to include the multi-consequential role of different biological processes, particularly the role of bacteria, the distribution forms of phosphorus and the transport processes across the sediment-water interface (Enell et al. 1989).

The levels of phosphorus in the sediments are thus clearly important in any attempt to control the level of eutrophication in a system.

Nutrient levels in Orielton Lagoon sediments analysed in this study ranged from 75 to 564 μg/g dried sediment for phosphorus (Feb. to Oct.) and 521 to 2056 μg/g dried sediment for nitrogen (Feb. to March) as shown in Table 6.8. A considerable variation was noted in nutrient levels both from site to site at each sampling time and also on a seasonal basis.

Sediment nutrient levels had been reported in 1984 (Spratt 1984) but the lack of units, methodology and site locations make the data difficult to present and interpret.

In the 1986 report (DEP 1986) nutrient levels were recorded from sediments collected in September, 1986. The levels of total phosphorus in the sediments ranged from 1 to 680 μg/g dried sediment and for nitrogen between 420 to 2650 μg/g dried sediment. Except for one site, values for phosphorus from 1986 (Orielton study) were all below 40 μg/g of dried sediment. The sample collected in the SW corner of the lagoon, near the sewage treatment plant outlet, yeilded 680 μg/g of dried sediment for phosphorus. This is not far from Site 1 in the present study, which gave values ranging from 166 to 564 μg/g of dried sediment.

Phosphorus levels measured in sediment during the first three months of the current study were much higher than those reported in 1986, whereas nitrogen levels were similar. This led to a focus on measurement of phosphorus levels during the remainder of the current study period.

Total phosphorus concentrations in samples of sediment collected during September 1991 were lower than those from the first three months of the year at Sites 2, 3, 5, 6 and 7, as shown on Fig. 6.31. There was a significant increase in levels in the October samples from Sites 3, 6 and 7 and a dramatic increase in the level at Site 2. The concentration of total phosphorus showed a steady increase through the second half of the year at Site 1. These results correlate well with the observation of relatively low total phosphorus measured in sediments during September in the 1986 study.

The overall nutrient levels in sediments at Orielton Lagoon also correspond with values found in Tuggerah Lakes (Cheng 1987) where the values for nitrogen and phosphorus showed a variation associated with the nature of the substrate, the vegetation and the distance from the shore. The levels ranged from 12 to 642 μg/g of dried sediment for phosphorus and 18 to 3058 μg/g of dried sediment for nitrogen.

The phosphorus values reported in the sediments at Tuggerah Lakes were highest in the mud and lowest in the sand, but levels in the underlying clay sediments were high. Nitrogen levels were also highest in the mud sediments and lowest in the sand (Cheng 1987). The value for the sand sediment was 32 μg/g and for the clay-mud component the phosphorus level was 337 μg/g dried sediment in Tuggerah Lakes. This corresponds with observations for some sites in Orielton Lagoon. Site 5 was consistently higher in silt-clay and phosphorus, and Sites 6 and 7 which were higher in the sand component had lower nutrient levels.

Similarly, sediments from two freshwater lakes in Australia, Lake Burley Griffin and Lake Ginninderra, were found to have phosphorus levels between 340 to 455 μg/g which were described as "at the lower end of the range and typical of those lakes in which the inflowing waters carry a high load of suspended solids" (Rosich & Cullen 1980a, p. 107). This would suggest that the phosphorus concentrations in Orielton Lagoon are also at the lower end of the scale in relation to these types of lakes.

Rosich & Cullen (1980a) reported a seasonal variation in total nitrogen which was accounted for by increased denitrification.

The levels of nitrogen in the sediments in Orielton Lagoon showed a wide spatial variation but, as figures for the February and March samples of the present study (520 to 2057 μg/g of dried sediment) corresponded to the September results of the 1986 study (420 to 2650 μg/g of dried sediment, DEP,1986) it was assumed that there was no seasonal variation. Further testing of the sediments from the spring samples would be needed to confirm this.

The change in phosphorus levels in the sediments could be accounted for :

a) by sediment movement around or out of the lagoon; or

b) by the release of phosphorus from the sediments into the water column and its subsequent removal from the lagoon as phytoplankton or soluble phosphorus.

Alternative a) would be feasible if there was a movement of sediment-bound phosphorus from some areas of the lagoon during late winter and early spring . This material may have left the lagoon or moved to areas unsampled in the present study. Further work involving sedimentology techniques would be necessary to determine the exact fate of the material. Turbidity values of the water leaving the lagoon during July and August suggest some movement of the sediment; and the silty-clay layer appeared easily dislodged. Field observations with the viewing tube showed a clear sandy bottom in some areas of the lagoon which had previously been covered in a brown-grey material. This was particularly obvious at Site 7 where the shallow depth, approximately 0.3 m, enabled the sediment to be easily seen on still days.

This movement of the finer sediment fraction would result in a change in the silt-clay to sand ratio at some sample points. However, results from particle size distribution in the sediments did not indicate a significant change in the sand to silt/-clay ratio from the early months of the study through to September.

Alternative b) is also supported by observation and references from literature. Phosphorus in sediments may be mobilised into soluble phosphorus (Håkanson & Jansson 1983) and the rate of mobilisation is dependent upon the nutrient level in the water column.

The levels of total phosphorus in water leaving the lagoon during July and August were higher than the levels measured at the sampling points remote from the outlet. However, by September outlet levels had dropped to values similar to those at the sample points. Lower levels of total phosphorus in the water in August may allow the continued release of phosphorus from sediments through September.

After water movement from the lagoon had ceased, at the end of September, the nutrient gradient between the sediment and the water column was no longer sufficient to promote the release of phosphorus. The sediments then began to act as a sink for the nutrients, with the result that sediment nutrient levels rose in October. This suggestion is supported later by a nutrient balance for the lagoon presented in Section 8.2.10.

In the Harvey Estuary, phosphorus was taken up by diatoms during a spring bloom and recycled from the sediments after the death of the bloom, providing a ready source of nutrients for the *Nodularia* bloom (Lukatelich & McComb 1986). In Orielton Lagoon there was no spring bloom, possibly due to different temperature conditions. However, the development of a diatom bloom in December could have utilised some of the sediment bound phosphorus. This is considered unlikely at Orielton Lagoon as a ready supply of soluble nutrients would be available from the sewage inflow and further conversion of nutrients from the sediments would be unlikely, due to the predicted build up of nutrient levels in the water at this time of the year. The calcium-rich, basic nature of the sediments supports the suggestion that the sediments act as a sink for phosphorus.

The two alternatives are by no means mutually exclusive and both processes may act in tandem, the importance of each depending upon various chemical, hydrological and meteorological conditions.

If there is movement of sediment-bound phosphorus from the lagoon during periods of flushing, the problem of nutrient release may be readily solved by an increase in the amount of flushing. In-situ work on sediment nutrient release and sedimentology studies may give a clearer indication of the fate of the nutrients in the lagoon sediments but the expense involved in a series of complicated tests may be better spent following the management strategy outlined in Section 10.3.

The nutrient levels associated with the mud and sand-mud component in Tuggerah Lakes, 337 µg/g of dried sediment, were considered sufficient to warrant removal by dredging the area (Spratt 1991). Based on these figures the only areas of Orielton Lagoon which would qualify for dredging would be Site 1 and the SW corner of the lagoon. These are not areas mentioned in the report put forward to the Sorell Council by Spratt (1991) which supported dredging. Furthermore, studies of various lakes in Western Europe (Sas 1990) showed that levels above 1000 µg/g of dried sediment were likely to show several years of net annual phosphorus release after the removal of external nutrient sources. Levels below 1000 µg/g of dried sediment, still well above levels at Orielton Lagoon, were considered low.

8.2.10 External Nutrient Sources and the Nutrient Budget

Research over the years has indicated the importance of external nutrient sources in the processes of eutrophication. Most of these nutrient sources have anthropogenic origins, hence eutrophication is frequently seen as totally anthropogenic. However, there is evidence that blue-green algae blooms occurred as a "natural phenomena in the Baltic Sea and were recorded as far back as the middle of the 19th century" (Granéli et al. 1990, p. 145). Sediment studies have shown periods of abundant algal growth,in some Swiss lakes, in the Middle Ages or before (Jost et al. 1991). There are other examples of naturally induced eutrophication such as that produced on an isolated lake in Illinois, by a transient population of wild ducks (Cooke & Williams 1973).

Estuaries are particularly prone to eutrophication as they are already among the most intensively fertilised environments on the earth. They receive the accumulated run-off from large catchment areas and as such are particularly sensitive to land management practices in the watershed (Nixon 1991).

As such, land management is considered one of the main issues to be approached in attempting any reversal of the eutrophication of waterways, be they marine estuaries, natural lakes or man-made reservoirs. Land management issues are not only concerned with agricultural use but include the use of land for urban and industrial uses. Nutrients involved in the eutrophication process can be found in the run-off from any of these sources. These include industrial effluent, sewage effluent, effluent from intensive animal husbandry and storm water. In this study the relative contribution of nutrients from a point source and non-point source is examined with relation to a phosphorus budget for the lagoon.

The nutrient budget for the first nine months of 1991, described in Section 6.11, clearly indicates that in this year the major contributor to the phosphorus load was the steady input from the sewage treatment plant.

An annual average input from the agricultural sources was estimated at 178 kg of phosphorus assuming an average daily flow of 0.113 cumecs (calculated from 17 years of data. RWSC, 1991) and an average phosphorus concentration of 50 µg/L in the rivulet. This level is conservatively higher than the actual average value obtained for 1991 to allow for the increased component under flood conditions which did not occur during 1991. Values for the mean phosphorus concentration in a river entering Lake Burley Griffin ranged from 17 µg/L in a drought to 257 µg/L in a flood situation. Similarly there was a difference in the phosphorus input from the Little River catchment in Sydney following a bush fire when the phosphorus in the stream went from 6 µg/L to 68 µg/L immediately after a fire (Cullen & Smalls 1981). The value of 50 µg/L is thus slightly higher than average for an Australian soil but much lower than can be expected in a flood situation. The flow rates for Orielton Rivulet for 1991 were lower than average so the 1991 average phosphorus input from the rivulet would be expected to also be lower than the long term average value.

In Britain, water draining clay soils averages about 50 μg/L of phosphorus and 100 to 200 μg/L from sandy soils (Cooke & Williams 1973). The phosphorus levels in the rivers feeding the Peel-Harvey estuary system in W.A. indicated a much higher level of phosphorus from sandy soils which drained intensively farmed land (Birch 1982). As Orielton Rivulet passes through clay soils which are not intensively farmed and has a low average flow rate it is not unexpected that the input of phosphorus in normal years is low. A report from the Land Management and Chemistry Branch of the Tasmanian DEP, commenting on likely phosphorus levels in the Orielton Rivulet, stated that "Water phosphate levels measured in the adjacent Coal River Catchment are negligible. Whilst soils of the Coal River catchment are similar to those of the lagoon catchment, farming is more intensive" (DEP Files 1990). It was thus expected that phosphorus levels in the Orielton Rivulet would be even lower than the known low levels in the Coal River.

The nutrient budget for Orielton Lagoon for 1991 suggested an annual input of phosphorus from Orielton Rivulet of 58.8 kg and an input of 2154.6 kg from the sewage treatment plant for the same period. The estimation for the input from the sewage is expected to be lower than the actual value as the volume of effluent used in the analysis was based on flows obtained in 1985. The population of the area has increased in the last five years.

Phosphorus levels in the sewage have been based on the value 12 660 μg/L measured on 3 December 1991. This is higher than DEP values of 5 200 to 16 000 μg/L, average 10 400 μg/L (DEP 1986) but considerably lower than 36 500 μg/L measured in 1984 (Spratt 1984). Values from St. Marys Water Pollution Control Plant, Sydney averaged 10 500 μg/L of phosphorus as phosphate (Cordery 1977). Total phosphorus in raw sewage shows some temporal variation (Cohen 1972) which may be reflected in the effluent from the simple treatment plant at Midway Point.

While the values obtained from this study identify the effluent from the sewage treatment plant as the main contributor to the phosphorus levels in Orielton Lagoon there is evidence that the input from non-point sources can vary dramatically, particularly during flood periods as particulate material is brought into the system (Cullen & Rosich 1979). This material would include sediment-bound phosphorus which could later be available for plant growth. However, at Orielton Lagoon the larger particulate matter would be deposited in the upper reaches where the fresh water from the rivulet would meet the salt water from the lagoon, and stream velocity would be sharply reduced.

The 1986 study (DEP 1986) indicated a phosphorus concentration in the Orielton outflow greater than that of the fresh water inflow, which would suggest an outflow of phosphorus during the period of high flow. In the present study there were no flood periods but the measured levels of phosphorus leaving the lagoon were consistently higher than those measured in the body of the lagoon. This would indicate a net loss of phosphorus from the lagoon during the periods of outflow.

Table 6.7 shows the annual input, output and retention rate for the lagoon and indicates the importance of outflow in altering the phosphorus levels. The negative retention rate in August clearly compensated for the input from the sewage and such an export of phosphorus should also compensate for flood periods. The negative retention in July and August could account for the reduced phosphorus levels found in the sediments in September as there was no other source of nutrients throughout that period. The retention rate for phosphorus entering Lake Burley Griffin over a period of 18 months during 1975/76 was 40%. The highest input for this system was from rural lands during two floods, one a 1-in-10 year and the other a 1-in-24 year flood. However the retention rate for the system varied from 65% with normal flow to 91% in drought conditions (Cullen & Rosich 1979). The retention rate in Orielton Lagoon is thus lower than that in Lake Burley Griffin particularly as 1991 was a dry year.

Considering the sewage treatment plant as the only source of nutrients, the estimated change in total phosphorus levels in the lagoon can be calculated for a period of no outflow by estimating the sewage input for that period of time and dividing the result by the total volume of water in the lagoon. Using this calculation the predicted increase in total phosphorus over two months would be 138 μg/L, which is greater than the observed change in total phosphorus from the end of August until the end of October.

The change for that period of time was 62 μg/L, from 85 μg/L at the end of August to 147 μg/L at the end of October. Although the chlorophyll levels did not rise in that time, phosphorus may have been taken up by the developing *Cladophora* sp which appeared two weeks after the October samples were collected. *Cladophora* sp. would not have been included in the chlorophyll measurements. Phosphorus concentrations in the water, at the time algal mats were present, were only sampled once and the 89 μg/L recorded was considerably lower than the level which would be predicted from the calculations described above. This suggests that phosphorus was taken up by the macro-algae and not available for phytoplankton. Total phosphorus levels for December were not available at the time of writing.

8.2.11 Nutrient Balance and Water Exchange

Calculations described in Section 6.12 indicated that there is considerable movement of phosphorus out of the system when there is some water exchange with Pittwater. Estimates of the water exchange from the model described in Sections 5.2 and 6.12 show a water exchange of 23% in August while estimates of water exchange with lower culvert sills increased to 61% in July (Table 5.2). Such an increase in water exchange at lower sill levels would be likely to dramatically lower the retention rate of phosphorus in the lagoon, particularly as water exchange would exceed the present maximum exchange rate in 7 months each year, with positive exchange in all months.

This higher exchange rate would significantly affect the levels of nutrient in the water column in the short term and probably the sediments in the longer term. Reduced chlorophyll levels and increased water clarity would be expected to result. This is discussed in Section 8.2.12. The importance of improved flushing is discussed further in Chapter 10 .

8.2.12 Phosphorus Loading, Predicted versus Actual Chlorophyll Levels

Using figures from phosphorus concentrations in the input from the sewage treatment plant and models outlined by the OECD report (OECD 1982) chlorophyll levels were predicted as presented in Section 6.10.

The predicted and the actual chlorophyll levels were similar and, as the OECD figures have been prepared for freshwater systems, the predicted chlorophyll values are remarkably good. The summer maximum chlorophyll level in the present study was 81.76 μg/L and the predicted level was 85 μg/L. The predicted mean value was 25 μg/L and the actual mean value for the system was 18.98 μg/L. The small difference between the predicted and the actual chlorophyll levels is surprising as the system appeared from earlier calculations to be nitrogen-limited, whereas the OECD (1982) survey excluded those which were considered to be nitrogen-limited.

Calculations in Section 6.10 have predicted total phosphorus loads to develop different chlorophyll levels in the lagoon with various water retention times. To reduce chlorophyll levels to those in Pittwater (1 to 2 µg/L) the total phosphorus input would need to be limited to 37 kg which is very low relative to the present load from the sewage. It is also lower than the predicted average agricultural input of 178 kg which is much higher than that which actually entered the system from agricultural sources in 1991 (estimated 59 kg in 1991). It seems that the total phosphorus from the agricultural source may be more than sufficient to raise the chlorophyll levels over those in Pittwater.

If an average chlorophyll level of 5 µg/L is acceptable, the permissible phosphorus load is much higher, at 119 kg. While this would adequately account for the input from agricultural sources for some years, it would be exceeded by only one month of sewage input.

The effect on the chlorophyll levels of lowering the culvert sills can be predicted from these graphs. A low chlorophyll level of 1 µg/L with lower water residence time (lower sill levels) would give a permissible total phosphorus load of 49.1 kg/yr. This is not a large increase on the permissible load when the sills are at the present sill height and reflects the log-log relationship between chlorophyll levels and phosphorus concentrations. This level is still in excess of the predicted average agricultural input although it may be larger than the actual agricultural loading during dry years.

Even if an average chlorophyll level of 5 µg/L is acceptable, the permissible phosphorus load would be 398 kg for the lowered sill case. This would be expected to account for input from agricultural sources, even in flood situations, but the level would still be exceeded by only two months of sewage input.

Lowering the culvert sills but maintaining the present level of phosphorus input would give a decrease in the average chlorophyll level from the present predicted 25 µg/L to 15 µg/L. This should make a significant difference to water clarity as turbidity and chlorophyll levels are directly related. This predicted chlorophyll level is still significantly greater than that in Pittwater and the lagoon would still be expected to have a lower clarity relative to Pittwater which would be readily discernible to the general public.

Based on the above discussion, lowering the sills alone would not be sufficient to reduce the chlorophyll levels to those approaching Pittwater but removing the sewage input would reduce the levels slightly. To achieve water quality similar to that of

Pittwater it would be necessary to both remove the sewage source and also to lower the sill level of the outlet culvert.

8.2.13 Plankton Changes Throughout the Year

The changes plankton have been outlined in the results and show a succession of algae and zooplankton, particularly a marked change in the diatom community. The sharp chlorophyll peaks in April and December corresponded to similar peaks described by Jeffrey (1980) in phytoplankton populations off the east coast of Australia at Port Hacking station, 100 m depth and 12 km off the coast of NSW. These peaks have been "associated with periodic intrusions of cold nutrient rich 'slope' water into the lighted surface areas of the continental shelf " (Jeffrey 1980, p. 263). Further work showed that the chlorophyll increases occurred only in the larger, diatom-rich fraction of the phytoplankton. The diatoms that dominate the spring bloom differ from those that appear in the autumn bloom (Jeffrey, 1980).

The population changes at the Port Hacking coastal station are best summarised in the following quote

> ".........sequence of small chain-forming diatoms beginning the spring diatom bloom, followed by larger centric diatoms, then mixed populations of coccolithophorids, microflagellates and dinoflagellates. Dinoflagellate abundance was strongest in mid-summer, with diatoms virtually absent............Generally, diatoms reappeared in May (autumn), with dominance of species largely different from those which began the spring bloom. The annual cycle ended with a minimum of all species in the winter." (Jeffrey 1980, p. 264).

In the cycles of phytoplankton found in Orielton there was a similar variation in the diatom species throughout the year as well as a succession of algal types. The variations described for Port Hacking emphasise the summer months, one of which (January) is unfortunately missing in the present study. However, the smaller chain-forming *Chaetocerus* sp was abundant at the beginning of the spring followed by the larger centric diatoms in October, with the large *Rhizosolenia* sp. dominating all samples examined. The bloom in December was dominated by microflagellates and single-celled *Pleurosigma, Gyrosigma, Navicula,* and *Nitzschia.* Other common species were the centric diatoms including *Rhizosolenia, Biddulphia, Entomoneis.* While this succession is not precisely that described by Jeffrey (Jeffrey 1980) it follows the basic pattern, particularly with the difference in phytoplankton in the autumn bloom, i.e. *Gyrosigma, Pleurosigma* and to a lesser extent *Chaetoceros.*

The phytoplankton populations in water moving in and out of the Peel-Harvey system in WA were dominated in summer by the same genera as were found in the December samples in Orielton, namely *Pleurosigma*, *Gyrosigma*, *Nitzschia*, and *Navicula*. The microflora in winter was dominated by *Chaetoceros*, and *Rhizosolenia*, with *Nitzschia*, *Navicula* and *Melosira* (Black et al. 1981). However, the winter samples in Orielton did not correspond being dominated by *Entomoneis*.

The diatoms are a class which is dominant in eutrophic water bodies, although the species composition varies geographically, and some species are better indicators of eutrophication than others (Jeffers 1980). The presence of the blue-green algae *Oscillatoria* sp. in Orielton Lagoon is also a symptom of eutrophication (Olsén & Willén 1980).

Diatoms in freshwater reservoirs can cause serious problems associated with taste, odour and blockage of filters when they occur in large numbers. They also form a brownish film on submerged plants and rocks (Anon 1990), as seen in Orielton Lagoon. Consequently, a reduction in the diatom population may improve the appearance of the substrate in the lagoon.

The presence of diatoms is generally more desirable than an abundance of blue-green algae, dinoflagellates and green macro-algae. Diatoms have a high nutritive value for zooplankton while the other species are associated with toxicity, scum formation and accumulation on the shore (Granéli et al. 1990). In this respect the abundance of diatoms in Orielton may be regarded as a preferable situation.

One possible effect of increasing the clarity of the Orielton water could be the reappearance of macrophytes. This may result in regrowth of the *Zostera* beds reported in 1976 (Buttermore 1977) but could also include nuisance growths of *Cladophora* sp if high phosphorus levels are maintained.

The zooplankton fauna in Orielton Lagoon was dominated by a succession of species throughout the year with tintinnids being replaced in April and May. There appeared to be an increase in zooplankton abundance in May which may have followed the phytoplankton bloom in April. Results of zooplankton collection in mid-summer did not show a very high population of zooplankton, from a quick examination of samples despite the phytoplankton bloom in December. The most abundant copepod was identified as *Acartia tranteri* and was totally dominant in winter samples but was replaced by crab zoea, in September and October samples, probably a reflection of the numerous *Paragrapsus gammardi* found in the lagoon. There was an apparent lack of larger dinoflagellates and no large predatory zooplankton, such as *Daphnia* sp. The zooplankton fauna may have been subject to heavy grazing by the fish population in the lagoon, although zooplankton populations have been found to be depressed in highly eutrophic environments (Harris 1986).

Although no fish were sampled the feeding activities of the cormorants and personal observations confirmed the presence of fish in the lagoon. One preliminary plankton sample, in December 1990, collected an atheriniid "hardy- head" *Atherinosoma microstoma* (Günther) a small fish commonly found in estuaries (Fulton 1989). Other fish observed during the year included a small flounder, a dead eel (after a series of hot days in November 1991) and the migratory species *Galaxias maculatus* in the upper reaches of the lagoon, just below the gauging weir. Shoals of small fish were occasionally seen during sampling trips but these could not be identified. As mentioned in the history there is considerable anecdotal evidence that there was a considerable fish population in the area in the early days of impoundment.

The relationship between fish, the abundance of zooplankton and their grazing effect on phytoplankton populations has been utilised in biomanipulation experiments (Lampert 1988, Shapiro & Wright 1984). These experiments have shown that there is an important relationship between the density of particular types of fish and the abundance of zooplankton. The size of *Daphnia* sp. found in lakes has been found to vary according to the presence or absence of fish (Moss et al. 1991). The water clarity in Round Lake improved after the fish fauna was changed to a predominantly piscivorous population but the improvement was not permanent; water quality deteriorated to premanipulation conditions after 2 years (Shapiro & Wright 1984). Further discussion on the interaction between fish and zooplankton populations is covered in Chapter 10.

Other factors influencing the distribution of zooplankton in Orielton Lagoon could include the high temperatures and the high salinities encountered in the lagoon.

8.3 Odour and Rainfall Patterns

Anecdotal evidence suggests that the odours associated with Orielton Lagoon occurred more frequently in dry, hot years. To assess the possible relationship between the climatic conditions and the occurrence of the odour, available climatic records were reviewed in conjunction with information on odour complaints from the DEP files (DEP 1972 to 1991) previously discussed in Section 3.3.

Rainfall records for Sorell were available (K. Allen, pers. comm.) from 1887 to 1990 and were divided into monthly figures. The flow rate for Orielton Rivulet was available from 1972 (RWSC 1991) and the summer monthly weather, from October to March, was available from the Bureau of Meteorology "Monthly Weather Review" (1975 to 1991).

The results of this examination are summarised in Table 8.1. which includes the date of the smell complaint, the annual rainfall, the month with the greatest flow rate, the maximum flow rate for that month, the volume of that maximum flow relative to the total lagoon volume and the monthly conditions for that time.

Date Odours Reported	Annual Rainfall (mm)	Month of Max Rain, Rain (mm)	Inflow as Proportion of Lagoon Volume	Prevailing Summer Weather Conditions
Dec 1959	524.5	Jan, 94.9	N.A.	N.A.
Mar 1973	571.9	Oct, 95.2	50%	
1974	669.6	July, 141.8	90%	
1975 April to Nov	701.6	Oct, 122.4, Nov, 106.2	32% 96%	Oct temp low, Nov.above average rain. Dec. temp slightly up
Sept 1978	555.0	Nov, Feb, 83.2		
Nov 1981	566.2	Aug, 112.0	109%	Nov. average, temp, low rain
Dec 1983	529.0	Apr, 81.8		Average temp up slightly
Feb Mar 1984	533.6	Sept,103.6	58%	Feb.temp up March temp down
Dec 1985	669.9	Dec, 230.8	115%	Cool
	461.2	Oct, 80.2	19% 9.96	Oct. temp average,rain up Nov. temp slightly up rain low Dec. temp up by ≈ 1°C low rain
Jan 1990	496.4	July, 101.2	14%	Slightly above av. temp.

Table 8.1 Dates of Odours Reported compared to rainfall, flood flows and weather conditions.

The complaints from 1959 concerned "slimy weed" (DMR Files, 1960) which washed on the shore and resulted in obnoxious smells. This had occurred during the previous two summers, had spoilt local picnic spots and was considered a hazard to health.

Although there were no odours reported during the 1960s a report by the RWSC (Lynch 1971) described the general presence of considerable amounts of aquatic weed, including *Cladophora* and *Enteromorpha* which produced an obnoxious smell as it decayed during the period. As dates are not available, the rainfall patterns for the years are not presented.

The rainfall for December 1970 was 166.5mm, well above average, and no further odours were reported until March 1973. This followed a very dry year with an annual rainfall of only 357.5mm. Dead fish were reported in December 1973 (Lynch 1974), due primarily to high temperatures in the water 23^{0}C.

Despite heavy rain in July 1974, pungent odours were reported in the SE corner of the lagoon in early April of 1975.

Following the removal of the baffles in April 1975 (which had raised the sill height by 50cm in 1963) (Lynch 1971), and heavy rainfall (32% of the total lagoon volume in October and a further 96% in November) there were no more reports of odour until 1981. The reports of odour in November 1981 describe an offensive odour from a green weed on the lagoon. This may have been the normal rotting vegetation but, as the description identified the odour as coming from the centre of the lagoon, it may indicate the presence of a blue-green algae. The complaints received at this time were very short-lived and the high input of fresh water only two months before may have lowered the salinity sufficiently for blue-green algae to develop.

No odour problems were subsequently reported until the summer of 1983-84 and in late 1985 the problems developed again with reports of large mats of algae with the potential for the odour to be worse than the previous year (DEP Files, 1985). However, after a very high rainfall in December there were again no complaints for four years. This is despite the occurence of a blue-green algae bloom in February of 1986. The scum produced by this is shown in Plate 2 . The algae was identified as *Aphanizomenon* sp. and is shown in Plate 5 and Plate 6 (Courtesy G. Hallegraeff, CSIRO, Division of Fisheries).

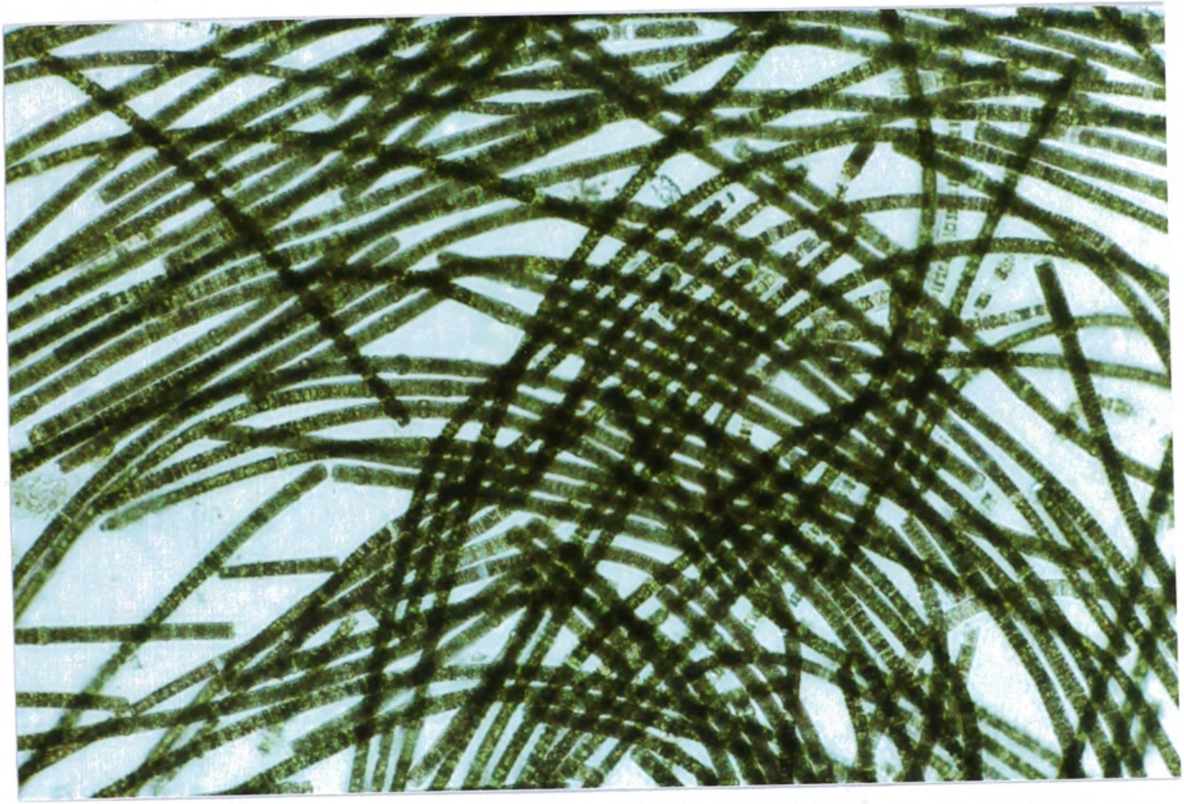


Plate 5 : Tangled filaments of blue-green algae, *Aphanizomenon* sp., Orielton Lagoon, February, 1986. photo - G. Hallegraeff

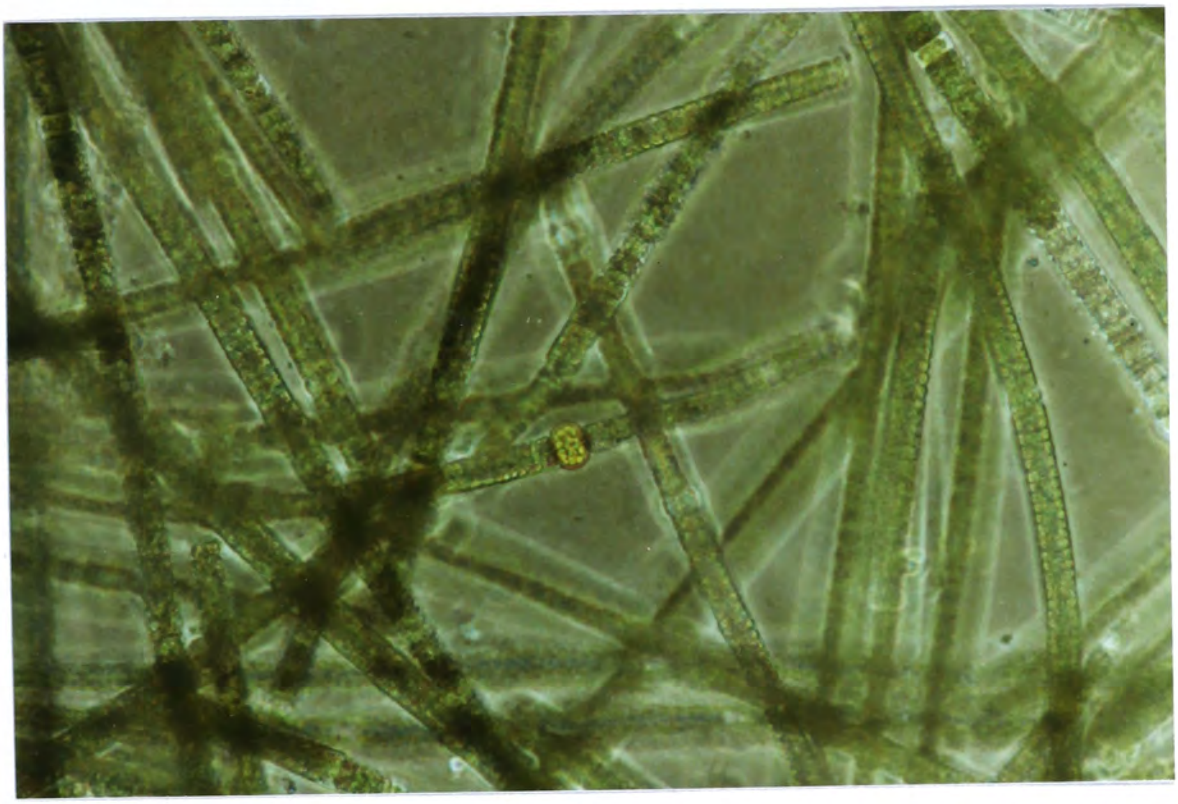


Plate 6: Enlargement of the filaments in Plate 3, with heterocysts and gas vacuoles in *Aphanizomenon* sp., Orielton Lagoon, February, 1986. photo - G. Hallegraeff

The salinity of the lagoon during the summer of 1985-86, would have been lowered as there was heavy rainfall in January of 1986. The occurence of this positively identified bloom supports the idea that the odour reported in 1981 may have been blue-green algae, particularly as the odour produced by these is described as "earthy, musty, fishy, grassy or rotten smells" (CSIRO 1991).

The summer of 1989-90 was also a year of very bad odour problems and followed 3 years of low rainfall with no significant flood events. However, the odour disappeared in the autumn of 1990 and has not recurred to date (summer 1991-92), despite continuing dry climatic conditions.

The influence of summer temperatures on the development of the odour problem is not clear cut although there is certain to be some relationship, particularly as the January temperature for 1990 was above average while the summer of 1991-92 was below average with January 1992 recording the lowest average for 27 years (Bureau of Meteorology 1992).

The patterns outlined above support the idea that there is a connection between rainfall events and odours, with evidence that the occurrence of heavy rainfall is a factor in reducing the development of the odour. This is supported by the lack of odours after November 1975 and more recently since December 1985. A possible reason for this effect is the increased flushing and of water exchange during flood conditions and the resulting loss of nutrients from the system.

This gives some indication of the importance of flushing in such an enclosed system and supports the proposal to increase flushing by lowering the culvert cills. It does not support the hypothesis that there is a large input of nutrients from agricultural regions which then release sediment-bound nutrients, as described for Lake Burley Griffin (Cullen & Rosich 1979).

In Orielton Lagoon there is no indication that there is a release of nutrients from the sediments following floods as the symptoms of eutrophication are not reported for several years.

It is proposed that between flood events the nutrient levels in the lagoon are increased by the continual input of nutrients from the sewerage treatment plant at Midway Pt. As these levels increase, the problem of rapid algal growth and its subsequent decomposition intensifies until another significant flushing takes place. The importance of tidal flushing during the winter months may also have an impact on the frequency of odour problems as the spring tides in 1991 were particularly high (personal observation) and may have reduced the nutrient loads in the lagoon to a significant extent.

Growth of the dominant algae forming the small mats that developed in 1991 (i.e. *Cladophora* sp, which is perennial, with a rhizome system) may be related to the flushing that occurs during periods of high inflow. The rhizomes may be dislodged if sufficient water movement occurs and although it may be re-established the following year the rate of development would be at a lower rate than it would be if the growth occurred from established rhizome systems. This could mean that large mats of growth may not appear for several seasons depending upon the exact development rates. Examination of the biology of the particular algae involved is an area for further work.

The above discussion is, by its nature, somewhat tenuous as it must take into account the reliability of the reports recorded in the files.

Chapter 9

Conclusions

This study has examined a shallow coastal bay which was impounded some 40 years ago by the construction of an extended causeway. Concrete culverts with a sill height above average high tide level restrict outflow and tidal inflow. This results in limited water exchange, with the lagoon acting essentially as an enclosed system for 9 months of the year.

The occurrence of odours emanating from Orielton Lagoon have been investigated with the intention of proposing mechanisms to alleviate future problems.

The main conclusions are outlined below.

9.1 Historical Developments

a) Initial development of the causeway system at the end of the nineteenth century, utilising large-span bridge sections, did not appear to have led to the development of any significant environmental effects on the arm of the Pittwater estuary now known as Orielton Lagoon.

b) Reports of odours, due to decomposition of macrophytic algal growth commenced in the late 1950's, several years after construction of a road causeway with very limited capacity for water exchange.

c) The design intention of the limited outlet capacity was to convert the estuarine bay into a freshwater lake. Experience has shown this to have been an ill-considered decision with the subsequent development of an eutrophied, highly saline environment.

d) Farming activity in the district has seen a change over the years from cereal production to mixed farming. The use of superphosphate commenced in the 1930s and peaked during the 1970s before decreasing over the past decade. Nutrients from agricultural land have been blamed in the past for initiating eutrophication in the lagoon and causing the resultant odours. It is likely that nutrients from this source could have been at least partly responsible for the initial development of odour problems in the late 50s. However, current nutrient input from catchment run-off is relatively insignificant.

e) An early attempt to reduce macrophytic growth by increasing the outflow sill level and preventing tidal inflow, and by introduction of brown trout, was unsuccessful. Subsequent fish deaths were attributed to excessive water temperatures. Salinity in the lagoon did not decrease as a result, mainly due to the relatively low inflow of fresh water and the significant effect of evaporation and seepage through the causeway.

f) Residential development at Midway Point led to the construction of a sewage treatment plant and to the discharge of primary treated sewage into the lagoon. The nutrient input from the sewage is now considered to be the primary source of nutrients leading to increased eutrophication in the lagoon. This conclusion is supported by evidence from the current study presented later in this chapter.

g) A proposal for land disposal of sewage in the late 1970s was rejected on political and economical grounds. With hindsight this appears to have been another ill-conceived decision.

h) Both State and Local Government have, over the last decade, been unable to agree on appropriate management methods and responsibility for their implementation. Currently nine government bodies have some jurisdiction over the area with the result that there is little incentive for any one body to initiate restoration strategies.

i) A private organisation is currently investigating the potential for zooplankton farming in the lagoon. Claims that such an operation would alleviate odours have been made but are considered, by the author, to be doubtful.

9.2 Physical, Chemical and Biological Measurements

a) Water movement is dominated by wind for most of the year with the shallow nature of the lagoon allowing significant resuspension of fine sediment by wind-induced wave action.

b) Siltation does not appear to be significant in the body of the lagoon. The substrate appears to be essentially sandy estuarine deposits with areas of mudflat formed prior to impoundment. Minor, silty, surface sediments appear to be mobile and are, at least partially, washed through the lagoon during flood outflow. The depth of the lagoon appears to have been relatively constant over the last 16 years.

c) The organic content of sediments is generally low, being less than 5%. This is believed to limit the extent of potential absorption and later release of nutrients from the sediments.

d) Particle size distribution in the lagoon sediments has remained consistent since at least 1968.

e) Water temperatures in the lagoon can become significant in hot weather. Temperatures up to 23° C have been recorded. Evidence suggests that high temperatures result in the deaths of large numbers of crabs and fish.

f) The lagoon water quality is characterised by high turbidity and low g440 levels. Secchi Disc transparencies indicate that Orielton Lagoon is hypertrophic with SD transparencies between 0.35 m and 0.65 m.

g) The lagoon was hypersaline for most of 1991, reducing to saline only during early spring. Historical evidence suggests that at times the lagoon can become brackish.

h) The lagoon was alkaline throughout the year with pH above 8.2. This would suggest that nutrients would tend to be absorbed into sediments where clay and organic content are high and the effect would be enhanced by the presence of calcium. The areas with these conditions are limited. However, an anoxic layer above the sediments was noted on a particular calm warm day and under such conditions nutrients may be released.

i) Chlorophyll levels were high throughout the year with peaks in April and December. These levels placed Orielton Lagoon in the eutrophic range.

j) Historical evidence suggests that floods serve to reduce the development of large mats of macrophytic growth rather than fuelling the sediment nutrient cycle.

l) Throughout the study period diatoms dominated the phytoplankton and low levels of zooplankton were present. The high turbidity caused by diatoms may have been a contributing factor in the reduced macrophytic growth evident.

9.3 Mathematical Modelling of the Movement of Water Through the Lagoon.

a) Mathematical modelling confirmed the observed water level variations throughout the study year. The model highlighted the very limited flushing effect.

b) The model predicted a significantly increased tidal water movement and a consequent high level of flushing, based on a lowering of the sill level by 0.3 m.

c) With the current culvert width, the model predicted little additional effect by further lowering of the sill.

d) Lowering the culvert sills would undoubtedly increase the flushing of the lagoon but this alone would not be sufficient to reduce chlorophyll levels to those in the adjacent Pittwater area. The removal of the most readily controlled source of nutrients, the sewage treatment plant, would be necessary to achieve significant reductions in chlorophyll levels.

9.4 Review of the Nutrient Balance Within the Lagoon by Examination of the Relative Inputs from Various Sources of Nutrients.

a) Soluble nutrient levels in the lagoon indicated a nitrogen-limited system. Nitrate levels in the lagoon are similar to those in Pittwater but phosphorus levels, as phosphates, in the lagoon were double those in Pittwater.

b) Total phosphorus levels in the lagoon were consistent with those expected in a eutrophic water body.

c) There was no apparent relationship between soluble nutrients and chlorophyll levels. A positive relationship between turbidity and chlorophyll levels indicated that a reduction in chlorophyll levels would improve the clarity of the system.

d) Total phosphorus in the sediments varied seasonally. This supports the suggestion that nutrients leave the lagoon during winter flushing.

e) A phosphorus budget for the lagoon indicated that the sewage treatment plant was the primary source of nutrients. Nutrients from agricultural sources may contribute to the total nutrients in the lagoon during flood periods but historical evidence does not support this.

These conclusions formed the basis of a recommended management strategy for Orielton Lagoon.

Chapter 10

Management Strategies

10.1 General

With increasing human populations and decreasing resources, including space and energy, there have been proposals to "manage " the environment in ways seen as fitting for the local community. Frequently this has not taken into account the long term implications of decisions, nor their effects on the surrounding environment or their likely global impact. These problems have not arisen from malice towards the environment but reflect insufficient understanding of the basic processes that underlie natural biological systems. An example of this is the increased eutrophication of waterways both fresh water and, more recently, coastal marine environments. Many of the waterways have acted as receivers for large volumes of effluent resulting from human activities. The valuable land surrounding these areas is frequently wetland which is subject to a large degree of manipulation to suit the needs of the surrounding human population.

In-filling, dredging and draining are some of the activities designed to better such areas but these activities can lead to even larger stresses being imposed on the adjacent waterways. The importance of wetlands as a controlling factor in the state of estuaries has been emphasised by a proposal in Sweden to construct artificial wetlands as a means of reducing the input of excess nitrogen into Laholm Bay (Andréasson-Gren 1991). The area surrounding the northern end of Orielton Lagoon is therefore particularly important in terms of its impact on the lagoon and on the birdlife, as well as being important in its own right.

The processes of eutrophication as described earlier have produced environments undesirable for further human activities, including recreation, fishing and use as a water supply. Following intensive study by the OECD (OECD 1982), on the eutrophication of freshwater bodies in the Northern Hemisphere, a set of management strategies were developed with the intention of restoring the trophic status of an affected water body to one approaching its original state. The desired water quality would vary depending on local conditions and local expectations but there has been a protocol established to manipulate the nutrient levels in such water bodies to produce the desired changes. This protocol is further supported by recommendations for nutrient management proposed for the Baltic Sea and the surrounding marine environment, and by similar protocols proposed by other world-wide agencies such as "Man and the Biosphere" (MAB) and UNESCO (Jeffers 1989).

Successful management of nutrient loads in an aquatic environment is not a purely scientific and technical problem but must also take into account economic, legal and political considerations (OECD 1982). In the case of Orielton Lagoon the economic and political aspects of the situation have dominated previous management strategies.

The strategies recommended by the OECD are aimed basically at the nutrient phosphorus and "even when another nutrient such as nitrogen is (occasionally or normally) the limiting factor, phosphorus may still be made to play the role of limiting factor through appropriate control" (OECD 1982, p. 10). Thus, even in a marine environment such as Orielton Lagoon, where nitrogen may be the limiting nutrient, the control of phosphorus input is of critical importance.

The following is a brief outline of the sequence of priorities outlined by the OECD in order to establish the best solution for the problem (OECD 1982, pp. 139-145).

1) Establish a co-ordinating and administrative machinery to assess the problem, to establish a timetable; to develop co-operation between various bodies; to provide funding; to establish the desired trophic levels, estimated loading reductions and to allow public review of the process. The biological nature of the problem should not be overlooked and the expertise of workers skilled in this area should be included in any program.

2) Establish existing trophic conditions and nutrient loads from all sources. Establish a water quality objective.

3) Determine nutrient reduction needed to meet the required trophic state considering geographical and hydrological conditions of the water body.

4) Determine if control of point-source load is sufficient to meet criteria. If not initiate measurements on diffuse loading.

5) Assess realistic totals that can be removed from all sources. If this is insufficient to achieve trophic response desired, indicate best possible result.

6) Assess time required for any control measure to have effect. This will depend on history and nature of the problem.

The above outline gives an indication of the expected procedures that could be followed in attempting to find a solution to the problems facing Orielton Lagoon.

If the above protocol can not be adhered to or followed to some degree there are a series of in-lake procedures that can be followed.

These manipulations are used if it is not possible to sufficiently reduce the source of nutrients or if there is internal loading from the sediments. The problem of internal loading becomes apparent when the expected decrease in eutrophication does not occur after external nutrients have been limited.

10.2 Previous Management Strategies

Proposals for the restoration of Orielton Lagoon put forward by the Sorell Council will be examined relative to the above discussion recommendations.

Historical descriptions of the lagoon prior to its management by IFC indicate that it was probably bordering on a eutrophic state but supporting a large range of fish including flounder which were fished commercially. There were anecdotal descriptions of large mats of weed through which the eels moved. The mats were mobile, moving around the lagoon depending upon prevailing weather conditions (I. Cleaver, pers. comm.).

Management strategies implemented in the early 1960s by the IFC have been discussed in Chapter 3. Increasing the water depth and stocking the lagoon with adult brown trout initially met with success. However, as the lagoon underwent environmental changes, resulting in regular fish deaths, the stocking of the lagoon was stopped, and the water circulation was improved by the removal of the culvert baffles. The increasing urbanisation of the surrounding area and the introduction of sewage effluent into the lagoon were mentioned as factors causing change in the lagoon (Lynch 1971, 1974). Although there was a call for "An ecologically sound approach to the problem which is to prevent the introduction of excessive nutrients resulting from man's activities" (Lynch 1974, p. 21) there was no move to eliminate the point source of nutrients.

In 1972 the DMR recommended the removal of the Midway Point Sewerage Outlet to the sea-side of the causeway as the first step in any remedial action (DMR Files 1972). This suggestion is in line with OECD recommendations but there was no further action apart from a study undertaken to establish basic data, in 1975 (Buttermore 1977).

Management proposals put forward by Buttermore included a suggestion to improve the water circulation and to remove plant debris. "At this stage, in view of the relatively small size of the lagoon, removal of plant debris by local council workers might provide a temporary solution until long term improvements can be made" (Buttermore 1977).

Again, in 1977, the removal of the sewage outlet from the lagoon was seen as critical to any restoration program and three alternatives were proposed in the Southern Regional Metropolitan Sewerage Study. One proposal for land disposal of the effluent at a site in Penna was recommended and land purchased for this purpose (DPWH Files 11/10/78). However this proposal was not followed through and yet another study was undertaken in 1983 by the Sorell Council's consulting engineers, England, Newton, Spratt and Murphy Pty. Ltd.

This series of reports did not result in a real management plan. This was a reflection on the economic aspect of the problem, with limited funding being the main impediment to any long term solutions. It also reflects the episodic nature of the problem which appears to reduce the incentive to undertake long term alterations.

10.3 The Latest Management Strategy

In 1990 the Sorell Council proposed a restoration strategy based largely on a report undertaken in 1984 (Spratt 1984) and a visit to Tuggerah Lakes where there is a problem of excess macrophytic growth resulting in reduced fishing and amenity. The proposal is outlined below.

1) Public meeting outlining Council's work and intent.
2) Involve State Government Authorities.
3) Carry out sediment removal works.
4) Remove summer algal bloom as it occurs.
5) Construction of artificial wetlands and sediment nutrient traps on inlets.
6) Examine lowering the culvert level.
7) Carry out flushing study of the lagoon.

8) Develop Lagoon Management Plan with authority to control the lagoon and its catchment (Spratt 1991).

Further proposals for harvesting zooplankton from the lagoon were later included in the management strategy and a research program was also added. Possible solutions to overcome the problem were outlined which included :

harvesting zooplankton
sediment removal
sediment trapping
sediment control
nutrient diversion and or extraction
lagoon flushing
artificial wetlands (Spratt 1991).

A special group was established in 1991 to liaise with the local council and various government departments with regard to implementation of the Management Strategy. This is definitely an important first step in line with accepted protocol. However, the committee has only met twice to date. The only decisions made have been:

1) provision of funding to the University of Tasmania for research (which to date has not been received), and

2) approval for Frish Pty Ltd to carry out trials of biomanipulation in enclosures within the lagoon.

Research work undertaken to date by the University of Tasmania has comprised the study outlined in this thesis. Biomanipulation trials have been undertaken during 1991-92 but results have not been reported.

It is noted that the two options for management apparently preferred by the Sorell Council, namely zooplankton harvesting and sediment removal are both options which are classified as "in-lake" manipulations and are not generally recommended by OECD until options further up their list of options are implemented. The diversion of nutrients from the lagoon would be an essential first step to establish if internal loading is going to be a problem.

Results from the present study indicate that sediment removal from areas outlined by the Council is unlikely to have any impact on the nutrient levels in the water body.

Considering phosphorus to be the nutrient to be controlled, there are a wide range of conditions and processes involved in the absorption and release of phosphorus from sediments. As mentioned in Chapter 8, calcium-rich sediments with a pH less than 9 act as a sink for this nutrient (Fox et al. 1989) but, simultaneously, resuspension of sediments and anoxic conditions are also known to be important in the release of phosphorus (Hakanson & Jansson, 1983, Furumai & Ohgaki 1989).

The amount of phosphorus in the sediments is also important in the rate of release or absorption. Nutrient levels in the sediments do not appear to be high by recognized standards, except for two sites near the sewage outlet. The concentrations vary seasonally indicating some loss of nutrients possibly due to increased water movement during winter.

Dredging such sediments would therefore be unlikely to reduce the nutrient load but would have considerable impact on the birdlife. The area proposed for dredging included the edge of the "Samphire Flats", the wetland area at the north of the lagoon favoured by the wading birds.

The dredging program undertaken in Tuggerah Lakes is only a relatively small part of the restoration program for those waterways. One of the prime contributors to the increased weed growth in the worst affected lake, Lake Munmorah, has been the operation of a thermal power station. Reduction in the use of this plant has been undertaken. Also, following a government committee report in 1979 recommending an accelerated sewerage program, upgrading of local schemes has accelerated and has "already contributed significantly to the health of the lake system"(Jackson 1991, p. 18). Recently the Wyong shire has extended the sewerage scheme to cover virtually all urban areas and, from 1989, secondary treated sewage has been discharged via an ocean outfall, 10 km north of The Entrance (Jackson 1991). The restoration program involving sediment reclamation has only covered 7 km out of a total 110 km of foreshore and has been supported by the development of "gross pollutant traps" at stormwater outlets and "mini wetlands" which have been planted to assist with the uptake of nutrients (Jackson 1991). Public awareness, regrassing of verges and a general catchment management program have also been included in the restoration program. In this program the point sources of nutrients were dealt with first and then, as it was shown that non-point sources were still allowing increased nutrient input, these were also tackled. Much of the non-point source input was in the form of nutrient-rich sediment from surrounding land. The sediments, which appeared to be a continual source of nutrients to the macrophytes, were removed in some areas (Anon 1989). The success of this operation has been encouraging in the limited areas undertaken but it is clearly an "in-lake" solution which has been undertaken **after** external nutrient sources had been reduced or diverted. A similar approach should be undertaken in Orielton Lagoon .

The possible solution currently being supported by the Sorell Council is the harvesting of zooplankton from the lagoon to form a live food source for white-bait which are, in turn, to be the food stock for a stripey trumpeter farm.

The process of removal of zooplankton from the lagoon has been predicted, by Frish Pty Ltd, to reduce the level of nutrients in the lagoon and indirectly control odour development.

This process of biomanipulation is still very much in the experimental stage with some evidence of a reduction in nutrient levels in a small freshwater lake in USA after biomanipulation. There was also a reduction in chlorophyll levels as the *Daphnia* species became dominant. However, the results were not conclusive, with the lake reverting to pre-manipulation conditions after two years (Shapiro & Wright, 1984). Further work has been carried out in many areas but in South Africa it has been found that large filter feeders such as *Daphnia* are unlikely to be able to retard the development of Cyanophyceae blooms by high grazing pressure. This is largely to do with the blockage of the filtering apparatus by the filamentous Cyanophyceae (Jarvis 1986). This has been further substantiated in the Netherlands (Davidowicz et al. 1988) and more recently in England (Moss et al. 1991).

The systems described above were fresh water and, although they may not be directly applicable, it must be recalled that, although the lagoon is presently diatom dominated, the main source of odour over the years has been the decay of larger filamentous algae such as *Cladophora* sp. and *Enteromorpha* sp. These filamentous algae may have a similar effect to the Cyanophyceae on the ability of grazers to effectively reduce the algal population. Furthermore there has been no major grazer identified in the zooplankton populations in Orielton Lagoon and although the introduction of such a species may be an interesting experiment, if kept suitably enclosed, it would not appear to be a necessary component to a restoration project at this stage. The effect of a larger grazer on the diatom populations may see reduction in their density but the impact upon the phytoplankton in neighbouring Pittwater must be carefully considered. Any alteration in the food source for the oyster farms at the mouth of the Coal River must be prevented as this is a very lucrative industry at present (G. Hallegraeff, pers. comm.).

Further work in two small, shallow, eutrophic lakes in Great Britain suggests that, in the absence of fish predation and in the presence of adequate food (not filamentous cyanophytes), large grazer populations of *Daphnia* can be maintained for an extended period (Moss et al. 1991). In this experiment, as with the earlier ones discussed (Jarvis 1986, Davidowicz et al. 1988), there was a dramatic alteration of the system by the removal of fish populations. In Orielton Lagoon the removal of fish populations would have an undefined impact on the birds which are dependent on fish.

It may also become important to maintain a high level of nutrient input to maintain commercial quantities of zooplankton and increased eutrophication of the lagoon could become a higher priority than restoration of its original recreational and aesthetic aspects. As a ready source of nutrients is available from the sewage effluent, the use of this for further enrichment could pose health threats for the local community.

Further possible solutions in the current Management Strategy include the use of sediment trapping and sediment control. These are both solutions which could be readily applied to stormwater outlets in a wide range of areas, not just the drainage basin for Orielton Lagoon. The input of nutrients from stormwater is not clearly understood and has been poorly documented in Tasmania (C. Jennings, pers. comm.). However, at Orielton Lagoon these are considered to be minor sources due to the low rainfall of the area.

The development of artificial wetlands is another option in the current strategy. These would be used at stormwater inlets and at the northern end of the lagoon. The later would be designed to reduce nutrient input from the Orielton Rivulet and the Frogmore Creek. Whilst these proposals are regarded as worthwhile, they are still considered to be addressing only a minor source of nutrients.

Nutrient diversion is included in the Management Strategy as a low priority. However, this is one of the highest priorities suggested in the OECD recommendations and has successfully been undertaken in Cockburn Sound where point source nutrient input had detrimental impacts on the sea grasses in the area (Hillman et al. 1990). It has also been adopted by the Tuggerah Lakes Restoration Program (Anon 1989) and has been the prime option in a range of overseas situations (Ahlgren 1980, Olsén & Willén 1980, Jost et al. 1991).

Similarly, nutrient extraction has been mentioned in the Management Strategy but as a low priority. Nutrient extraction, prior to the disposal of sewage, has been undertaken extensively in many overseas countries. More recently some sewage plants in Australia have undergone this level of upgrading. However, these processes have concentrated on removal of phosphorus as it is not technically difficult. Removal of nitrates has been found to be more difficult and costly, partly due to the wider range of sources in addition to sewage. Effluent discharged into Lake Burley Griffin now has undergone nutrient removal prior to its discharge (Cullen, 1986). The new Pasveer Ditch sewage treatment plant is believed to include "nitrogen reducing tanks". The effect of these on nitrate removal is unclear but it is not expected that there will be any marked reduction in the more important phosphate levels.

Lake flushing has consistently been an option in management plans over the past 30 years. In the current Management Strategy flushing is mentioned but seems to have a low priority. It is believed that flushing should have a high priority as will be discussed later in this chapter.

10.4 Management Proposals From the Present Study

This study was commenced prior to the formation of the Orielton Lagoon Rehabilitation Technical Committee but, since this committee's inception, the author has been involved in committee meetings. The prime aim of the committee is to undertake monitoring and make recommendations that may lead to the prevention of the odour from the lagoon.

The results of the study reported in this thesis have been used to propose a management plan which should produce significant positive changes to conditions in the lagoon. Most of these changes will be associated with some degree of reversion to a pre-impoundment condition but clearly this will be a slow process. Justifications and implications of the plan are discussed and approximate costings are presented where possible.

The proposed Management Plan is summarised below.

1) Improve water circulation in the lagoon by lowering the existing culverts by 300 mm.
2) Divert the sewage outlet, preferably to land disposal or, alternatively, an outlet below low water mark in Pittwater.
3) Install sediment traps on stormwater outlets.
4) Instigate a Land Care project in the catchment and a public awareness program.
5) Declare the proposed Nature Reservation for Orielton and Barilla Bay and the mouth of the Coal River, and a Wildlife Sanctuary (Conservation Area) for the rest of the estuary above the causeways.
6) Carefully monitor the contribution of nutrients from agricultural run-off and possibly remove the nutrients before entry to the lagoon, perhaps using an artificial wetlands system.

It is preferable that all options are undertaken together, or, if this is not possible, then options should be carried out in order of priority as listed.

The proposed Management Plan is justified below.

1) <u>Improved Water Circulation</u>

The first option, involving an increase in water circulation by lowering the culvert levels, has been based on the results from the mathematical modelling of inflow and outflow from the lagoon. This information is related to the nutrient balance and the seasonal changes that occurred as the lagoon was subject to increased flushing.

The changes associated with a reduction in the culvert level are most clearly outlined in Table 5.2 which indicates the increased rate of water exchange, particularly during the summer months. The level of flushing in August is predicted to rise from the current monthly maximum of 23%, at the present sill levels, to 58% at lower sill levels. Most of the other months would show a similar increase in flushing with 7 months having greater than 23% flushing.

During the study for this thesis, the water quality was noted to improve during late winter and early spring. This was partly due to seasonal effects, but more significantly due to the flushing of the system by inflow from winter rain and seasonal high tide levels. The increased flushing with a lower sill level would be expected to result in similar improvement on a year-round basis.

The present study showed a net export of phosphorus from the lagoon in August and a corresponding decrease in the chlorophyll and nutrient levels in the lagoon. This resulted in improved clarity (as measured by turbidity) and increased Secchi disc depth to a maximum of 63 cm in September. These results suggest that there would be considerable improvement in the water quality and a continual export of phosphorus from the system with additional flushing. An equilibrium would be reached when nutrients entering were equal to those leaving. If this was achieved with the improved flushing, water quality characteristics would be expected to improve.

Lowering the sill level further, to low tide level, does not improve the water exchange given the present culvert dimensions and would leave much of the present lagoon as mudflats which would only occasionally be inundated. This could be alleviated by increasing the width of the culvert section. It would be possible to estimate the extent of culvert enlargement to provide sufficient flushing to reduce chlorophyll levels to a similar value to Pittwater. However, due to the log-log relationship between chlorophyll and nutrient levels, the degree of flushing required leads to the need for a very significant increase in culvert size to improve the water quality that would be achieved by the modest increase proposed.

Improving the flushing rate of a water body reduces the water retention time and this has been shown to have direct impact on the chlorophyll and nutrient levels (OECD 1982). "If water retention time is reduced to 3 to 5 days, the algal biomass remains low, regardless of the amount of nutrient available for algal growth" (OECD 1982, p. 103). The low water retention time (29 days) of a lake in China (Hsiang & Ying 1991) has been cited as a reason for the lower than predicted chlorophyll levels in the lake, which acts as a major water supply for Shanghai. This should be compared to the current average retention time in Orielton Lagoon, of 0.43 years.

Improved flushing would also lead to significant benefits for recreational fishing, returning the area to an essentially marine/estuarine environment and facilating migration and colinisation by important recreational species such as flounder and flathead.

In two extensive studies of enclosed, eutrophic estuaries in Australia, improvement of the flushing rate via increased water exchange with the ocean has been adopted. At Tuggerah Lakes "the dredging program at The Entrance and other channels off nearby Pelican and Tenlbah islands has significantly improved the tidal flow, resulting in better fishing catches" (Jackson 1991, p. 20). The construction of the Dawesville Channel connecting the Harvey Inlet directly to the sea has been the major recommendation to deal with the eutrophication from non-point sources in an enclosed estuary (Hillman et al. 1990). The construction of the channel was due to begin in January 1992 and it is stated that "the addition of fresh seawater to the system will prevent algal blooms and effectively regenerate the marine environment" (Treadgold 1991, p. 36). Both these projects will be undergoing careful monitoring to prevent the channels closing with sand and will need dredging (Tuggerah Lakes) and a sand trapping system (Dawesville channel). Both restoration projects have been expensive, with the cost of the Dawesville Channel estimated at $76 million (Treadgold 1991) and the Tuggerah Lakes project having $11 million from the NSW government (Jackson 1991) as well as finance from the local shire.

The scale of the problem in the previous examples is far greater than that at Orielton Lagoon. The cost of lowering the culvert sills would be significant but not unrealistic in comparison with expenditure on other options. Lowering of the sill is believed to be feasible without undue interference with traffic on the causeway. Costs for the project are roughly estimated at below $500,000 (D.Brett, pers. comm.) which is below the cost of the new Midway Point Wastewater Treatment Plant at $670,000 (Mercury, 8/9/1991). The high volume of traffic on the causeway and its present narrow state may mean that an upgrading of the roadway will be imminent in any case.

Apart from water quality changes, reducing the sill level on the present culverts would maintain a relatively constant water level in the lagoon, in between the current high winter level and the low summer level. Natural revegetation of the increased mudflat area should re-establish the saltbush community. With the present high sill level the remains of this community are frequently inundated for most of the year in some areas of the lagoon . The increased summer water surface area should provide additional feeding grounds for the waders and enhance the area for the birds.

Questions arising from the likely impact of the increased outflow of nutrient-rich water on the rest of the Pittwater system must also be addressed. The two main questions that arise are:

i) the impact of the initial "slug" of nutrient rich water and

ii) the impact of another nutrient source on the Pittwater system.

The first question can be addressed by estimating the relative volume of Orielton Lagoon to the Pittwater system and by examining past flood events.

Given a total enclosed area of 39.2 km^2 for Pittwater (M. Rushton, pers. comm) at an average depth of 1 m, the estimated volume would be 39.2 x 10^6 m^3 compared to a volume of 1.5 x 10^6 m^3 for Orielton Lagoon. (Figures given in Harris give Pittwater 13 square miles and Orielton Lagoon 1 square mile (Harris 1968)). On this basis Orielton Lagoon is only approximately 3.8% of the total volume of the system and any material from the lagoon would be diluted by 1 in 30.

The history of past flood events shows that there have been times when water passing through Orielton Lagoon has been over 100% of the volume of the lagoon. This has happened in August 1981, a turnover of 109%, and December 1985, with a turnover of 115%. There does not appear to have been any dramatic change in the Pittwater system following those events. Large volumes from the Coal River associated with such flood events may have reduced any impact on the system by increasing the flow through to the sea. The currents in Pittwater were recorded in 1967 (Harris 1968) and are described as planar jets which show little mixing between the ebb and flood tides. There is only one point of interference between Orielton Lagoon and the mouth of the Pittwater estuary, at Lewisham. This combination of facts indicate that controlled release of water from Orielton Lagoon should not create any major disturbance. The detailed design of culvert sill lowering could readily allow for a staged release of excess water, preferably during a flood period.

The second question concerning an increase in nutrient load to Pittwater may have to be addressed, in any case, if there is diversion of the sewage outlet to a point below low tide level in Pittwater. This option was considered in several recommendations described in Section 3.3, but was ruled out because of financial constraints. Given the volume of Pittwater there should not be major problems associated with an increase in nutrient load from the Midway Point sewage. This aspect is presently being investigated by the Department of Primary Industry as further oyster farming in the lower areas of the estuary is planned. Careful monitoring of the area may give early indications of problems which could then be reduced by sewage diversion both from the Midway Point and Sorell treatment plants. Other smaller outlets into Pittwater may also need diverting if problems develop.

2) Diversion of the Sewage Outlet

The removal of the point source of nutrients is the recommended first stage of restoration programs for freshwater lakes and reservoirs (OECD 1982). It is considered that nutrient removal must, in reality, be undertaken in any serious attempt to restore the ecosystem at Orielton Lagoon. This approach has been successful at other Australian examples. The Tuggerah Lakes program undertook diversion and upgrading of sewage treatment plants (Anon. 1989) and nutrient reduction from point sources was successfully undertaken in Cockburn Sound (Hillman et al. 1990).

Estimations of the changes in the chlorophyll levels associated with increased flushing suggest only a 50% decrease with no nutrient diversion. Although these estimates may not be totally accurate, they give some indication of the very significant decrease in nutrient input needed to alter the trophic status of the lagoon.

Evidence that, in dry or normal years, the Midway Point sewage treatment plant is the main contributor of nutrients is supported by the nutrient balance from the present study. The nutrients result in peak algal concentrations dominated by diatoms which cause high turbidity and reduce macrophyte growth. Reducing the turbidity, by nutrient removal, without increasing the flushing rate may lead to a return to conditions existing in the lagoon before the addition of the sewage, where macrophytic algae dominated the lagoon. The steady state between these alternatives in a eutrophic lagoon is best described by Jeffers (1989): "one must consider the overall impacts of controlling macrophytes versus controlling phytoplankton in developing effective eutrophication control programs" (Jeffers, 1989, p. 82). This balance must be considered carefully if the option of nutrient diversion is considered in isolation and not in conjunction with increased flushing.

While flushing of the lagoon may at least partially preclude the necessity to divert sewage effluent, a reduction in the nutrient loading to the entire Pittwater system would be desirable as it is a water body with restricted tidal exchange. To date the impact of the present effluent disposal sites in the estuary appear to be limited but, as existing knowledge of the system is also limited, a cautious approach to future developments would be advisable.

Effluent from the Midway Point sewage treatment plant is likely to be suitable for land disposal as the effluent is domestic only, with no industrial contamination, and the surrounding rural areas are very dry with an unreliable rainfall. The possibility of disposal of part of the effluent to the Midway Point Golf Club has been put forward by the local consulting engineer (P. Spratt, pers. comm.).

3) Installation of Sediment Traps

This option is part of the second recommendation from the OECD report which recommends control of diffuse or non-point sources of nutrients. It also forms part of the restoration program proposed by the Sorell Council in 1991. In the present study the impact of such non-point sources was not measured but, with the low annual rainfall and limited urban development, it is not expected that this source of nutrients will be as important as that of the sewage treatment plant or agricultural input.

4) Monitoring Nutrients From Agricultural Run-off.

This option is also part of the second recommendation from the OECD for the control of non-point sources of nutrients and is an area of study which could be undertaken in a wide range of situations outside Orielton catchment as well. The removal of nutrients from such sources prior to entry into the lagoon could involve purchase of large areas of land for construction of artificial wetlands. This type of treatment system has been proposed as an alternative in the nutrient reduction program for the Baltic Sea (Andreasson-Gren et al. 1991) and has also been undertaken in the Tuggerah Lakes area in conjunction with gross pollutant traps (Jackson 1991).

Works required to implement points 3 and 4, as outlined above, would have little impact on the surrounding birdlife except in the initial construction phase.

5) Development of a Land Care Program for the surrounding areas.

This proposal also involves the diversion of nutrients by not allowing excess nutrients into the waterways in the first place. The Wyong Council has adopted a Total Catchment Management Strategy which incorporates land use decisions and control of erosion, siltation and dune management (Jackson 1991). A similar program could be beneficial to the Orielton catchment (and many others) and could be incorporated into a Land Care program. The program need not concentrate only on the rural areas but could incorporate the urban developments in the catchment. This proposal is part of the OECD program to reduce nutrient loading but also goes further as it encourages active participation in a program to care for the existing waterways via an easily undertaken project.

6) Declaration of the Area as a Nature Reserve.

This proposal would have no immediate impact on the problem of eutrophication in the lagoon but would be the culmination of considerable lobbying from concerned groups. As it is presently listed under three international agreements the declaration of this area as a reserve or protected area would also ensure that the local community undertook its international obligations seriously with regard to the environment. Such an undertaking would preserve the area as a bird habitat by providing a safe refuge with feeding grounds.

REFERENCES

ABBOTT, D., 1991; Pittwater and Orielton Lagoon, Threatened Species Network, p. 11.

AHLGREN, I., 1980; A dilution Model Applied to a System of Shallow Eutrophic Lakes after Diversion of Sewage Effluents, *Arch. Hydrbiol.,* **89**, 17-32.

ANDREASSON-GREN, I.M., FLEISCHER, S., and STIBE, L., 1991; Can we Implement a Cost Effective Nitrogen Reduction to the Laholm Bay?, *Ambio*, **20**, 94.

ANON., 1989; Draft Report on Tuggerah Lakes System Restoration Requirements, Wyong Shire Council, Wyong, NSW, Aust.

ANON., 1990; Blue-Green Algae in Drinking Water Supplies, Working Party on Blue-Green Algae in Water Supplies, Health Department, Victoria, Aust. p. 34.

AUSTRALIAN BUREAU of STATISTICS, 1971-1986; *Census of Population and Housing, Preliminary Characteristics,* June 1976, June 1981,No. 2201.6(9), *Characteristics of Persons in Hobart Suburbs* , 1986, No. 2201.6, *Tasmanian Year Book,* 1987, No. 1301.6, Australian Bureau of Statistics, Hobart, Tasmania.

"BACK TO SORELL" CELEBRATIONS, 1960; Souvenir Program, Cox Kay, Hobart, Tasmanian Reference Collection, State Library, Hobart, Tasmania.

BADEN, S.P., LOO,L.O., PIHL, L. and ROSENBERG, R., 1990, Effects of Eutrophication on Benthic Communities including Fish: Swedish West Coast, *Ambio,* **19**, 113-122.

BAVER, L.D., 1948; *Soil Physics,* John Wiley, New York, pp.10-62.

BIRCH, P.B., 1982; Phosphorus Export from Coastal Plain Drainage into Peel-Harvey Estuarine System of Western Australia, *Australian Journal of Marine and Freshwater Research,* **33**, 23-32.

BLACK, R.E., LUKATELICH, R.J., MCCOMB, A.J., and ROSHER, J.E., 1981, Exchange of Water, Salt, Nutrients and Phytoplankton between Peel Inlet, Western

Australia, and the Indian Ocean, *Australian Journal of Marine and Freshwater Research,* **32**, 709-720.

BLACKHALL, S., 1991; Unpublished letter to P. Spratt, England Newton Spratt & Murphy Pty Ltd from S. Blackhall, Department of Parks, Wildlife and Heritage, Hobart, Tasmania, Aust. p. 2.

BUTTERMORE, R., 1977; Eutrophication of an Impounded Estuarine Lagoon, *Marine Pollution Bulletin,* **8**, 13-15.

BUREAU OF METEOROLOGY ; 1975- 1990: *Monthly Weather Reviews ,Tasmania*, Bureau of Meteorology, Department of Science, Tasmania, Hobart.

CEDERWALL, H. and ELMGREN, R., 1990; Biological Effects of Eutrophication in the Baltic Sea, Particularly the Coastal Zone, *Ambio,* **19** ,109-112.

CHENG, D., 1987; Study on Sediment Bound Nutrients, Long Jetty, Tuggerah Lakes, Report Prepared for Wyong Shire Council, Wyong, NSW. Aust.

CHONG, R.W.T., 1987; Intermittent Extended Aeration Processes, *Australian Water and Wastewater Association & Department of Civil Engineering* Paper No. 4, Water and Wastewater Workshop, Darwin,1987, pp. 4-20.

COOKE, G.W. and WILLIAMS, R.J.B., 1973; Significance of Man-Made Sources of Phosphorus: Fertilisers and Farming, The phosphorus involved in agricultural systems and possibilities of its movement into natural water, *Water Research* 7, 19-33.

COHEN, J., 1972; Nutrient Removal From Wastewater by Physical-Chemical Processes, in *Nutrients in Natural Waters*, Eds. Allen, H.E. and Kramer, J.R., J. Wiley & Sons, New York.

COMMONWEALTH BUREAU OF CENSUS AND STATISTICS, 1969; *Tasmanian Year Book*, No. 3, Commonwealth Bureau of Census and Statistics, Hobart, Tasmania.

CORDERY, I., 1977; Quality Characteristics of Urban Storm Water in Sydney, Australia, *Water Resources Research*, **13**, 197-209.

COSSER, P.R., 1989; Water Quality, Sediments and the Macroinvertebrate Community of Residential Canal Estates in South-east Queensland, Australia: A Multivariate Analysis, *Water Research,* **23**, 1087-1097.

CSIRO, 1990; Smelly Water - What Could It Mean, Seeking Solutions, Division of Water Resources, CSIRO, Aust.

CULLEN, P., 1986; Managing Nutrients in Aquatic Systems: the Eutrophication Problem, *Limnology in Australia,* (De Decker, P and Williams, W.D., eds), Dr W. Junk, CSIRO, Melbourne.

CULLEN, P. and ROSICH, R.S., 1979; Effects of Rural and Urban Sources of Phosphorus of Lake Burley Griffin, *Progress in Water Technology,* **11**, No. 6, 219-230.

CULLEN, P. and SMALLS, I., 1981; Eutrophication in Semi-Arid Areas- The Australian Experience, World Health Organisation Water Quality Bulletin No. 6, pp 79-83.

DAKIN, W.J., and COLEFAX, A.N., 1940; *The Plankton of the Australian Coastal Waters off New South Wales,* The University of Sydney, Australasian Medical Publishing Company, N.S.W.

DAVIES, J.L., 1965; *Atlas of Tasmania,* Lands and Survey Department, Hobart, Tasmania.

DAVIES, J., 1988; *Land Systems of Tasmania,* Region 6: South, East and Midlands, Department of Agriculture, Tasmania.

DAWIDOWICZ, P., GLIWICZ, Z.M., and AGULATI, R.D., 1988; Can *Daphnia* prevent a blue-green algal bloom in hypertrophic lakes?, *Limnologie,* **19**, 21-26.

DEPARTMENT OF ENVIRONMENT AND PLANNING (TASMANIA), 1973-1991; Files related to Orielton Lagoon.

DEPARTMENT OF ENVIRONMENT AND PLANNING (TASMANIA), 1986: Orielton Lagoon Study; Preliminary Report, Unpublished Report to the Department of Environment and Planning, Hobart, Tasmania, Aust.

DEPARTMENT OF MAIN ROADS (TASMANIA), 1952-1982, Files related to the Sorell Causeways.

EMMERSON, W.D., 1989; The Nutrient Status of the Sunday River Estuary South Africa, *Water Research,* 23, 1059-1067.

ENELL, M., FLEISCHER, S., and JANSSON, M., 1989; Phosphorus in Sediments, *Ambio,* 18, 137-138.

ENOKSSON, V., SORENSSON, F. and GRANELI, W., 1990, Nitrogen Transformations in the Kattegat, *Ambio,* 19, 159-166.

FERRIS, J.M. and TYLER, P.A., 1985; Chlorophyll-Total Phosphorus Relationships in Lake Burragong, New South Wales, and some other Southern Hemisphere Lakes, *Australian Journal of Marine and Freshwater Research,* 36, 157-168.

FORSBERG, C., and RYDING, S.O., 1980; Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes, *Arch. Hydrobiol* 89, 189-207.

FOX, I., MALATI, M.A., and PERRY, R., 1989; The Adsorption and Release of Phosphate From Sediments of a River Receiving Sewage Effluent, *Water Research,* 23, 725-732.

FRANSON, M.A.H., 1990; *Standard Methods: For the Examination of Water and Wastewater,* 17th Edition, Eds. Franson, M.A.H., Clesceri, L.S., Greenberg, A.E., and Trussell, P.R., American Public Health Association, Washington.

FRESENIUS, W., QUENTIN, K.E., SCHNEIDER, W., 1988; *Water Analysis, A Practical Guide to Physico-Chemical, Chemical and Microbiological Water Examination and Quality Assurance,* Springer Verlag, Berlin.

FULTON, W., 1990; *Tasmanian Freshwater Fishes,* Fauna of Tasmania, University of Tasmania, pp. 80.

FURUMAI, H., and OHGAKI, S., 1989; Adsorption-Desorption of Phosphorus by Lake Sediments Under Anaerobic Conditions, *Water Research,* 23, 677-683.

FURUMAI, H., KONDO, T., and OHGAKI, S., 1989; Phosphorus Exchange Kinetics and Exchangeable Phosphorus Forms in Sediments, *Water Research,* 23, 685-691.

GEDDES, M.C., 1984; Limnology of Lake Alexandria, River Murray, South Australia, and the Effects of Nutrients and Light on the Phytoplankton, *Australian Journal of Marine and Freshwater Research,* 35, 399-415.

GORDON, D.M., BIRCH, P.B., and MCCOMB, A.J., 1981; Effects of Inorganic Phosphorus and Nitrogen on the Growth of an Estuarine *Cladophora* in Culture, *Botanica Marina,* 24, 93-106.

GRANELI, E., WALLSTROM, K., LARSSON, U., GRANELI, W., and ELMGREN, R., 1990, Nutrient Limitation of Primary Production in the Baltic Sea Area, *Ambio,* 19, 142-151.

HACH SPECTROPHOPTOMETER HANDBOOK, 1989; DR/2000 Spectrophotometer Instrument Manual, Hach Company.

HALLEGRAEFF, G. M., 1991; *Aquaculturists' Guide to Harmful Australian Microalgae,* Fishing Industry Training Board of Tasmania and CSIRO Division of Fisheries, Hobart, Tasmania.

HALLEGRAEFF, G.M., TYLER, H.L, and SUMNER, C.E, 1986; Phytoplankton Abundance and Growth of the Pacific Oyster (*Crassostrea gigas*) in Pittwater (Tasmania), Unpublished Manuscript, CSIRO Fisheries Division, Hobart, Tasmania, Aust.

HÅKANSON, L., and JANSSON, M., 1983; *Principles of Lake Sedimentology,* Springer-Verlag, Berlin.

HARRIS, G.P., 1986; *Phytoplankton Ecology - Structure, Function and Fluctuation,* Chapman and Hall, London.

HARRIS, M.F., 1968; *Sedimentology of Pittwater, Tasmania,* Unpublished Honours Thesis, University of Tasmania.

HEALY, T. and HARADA, K., 1991: Definition and Physical Characteristics of the World's Enclosed Seas, *Marine Pollution Bulletin,* Vol. 23, pp. 639-644.

HILLMAN, K., LUKATELICH, R.J., and MCCOMB, A.J., 1990; The impact of nutrient enrichment on nearshore and estuarine ecosystems in Western Australia, *Proceedings of the Ecological Society of Australia,* **16**, 39-53.

HSIANG, T.K., and YING, L.G., 1991: A Study of lake eutrophication in Shanghai, China, *The Geographical Journal,* **157**, 45-50.

HUTTON, J.T., 1950, C.S.I.R.O. Div. Soils Tech. Mem. pp. 7-50.

JACKSON, M.L., 1964; *Soil Chemical Analysis*, Prentice-Hall Inc., Engelwood Cliffs, N.J.

JACKSON, B., 1991; Rehabilitating a waterway, *Engineers Australia*, **63**, No.14, 18-20.

JARVIS, A.C., 1986; Zooplankton Community Grazing in a Hypertrophic Lake (Hartbeespoort Dam, South Africa), *Journal of Plankton Research*, **8**, 1065 - 1078.

JEFFERS, J.N.R., 1989, The Control of Eutrophication of Lakes and Reservoirs, *Man and The Biosphere Series* ,Vol.1, Eds. S.O. Ryding and W. Rast, UNESCO and The Parthenon Publishing Group, Paris.

JEFFREY, S.W., 1980; Phytoplankton Ecology- with particular reference to the Australasian region, in *Marine Botany, an Australasian Perspective*, Longman, Cheshire.

JONES, A., 1988; *Convicts and Carriageways,* Tasmanian Government Printers, Hobart.

JONES, R.A., and LEE,G.F., 1986; Eutrophication Modelling For Water Quality Management: An Update of the Vollenweider-OECD Model, *Water Quality Bulletin,* **11**, 67-74.

JONSSON, P., CARMAN, R., and WULFF, F., 1990; Laminated Sediments in the Baltic - A Tool for Evaluating Nutrient Mass Balances, *Ambio*, **19**, 152-158.

JOST, B., LEUMANN, P., LIECHTI,P., and STADELMANN, P., 1991; Restoration of Eutrophied Swiss Lakes, *European Water Pollution Control,* **1**, 31-41.

JOY, C.M., BALAKRISHNAN, K.P., and JOSEPH, A., 1989; Effect of Industrial Discharges on the Ecology of Phytoplankton Production in the River Periyar (India), *Water Research,* **24**, 787-796.

KIRK, J.T.O., 1986; Optical Limnology - a Manifesto, *Limnology in Australia,* (De Decker, P and Williams, W.D., eds), Dr W. Junk, CSIRO, Melbourne.

KIRKPATRICK, J.R. and GLASBY, J., 1981; Salt Marshes in Tasmania, Distribution, Community Composition and Conservation, *Occasional Paper* No 8, Department of Geography, University of Tasmania.

LAMPERT, W., 1988; The Relationship between Zooplankton Biomass and Grazing: A Review, *Limnologica (BERLIN)* **19**, 11-20.

LEE, G.F., and JONES, R.A., 1984; Summary of US OECD Eutrophication Study. Results and their application to water quality management, *Verh. Internat. Verein. Limnol.,* **22**, 261-267.

LEE, G.F., RAST, W., and JONES, R.A., 1978; Eutrophication of Water bodies; Insights for an age-old problem, *Environment Science & Technology,* **12**, 900-908.

LUKATELICH, R.J. and MCCOMB, A.J., 1986; Nutrient levels and the development of diatom and blue-green algal blooms in a shallow Australian estuary, *Journal of Plankton Research,* **8**, 597-618.

LYNCH, D.D., 1971; Inland Fisheries Commission Report for year ending 30 June 1971. Hobart, Tasmania, Aust.

LYNCH, D.D., 1974; Inland Fisheries Commission Report for year ending 30 June 1974. Hobart, Tasmania, Aust.

MCCOMB, A.J. and LUKATELICH, R.J., 1986; Nutrients, and plant biomass in Australian estuaries, with particular reference to south-western Australia, *Limnology in Australia,* (De Decker, P and Williams, W.D., eds), Dr W. Junk, CSIRO, Melbourne.

MOSS, B., SANSFIELD, J., and IRVINE, K., 1991; Development of Daphnid Communities in Diatom and Cyanophyte Dominated Lakes and Their Relevance to Lake Restoration by Biomanipulation, *Journal of Applied Ecology,* **28** 586-602.

NEWELL, G.E., and NEWELL, R.C., 1973; *Marine Plankton: A Practical Guide,* Hutchinson Educational Limited, London.

NICHOLLS, K.H. and DILLON, P.J., 1978; An Evaluation of Phosphorus-Chlorophyll-Phytoplankton Relationships for Lakes. *Int.Revue ges. Hydrobiol.* **63**, 141-154.

NIXON, S.W., 1990; Marine Eutrophication : A Growing Problem, *Ambio,* **19**, 101.

ODUM, E.P., 1971; *Fundamentals of Ecology*, W.B. Saunders Co., Philadelphia.

ORGANIZATION FOR ECONOMIC AND CULTURAL DEVELOPMENT, 1982; *Eutrophication of Waters, Monitoring, Assessment, and Control,* OECD, Paris, France.

OLSÉN, P., and WILLÉN, E., 1980; Phytoplankton response to sewage reduction in Vättern, a large oligotrophic lake in Central Sweden, *Arch. Hydrobiol,* **89**, 171-188.

PARR, L.B., 1988; *The Status and Conservation of Shorebird Habitat in South East Tasmania,* Unpublished Masters Thesis, Department of Geography and Environmental Studies, University of Tasmania, Aust.

PARKS, WILDLIFE and HERITAGE FILES, 1960-1991; Department of Parks Wildlife and Heritage, Hobart, Tasmania.

PARSONS, T. R., MAITA, Y., LALLI, C.M., 1984; *A Manual of Chemical & Biological methods for Seawater Analysis*, Pergamon Textbook, Great Britain.

REID, O., 1979; *The South East*, Education Department of Tasmania.

RIVERS AND WATER SUPPLY COMMISSION, 1991, Flow Records for Orielton Rivulet from 1975-1991, Unpublished Data, Rivers and Water Supply Commission, Hobart, Tasmania.

ROSENBERG, G., ELMGREN, R., FLEISCHER, S., JONSSON, P.,PERSSON, G., and DAHLIN, H., 1900; Marine Eutrophication Case Studies in Sweden, *Ambio,* **19**, 102-108

ROSICH, R.S., and CULLEN, P., 1980a; Lake sediments: Chemical composition and some aspects of their formation and diagenesis. In "Biochemistry of Ancient and Modern Environments". (Eds. P.A. Trudinger, M.R. Walter and B.J. Ralph) pp.117-122, Springer-Verlag; Berlin.

ROSICH, R.S., and CULLEN, P., 1980b; Lake sediments; algal availability of Lake Burley Griffin sediment phosphorus. In "Biochemistry of Ancient and Modern Environments". (Eds. P.A. Trudinger, M.R. Walter and B.J. Ralph) pp.117-122, Springer-Verlag; Berlin.

ROSICH, R.S., and CULLEN, P., 1981; Sediments, algae, nutrients-interrelationships in Lakes Burley Griffin and Ginninderra, *Verh. Int. Ver. Limnol.,* **21**, 1009-1016.

RYDBERG, L., EDLER,L., FLODERUS, S. and GRANELI, W., 1990, Interaction Between Supply of Nutrients, Primary Production, Sedimentation and Oxygen Consumption in SE Kattegat, *Ambio,* **19**, 134-141.

SAS, H., 1990, *Lake Restoration by Reduction of Nutrient Loading, Expectations, Experiences, Extrapolations*, Acedemia Verlag, Berlin.

SHAPIRO, J., and WRIGHT, D.I., 1984; Lake restoration by biomanipulation: Round Lake, Minnesota, the first two years, *Freshwater Biology* **14**, 371-383.

SHAW, J.F.H., and PREPAS, E.E., 1990; Relationship Between Phosphorus in Shallow Sediments and in the Trophogenic Zone of Seven Alberta Lakes, *Water Research.*, **24**, 551-556.

SMITH, G.S., 1955; *Cryptogamic Botany; Algae and Fungi Vol.1.*, McGraw-Hill, London.

SPRATT, P., 1983; Sorell-Midway Point Waste Treatment Strategy Study, England Newton Spratt & Murphy Pty. Ltd., Hobart, Tasmania.

SPRATT, P., 1984; Preliminary Environmental Study of Orielton Lagoon, England Newton Spratt & Murphy Pty. Ltd., Hobart, Tasmania.

SPRATT, P., 1991; Municipality of Sorell: Orielton Lagoon Restoration, England Newton Spratt & Murphy Pty. Ltd., Hobart, Tasmania.

STEANE, J.D., 1975; Orielton Lagoon : A Preliminary Water Balance, November 1975, Unpublished report to Rivers and Water Supply Commission, Hobart, Tasmania, Aust.

TASMAPS, 1985; No. 5426, Tasmanian Government, Hobart, Tasmania.

TASMANIAN TIDES, 1991; Tasmanian Tides, Times & Heights of High & Low Water, Port Authorities of Hobart, Burnie, Devonport & Launceston, Tasmania, Aust.

TILT, J., 1965; The History of Wheat Growing in Tasmania, *Tasmanian Journal of Agriculture*, **36**, 25-30.

TREADGOLD, T., 1991; The end of the big stink is in sight, *Engineers Australia*, **63**, No. 18, 35-36.

UNDERDAL, B., SKULBERG, O., DAHL, E., and AUNE, T., 1990; Disastrous Bloom of *Chrysochromulina polylepis* (Prymnesiophyceae) in Norwegian Coastal Water 1988 - Mortality in Marine Biota, *Ambio*, **18**, 265-270.

WETZEL, R.G., 1983; *Limnology*, Saunders College Publishing, New York.

WOOD, T., 1991; *The Convict and the Carpenter : A History of Mary Springham and William Hambly and their Descendants*, Ed. R. Snell, "Go Between Publications", Hobart, Tasmania, Aust.

WULFF,F., STIGEBRANDT, A. and RAHM, L., 1990; Nutrient Dynamics of the Baltic Sea, *Ambio*, **19**, 126-133.

ZAR, J.H., 1974; *Biostatistical Analysis*, Prentice-Hall, New York.

APPENDIX A

Data from a study of Orielton Lagoon, Tasmania in 1991.

This appendix includes the data on various physical and chemical parameters of the lagoon during 1991, when the study was undertaken. It includes information recorded about prevailing conditions during the collection of the material and forms the basis for some of the discussion outlined in the thesis. The information is taken directly from field notes and as such may appear disjointed.

February

26/2/1991

Light winds with small waves, shoals of small fish observed. One flounder noted, black swans and kelp gulls seen. Few smelly spots where some muds were exposed. Sediments collected from Site 5 released strong sulphurous smells.

March

18/3/1991

Very warm, mild autumn day, little if any wind. Water surface very still, abundant small birds present but unidentified, black swans and pelicans also see. Sediments from Sites 5 and 6 were rather smelly but no smells from the rest of the lagoon. No evidence of water moving over the culvert, water level still well below sill level.

April

16/4/1991

Very windy cool day, later estimates of wind speed obtained from nearby Hobart Airport indicated wind speed of 43 knots. Waves frequently as high as the boat, sampling slightly difficult. Cormorants observed feeding on schools of small fish. Pelicans still present in the northern end of the lagoon but the number of black swans appeared lower. Many dead crabs or moults on the edge of the lagoon but still abundant live ones around the boat ramp. Water clarity very poor (in the estimation of the collectors). Orielton Rivulet almost cut off from the lagoon by a silted bar which shows evidence of old saltmarsh vegetation. There was only a small shallow channel connecting the two at Site 8. Still no evidence of water movement over the culvert.

May

21/5/1991

Mirror-like conditions in some areas of the lake. Large crabs seen not previously noted in the lagoon but no outflow from the lagoon. At least one hundred black swans in the northern end of the lagoon and a cormorant nesting on a nesting box. Local resident said that there was foam on the Sorell side corner yesterday, even though it was not windy. Site 8 sediments smelt strongly of hydrogen sulphide.

June

18/6/1991

Cold day with a light wind. Water almost over the top of the culverts with small waves occassionally overflowing. Calanoid copepods evident to naked eye in plankton samples. No pelicans present but some black swans and four domestic geese in the northern end of the lagoon, they went back to the local farm.

July

31/7/1991

Very cold and windy. SW wind with waves about 0.5 m high. Lagoon depth has increased with water flowing over the culverts at a depth of 3 cm. Green algae growing on the culverts, *Enteromorpha* sp.

August

26/8/91

Cold day with very light wind. It had been raining for the previous two nights and water was flowing over the culverts at 4 cm. Water on the Pittwater side looked a bit murky and bubbly. Slimy silt being deposited on the *Enteromorpha* in the culverts, looks as though the sewage plant may not be working with evidence of faecal matter. Lots of birds including small ones. Small fish darting around in schools.

September

24/9/1991

Cool to mild day with very light wind. Overcast, water just flowing over the culverts. Red branching algae and *Enteromorpha* on the culvert. Small scum appearing in the SW corner of the lagoon.

October

23/10/1991

Warm, calm day light breeze late morning and afternoon. Lagoon looks quite clean and pelicans, black swans and cormorants present. Also large flocks of small birds and curlews seen. Several different species of ducks and eagle in the northern end of the lagoon. No water flowing over the culverts.

December

18/12/1991

Water has been reported as being very green, still very green. No overflow through the culverts, calm quiet day. Lagoon becoming shallow boat grounded several times in the northern end of the lagoon. Spectacular sight of large spawning polycheate about 25 cm long. Several observed and one collected and later identified as *Austronereris* sp. Swans, pelicans and various other birds.

UTAS

Years Data   Sun, Apr 5, 1992 10:06 PM

Month	Air Temp	W Temp	pH	Salinity	Turbidity	Diss. O	g440	Chll a	PO4	NO3
Feb 91										
						Diss. Oxy.				
Units						%O, mg/L				
Site 1		17.000	8.280	41.000	18.000	79%	0.691	29.800		
Site 2		18.000	8.400	42.000	13.000	71%	0.691	20.620		
Site 3		18.000	8.280	41.000	17.000	87%	0.921	19.610		
Site 4		17.700	8.200	44.000	8.000	124%	0.921	15.620		
Site 5		17.000	8.290	45.000	20.000	85%	1.382	17.340		
Site 6		18.000	8.220	46.000	24.000	90%				
Site 7		17.000	8.220	46.000	20.000	93%	1.152	5.800		
Site 8		14.000	8.210	44.000	18.000	130%	1.036	19.610		
Site 9		17.300	8.150	44.500	16.000	128%	1.152	19.680		
						Diss.O			PO4	NO3
Mch 91										
Site 1	22.000	18.500	8.480	42.000	28.000	80%,7.8	1.266	22.690	0.025	0.01
Site 2	21.300	17.900	8.410	41.000	28.000	83%	1.842	14.030	0.015	0.012
Site 3	18.000	19.000	8.520	42.000	25.000	101%,9.3	1.496		0.081	0.012
Site 4	18.500	19.000		42.500	26.000	102%,9.7	2.418		0.018	0.009
Site 5	22.000	19.000	8.480	41.000	31.000	92%,8.7	1.612	22.680	0.015	0.01
Site 6	20.000	19.000	8.460	41.000	32.000	83%,7.7	2.187	3.430	0.013	0.01
Site 7	19.000	20.000	8.490	44.000	15.000	92%,8.3	1.842	12.340	0.022	0.005
Site 8	19.000	21.000	8.460	44.000	33.000	147%13.5	1.727	99.170	0.033	0.005
Site 9	19.000	20.500	8.300	44.000	33.000	101%11.5	1.842	20.290	0.007	0.011
Ap. 91										
Site 1	17.300	11.700	8.320	46.000	74.000		1.497	52.760	0.013	0.042
Site 2	15.500	11.800	8.200	44.500	103.000		1.382	31.590	0.012	0.01
Site 3	14.100	11.000	8.280	47.000	41.000		1.267	14.840	0.019	0.008
slte 4	13.100	13.100	8.370	46.000	72.000		1.497	27.530	0.011	0.006
Site 5	13.800	12.300	8.130	46.000	77.000		1.267	26.110	0.015	0.017
Site 6	13.200	12.500	8.260	44.000	145.000		1.382	35.360	0.013	0.039
Site 7	12.800	12.800	7.820	46.500	139.000		1.496	38.030	0.009	0.00.
Site 8	15.900	16.300	8.450	44.000	39.000		1.267	38.030	0.005	0.005
Site 9	13.900	13.900	8.220	38.000	157.000		1.496	40.180	0.006	0.012
May 91										
Site 1	11.000	10.600	8.210	46.000	28.000	80%,6.1	1.267	25.080	0.036	0.007
Site 2	11.000	10.900	8.280	46.000	26.000	72%,7.4	1.382	22.780	0.028	0.005
Site 3	10.800	11.400	8.320	46.000	23.000	70%.7.2	1.842	9.430	0.021	0.006
Site 4	13.500	13.100	8.350	53.000	18.000	75%,8.0	0.460	7.850	0.019	0.005
Site 5	11.500	11.100	8.300	46.500	26.000	70%,6.4	0.921	37.380	0.026	0.005
Site 6	11.500	11.000	8.290	46.000	26.000	64%,6.8	0.345	23.830	0.032	0.014
Site 7	11.500	11.300	8.240	45.500	25.000	66%,5.8	0.461	14.940	0.033	0.008
Site 8	11.500	11.600	8.300	47.500	25.000	66%,7.2	0.576	6.940	0.015	0.009
Site 9	12.000	10.800	8.170	44.000	30.000	72%,6.6	1.496	22.150	0.007	0.009
June91										
Site 1		9.100	8.250	31.000	26.000	81%,9.6	1.382	26.220	0.064	0.009
Site 2		9.100	8.500	37.000	26.000	86%,9.9	0.921	23.320	0.066	0.005
Site 3		9.100	8.320	44.500	25.000	78%,9.2	1.152	11.690	0.059	0.009
Site 4		10.200	8.320	45.500	30.000	94%,10.3	2.648	14.030	0.024	0.003
Site 5		9.000	8.190	41.500	29.000	78%,9.0	1.152	16.790	0.041	0.007
Site 6		9.000	8.090	44.000	33.000	74%,8.5	0.806	19.050	0.039	0.009
Site 7		9.200	8.140	44.500	33.000	79%,8.7	0.576	24.980	0.046	0.007
Site 8		9.500	8.340		30.000	104%11.6	1.152	20.330	0.038	0.005
Site 9		9.500	8.150	47.000	24.000	95%,10.9	1.382	22.120	0.036	0.009
Inflow		9.400	8.040	4.000	15.000	59%,6.8	2.533	0.595	0.700	1.100
July91						D.O.				
Site 1		7.600	8.640	40.000	27.000	90%,10.6	1.152	19.030	0.022	0.006

Month	Air Temp	W Temp	pH	Salinity	Turbidity	Diss. O	g440	Chll a	PO4	NO3
Site 2		7.200	8.600	39.000	29.000	90%,10.8	0.806	16.150	0.022	0.010
Site 3		7.300	8.360	40.000	27.000	91%,10.8	0.576	8.670	0.018	0.010
Site 4		6.700	8.520	41.000	24.000	96%	0.461	9.810	0.019	0.030
Site 5		7.600	8.250	39.000	26.000	93%,11.1	0.461	10.940	0.029	0.010
Site 6		7.600	8.250	39.000	27.000	88%,10.2	0.461	4.540	0.015	0.011
Site 7		7.900	8.040	40.000	29.000	55%,6.1	0.460	5.740	0.029	0.013
Site 8		7.500	8.440	39.000	28.000	89%	0.438	10.940	0.035	0.015
Site 9		7.200	8.330	41.000	27.000	87%	0.806	9.820	0.021	0.020
Inflow		7.100	8.420	3.000	7.000	80%	1.727	1.210	0.122	0.800
Outflow		6.800	8.530	42.000	27.000		2.072	13.930	0.04	0.017
Pitt W.		7.200	8.270	35.000	5.000		0.115	0.606	0.023	0.006
Aug 91										
Site 1			8.210	37.500	34.000	84%,67%	0.806	9.960	0.083	0.02
Site 2			8.220	36.000	21.000	82%,9.3	0.461		0.015	0.016
Site 3			8.230	35.500	21.000	96%,10.7	0.345	19.660	0.019	0.005
Site 4			8.120	34.000	18.000	96%	1.152	22.060	0.015	0.034
Site 5			8.250	35.000	37.000	52%	0.691	3.550	0.012	0.008
Site 6			8.210	33.500	29.000		0.576	20.840	0.015	0.006
Site 7			8.190	35.500	26.000		0.691	7.640	0.015	0.009
Site 8			8.110	33.000	20.000	85%	0.691	11.080	0.013	0.004
Site 9			8.070	29.000	19.000	96%,11.1	0.921	10.650	0.013	0.004
Inflow			8.010	3.000	16.000	82%,9.4	4.261	2.140	0.036	0.200
Outflow			8.190	34.000	19.000	86%,10	0.576	9.960	0.012	0.007
Pitt W			7.890	31.000	2.000	93%,10.9	0.345	0.072	0.012	0.003
Sept 91						D.O.				
Site 1		11.300	8.580	34.000	14.000	145%15.9	1.267	9.320	0.018	0.003
Site 2		11.300	8.610	34.000	18.000	136%149	0.921	10.920	0.025	0.007
Site 3		11.200	8.320	34.000	13.000	137%15.5	1.036	8.720	0.022	0.003
Site 4										
Site 5		11.300	8.270	35.000	13.000	134%14.8	1.267	7.010		
Site 6		11.500	8.150	35.000	16.000	118%	0.009	8.770	0.022	0.005
Site 7		12.000	8.240	35.500	16.000	126%13.5	1.727	9.610	0.025	0.006
Site 8		13.000	8.470	33.000	14.000		1.036	8.680	0.028	0.008
Site 9		13.100	8.430	30.500	14.000		1.267	8.740	0.022	0.008
Inflow		12.200	8.160	2.000	18.000		0.921	2.840	0.006	0.135
Outflow		12.600	8.510	35.500	11.000		0.921	10.420	0.022	0.002
Pitt.W.									0.009	0.007
Oct 91										
Site 1	19.200	13.800	8.010	33.500	42.000	97%,9.8	0.000	13.750	0.025	0.005
Site 2	17.300	15.000	8.190	34.000	39.000	94%,9.7	0.345	12.550	0.022	0.006
Site 3	17.200	14.300	8.100	32.500	44.000	99%,10.1	0.575	9.660	0.028	0.005
Site 4	21.200	22.200	8.330	32.000	26.000	161%14.6		2.790	0.025	0.005
Site 5	18.000	15.100	8.190	32.000	33.000	102%10.3	0.345	9.670	0.025	0.005
Site 6	19.300	15.400	8.240	34.500	31.000	105%10.5	0.575		0.022	0.005
Site 7	18.700	17.200	8.210	33.500	29.000	107%10.4	0.575	5.590	0.022	0.005
Site 8	19.600	21.600	8.430	33.500	28.000	191%17.9	0.345	7.480	0.025	0.006
Site 9	17.400	20.000	8.360	32.000	14.000	124%	0.691	3.470	0.022	0.008
Inflow	20.400	20.000		1.000	29.000	86%,8.6	4.145	2.210	0.003	0.126
Outflow										
Pitt W	16.700	16.200	8.200	28.000	22.000	98%,9.6	-0.461	1.660	0.012	0.006
Dec										
Site 1	18.100	19.500	8.480	38.500	97.000	9.4e-1	0.023	81.760		
Site 2	21.600	19.800	8.540	39.500	90.000		0.020	45.830		
Site 3	18.400	19.400	8.560	39.000	93.000		0.033	63.360		
Site 4	20.700	20.900	8.490	39.000	97.000		0.013	59.540		
Site 5	17.400	19.000	8.520	36.500	90.000		0.015	56.220		
Site 6	17.300	20.200	8.490	35.500	96.000		0.114	13.990		

Years Data Sun, Apr 5, 1992 10:06 PM

	Month	Air Temp	W Temp	pH	Salinity	Turbidity	Diss. O	g440	Chll a	PO4	NO3
:3	Site 7	17.500	19.500	8.430	39.000	98.000		0.192	11.860		
!4	Site 8	18.500	23.500	8.210	36.500	103.000		0.034	34.250		
:5	Site 9	16.600	23.500	8.210	36.500	14.000		0.022	4.090		

APPENDIX B

A Pictorial Survey of Phytoplankton Found in Orielton Lagoon, Tasmania in 1991. This survey was collated to allow the future identification of the species commonly found in the lagoon and should prove useful in following changes in species composition if the proposed management strategy results in positive action. All photographs and drawings were prepared by the author but bromides for the drawings were prepared by Airlie Alam.

UTAS

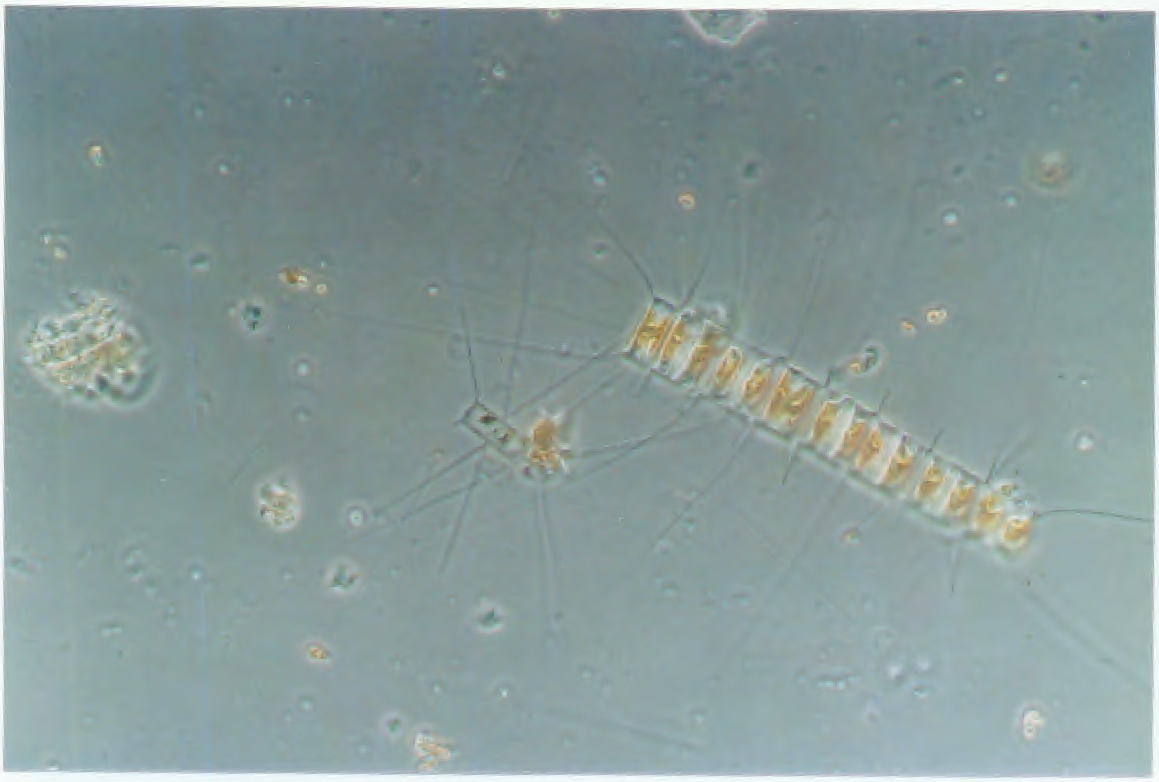


Plate 1. Two chain forming diatoms, both *Chaetoceros* sp.

Plate 2. *Chaetoceros* sp. and a tintinnid (top left).

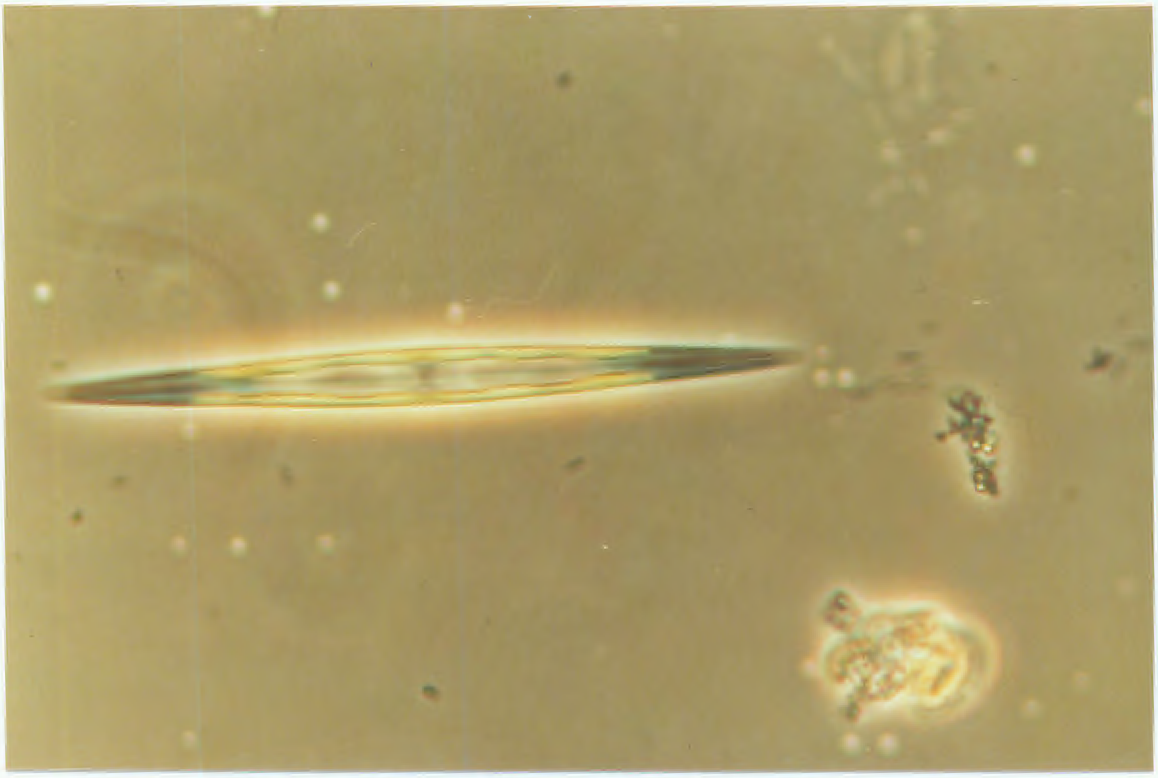


Plate 3. *Nitzschia* sp. commonly found throughout the year.

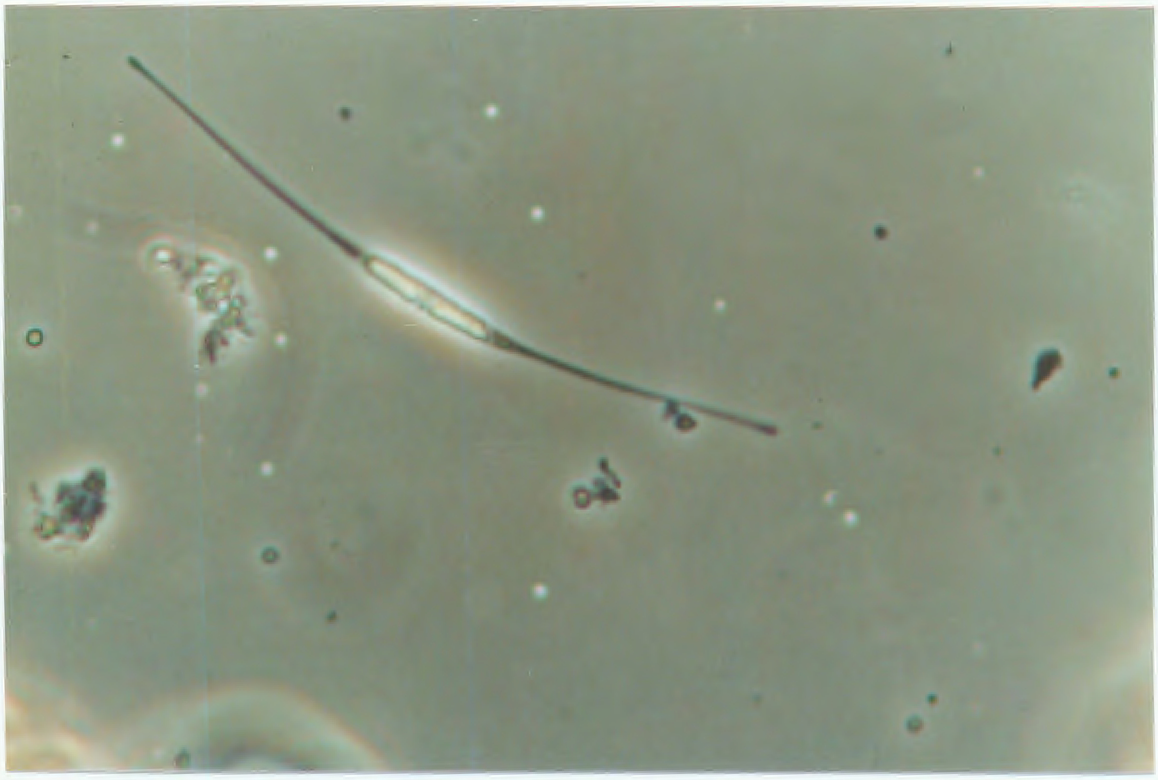


Plate 4. *Nitzschia closterium*, another common species.

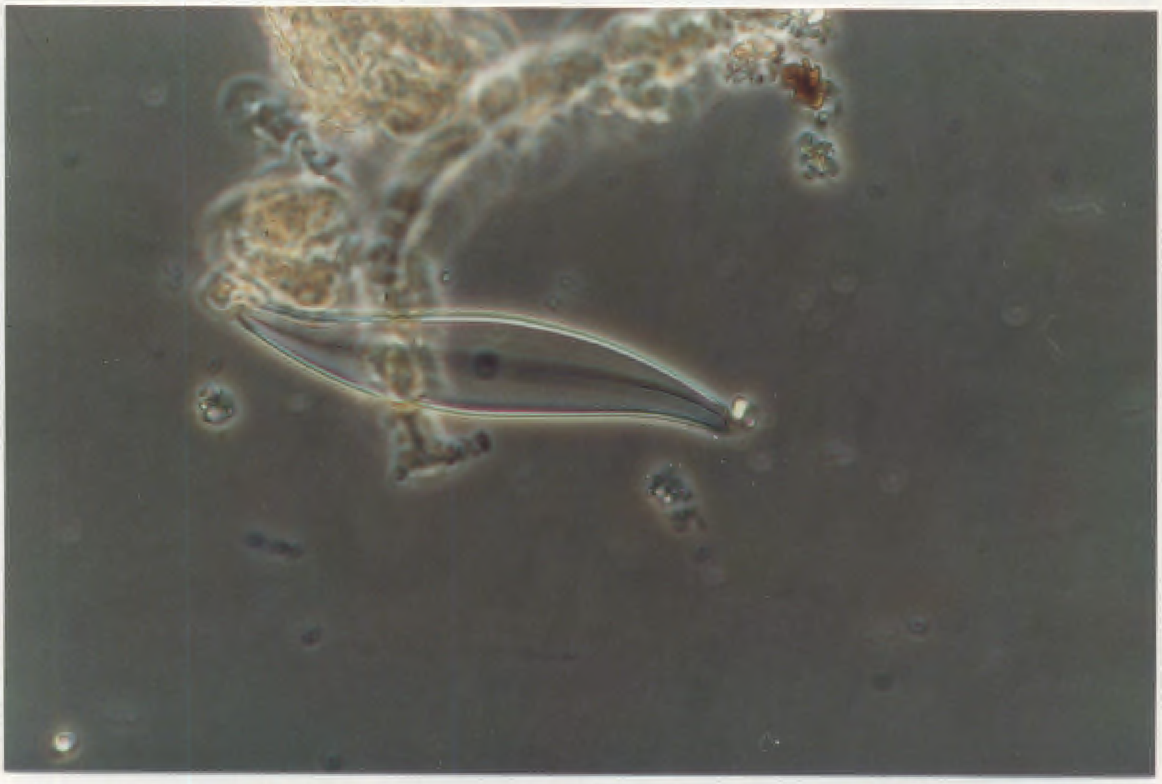


Plate 5. *Pleurosigma* sp. common throughout the year.

Plate 6. Amphiprora, *Entomoneis* sp. the most abundant species during the winter months

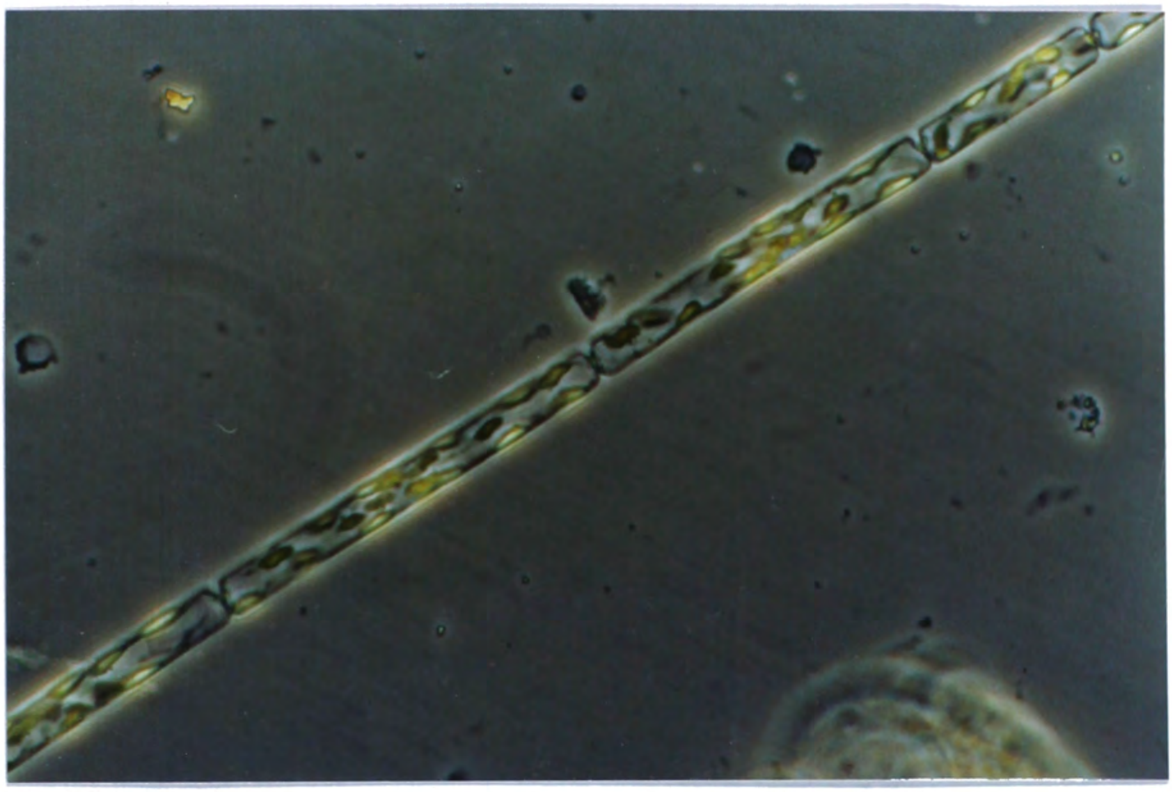


Plate 7. cf. *Leptocylindrus,* a chain forming diatom common in early spring.

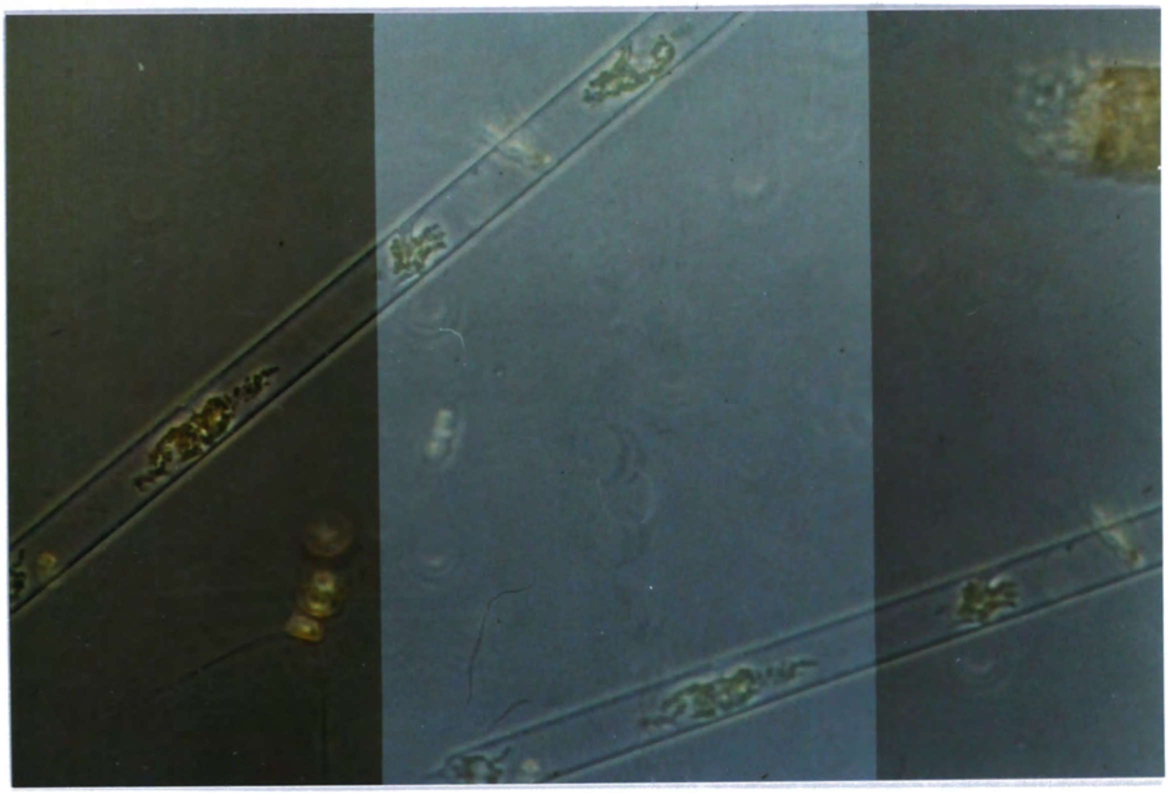


Plate 8. *Rhizosolenia styliformis,* this large diatom was totally dominant in samples collected in October, and intercalcary bands were very obvious although they did not show up in the print. Note sharp spine middle bottom.

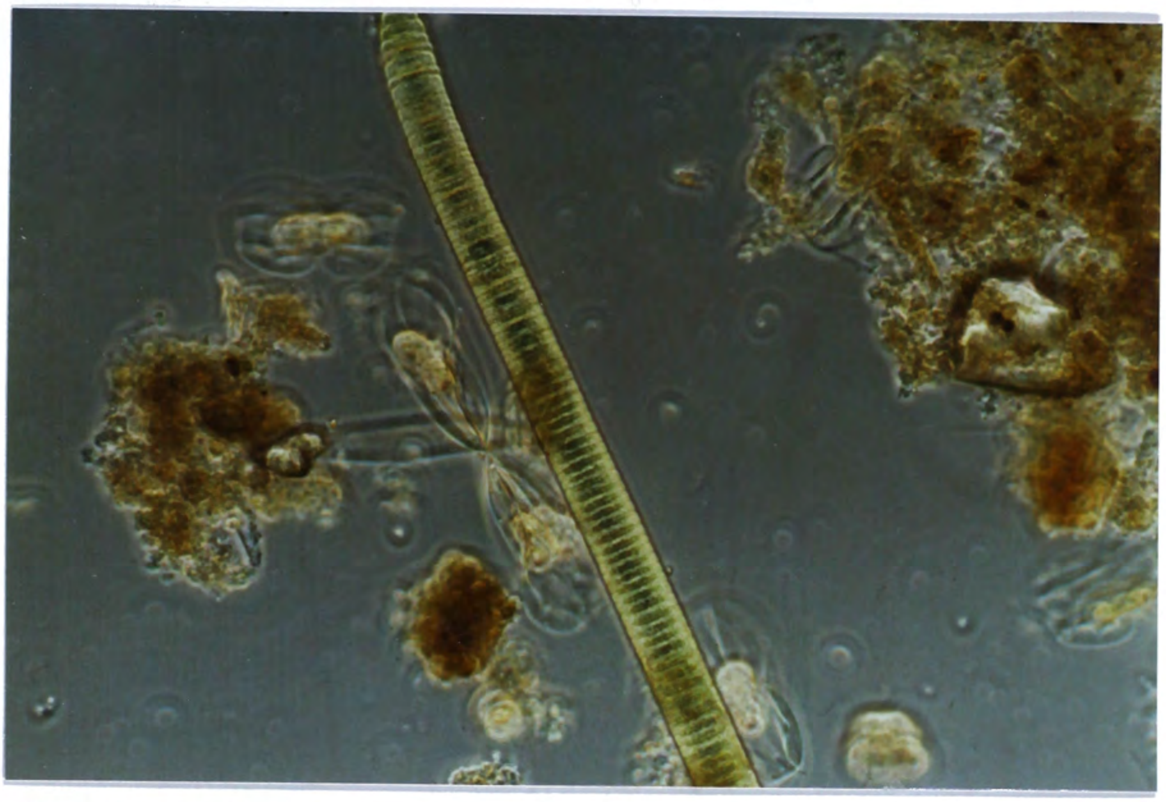


Plate 9. A strand of blue-green algae, *Oscillatoria* sp., small strands were present throughout most of the year.

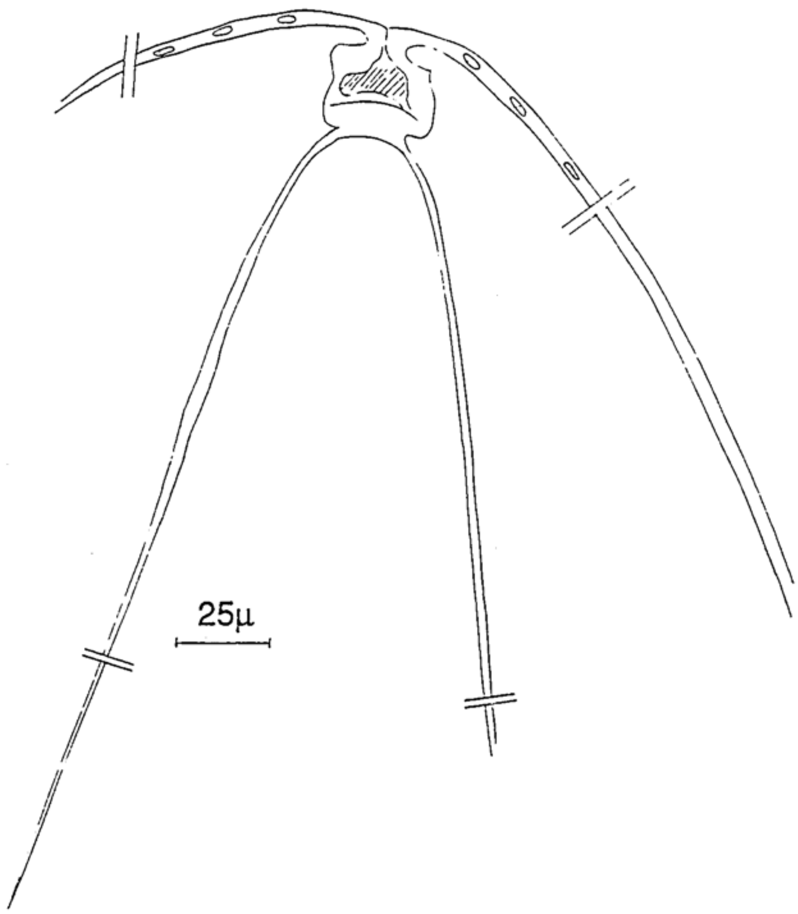


Figure 1. Large diatom cf.*Chaetoceros peruvianum*, not chain-forming.

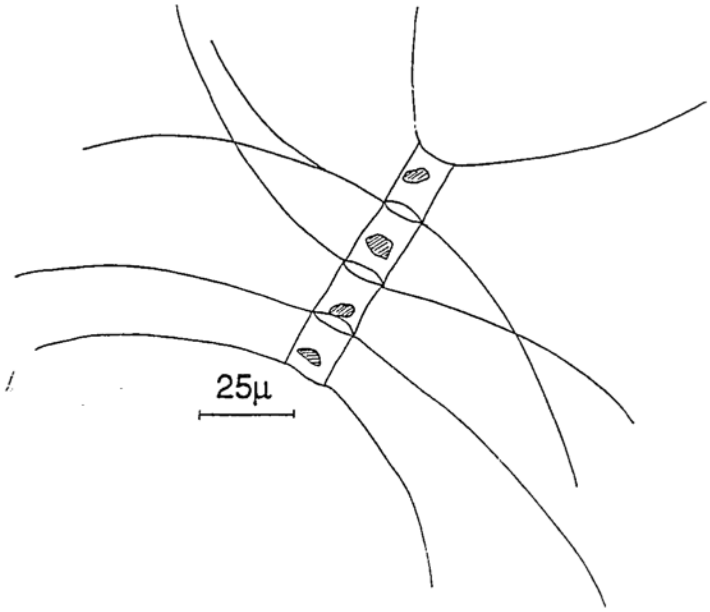


Figure 2. Chain-forming cf.*Chaetoceros lorenzianum*, a common species throughout the year.

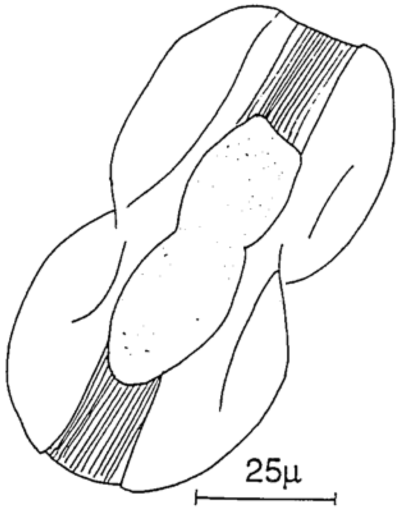


Figure 3.
A single celled Amphiprora, *Entomoneis* sp.,a common species throughout the year.

Figure 4.
Biddulphia sp. found during late winter and spring samples.

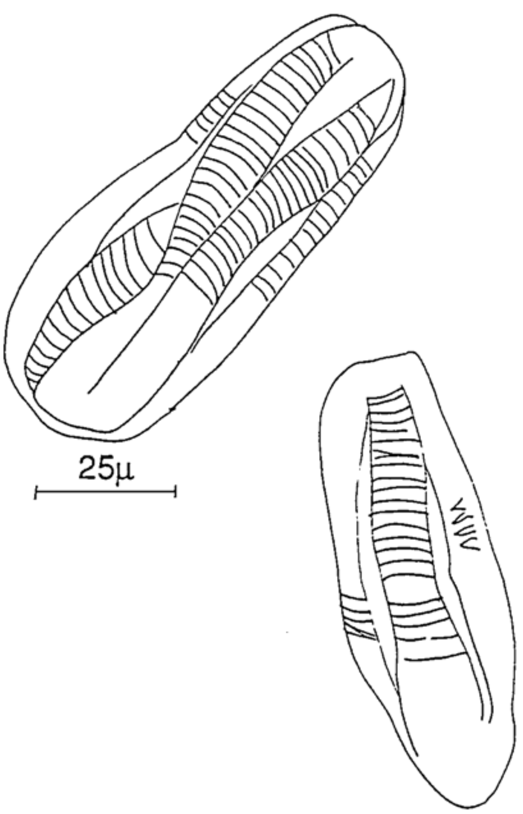


Figure 5. A species of Amphora, included as a naviculoid diatom, found in February samples.

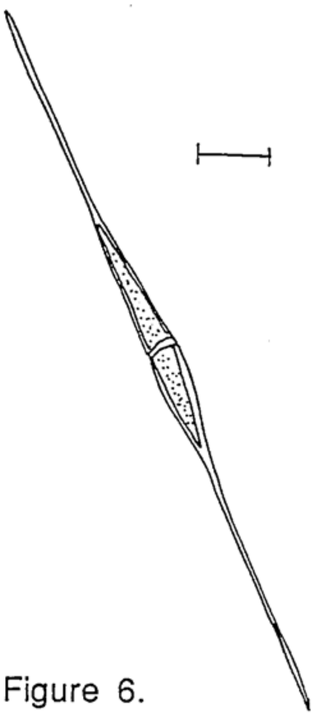


Figure 6.
Nitzschia closterium.

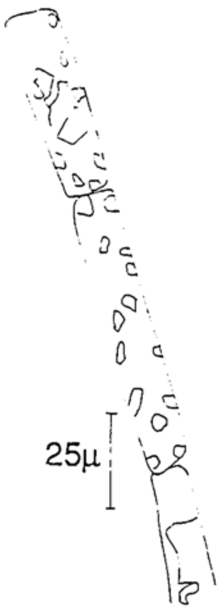


Figure 7.
Chain-forming algae,
cf. *Leptocylindrus.*

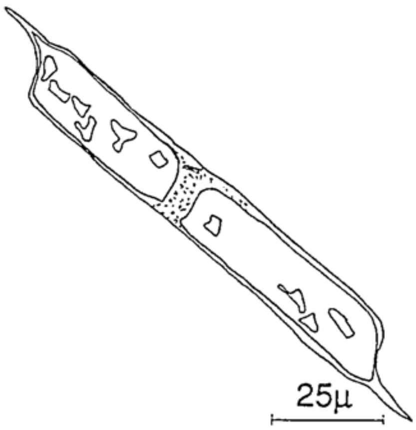


Figure 8. A large chain-forming algae, dominant in October, cf. *Rhizosolenia styliformis.*

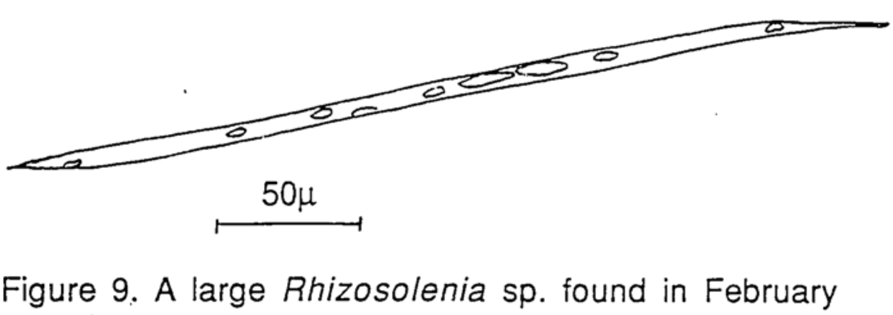


Figure 9. A large *Rhizosolenia* sp. found in February samples.

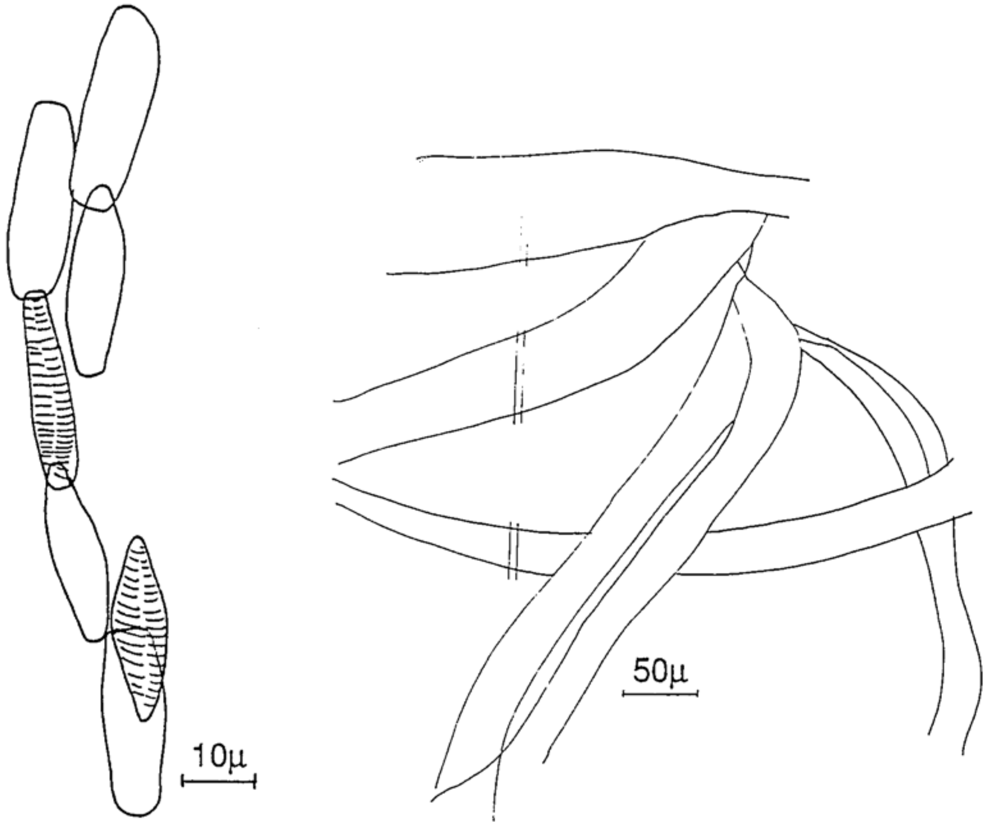


Figure 10a, 10b. A colonial naviculoid diatom which forms strands in mucous, cf. *Berkeleya* sp. found in July samples.

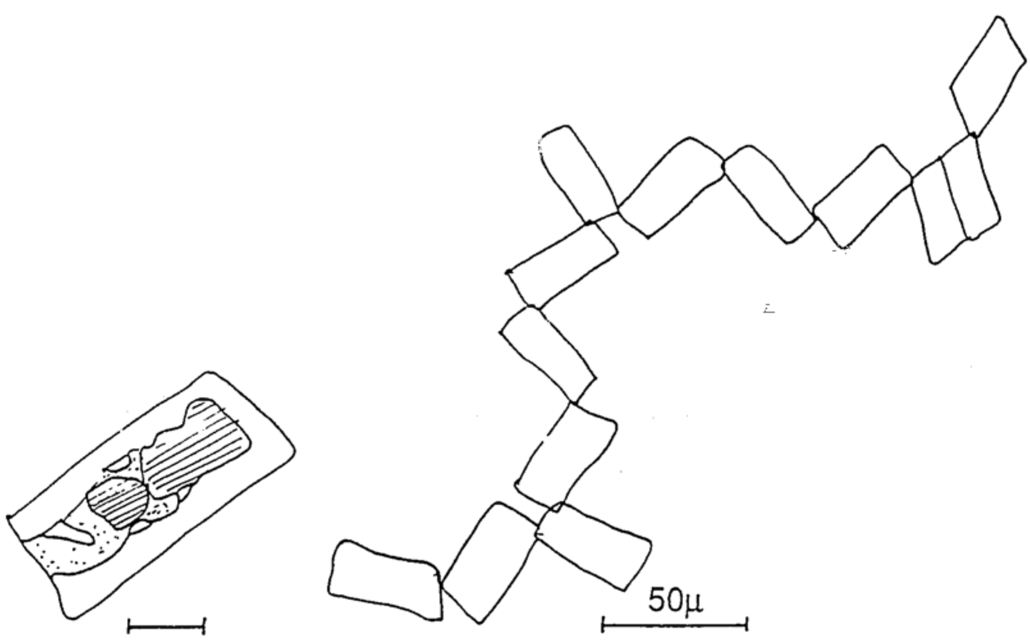


Figure 11a, 11b. Colonial diatom, cf.*Grammatophora* sp., July samples.

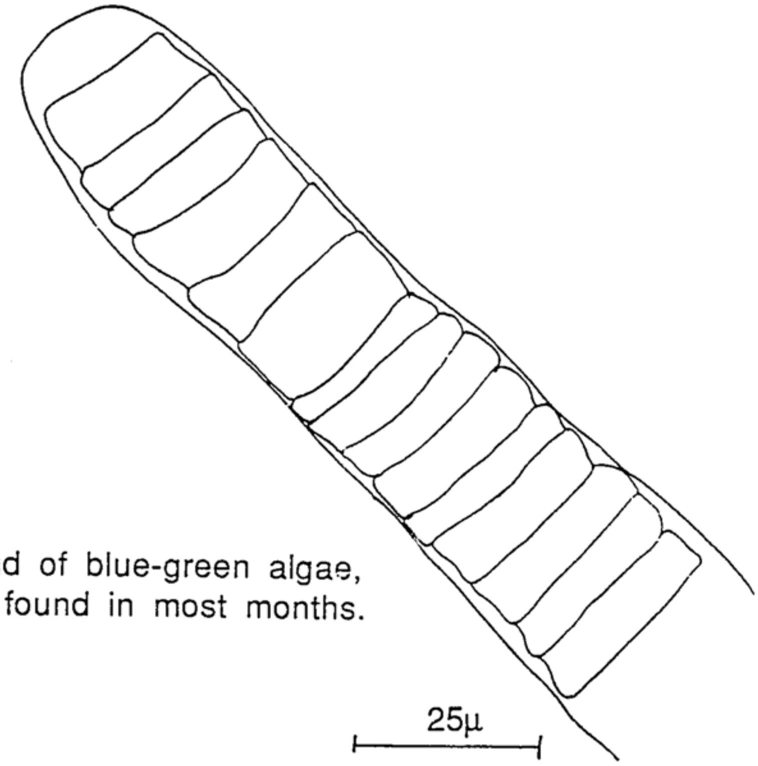


Figure 12. Strand of blue-green algae, *Oscillatoria* sp., found in most months.

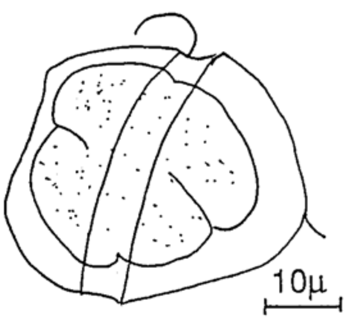


Figure 13.
Dinoflagellate, cf. *Scrippsiella* sp.

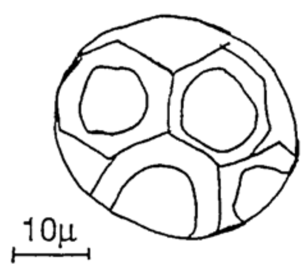


Figure 14.
A colourless chrysophyte, (Silicoflagellate), *Ebria* sp.

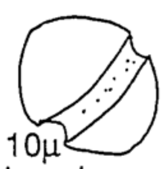


Figure 15.
Unidentified oval organism.

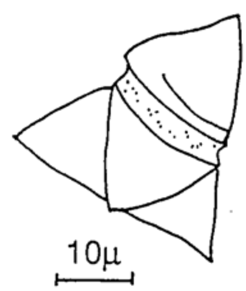
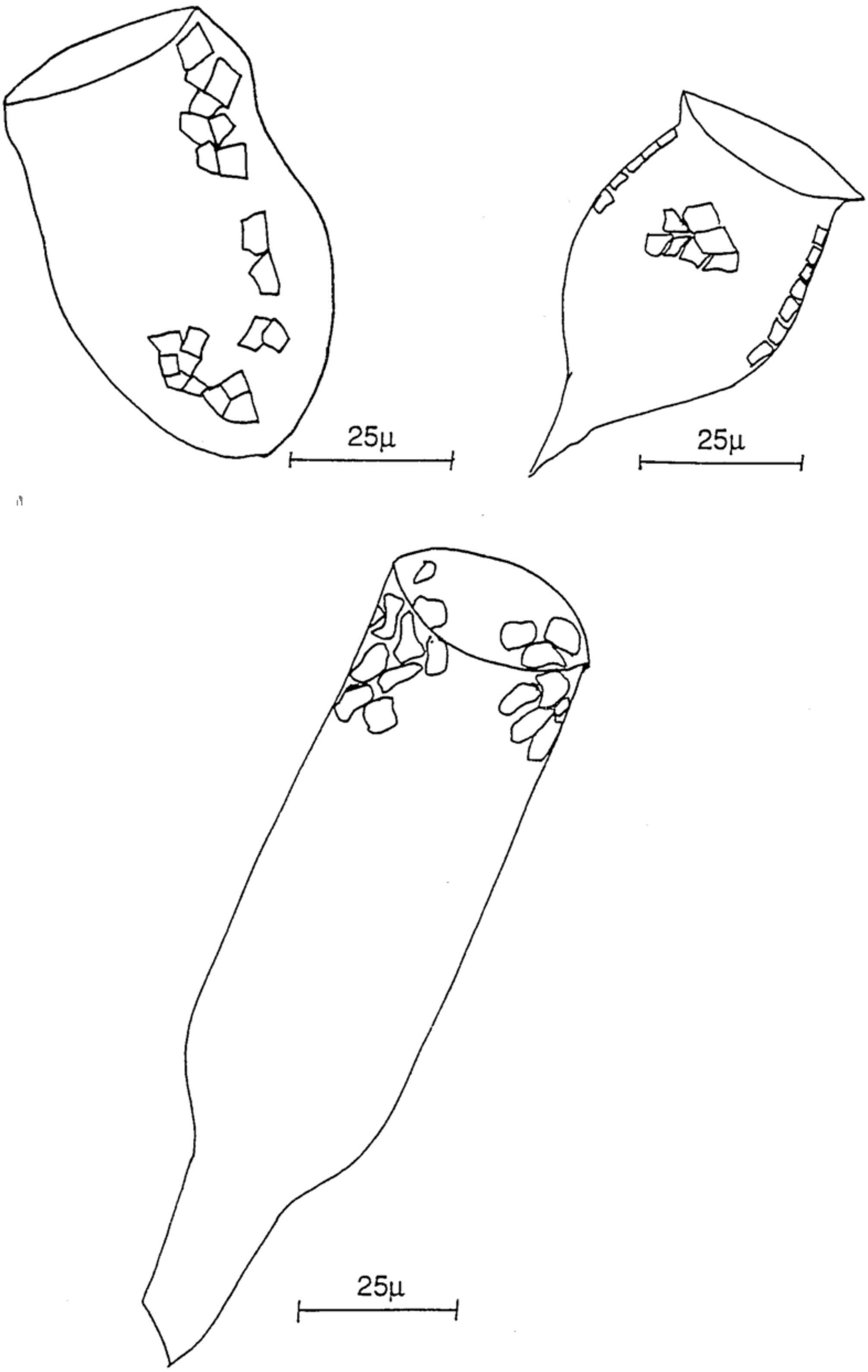


Figure 16.
Oval organism partially surrounded by shell.



Figures 17-19. Three species of tintinnids found in Orielton Lagoon.

APPENDIX C

Reports and Descriptions of the Odours

The information reported in this appendix includes all available documented information about the nature, occurence and location of the odours periodically reported from Orielton Lagoon. The information was found in Tasmanian State Government Files from the Department of Main Roads, the Department of Environment, more recently changed to the Department of Environment and Planning and from the files associated with Oreilton Lagoon held by the Department of Parks, Wildlife and Heritage.

Appendix C

1959

14/12/59 Bay covered with slimy weed, decays with obnoxious odours. This has happened over the last two years. (DMR Files,1959).

1973

20/3/73 High smells

1975

27/4/75 Odour noted in SE corner, pungent

21/5/75 Odour noted in SE corner, abated a bit.

6/6/75 Not as noticable, ambient temperature dropping.

1/7/75 Not as noticable, low, raining.

16/7/75 Non exisent

1/8/75 Barely noticable in SE corner, overcast.

12/8/75 Barely noticable in SE corner, overcast.

10/9/75 Change in wind direction, noticable at middle of lagoon, fair.

26/11/75 D of E survey. No actual reports at this time. Odour described as similar to rotting weed, rotting animals, lasts 4-5 hrs, 2-3 times a week. Worst in sea breeze, NE and SE. Others identified 2 odours, vegetable matter and sewage odour, the latter was considered the problem. Still others described the odour as similar to dead animals, silage pit odour, an old fashioned toilet, septic tank and a night cart. It was also compared to the sulphur smell at Rotorura, NZ. One lady said that the smell had become less offensive over the last 16 years, ie since 1959.

1978

8/9/78 R. Buttermore investigated odours and found decomposing Ruppia maritissa but this did not smell neither did the STP.

1981

26/11/81 Offensive odour from green weed on lagoon

27/11/81 Same as above.

1983

14/12/83 Five complaints invesigated, STP appeared to be working well but here was decomposing algae on the shore. The problem appears to have been present for two weeks.

1984

13/2/84	Letter complaining of the odour accompanied by rotting vegetation.
31/3/84	Letter to Mercury complaining about odour.
21/12/84	Odour from STP as opposed to lagoon, rotting vegetation in SW corner. Rotting anaerobically but not giving rise to any odour unless disturbed.

1985

3/12/85	Faint odour in vicinity of STP, also from sludge disposal area where dumping had occured recently. Rotting algae in bays giving off stench. A bad accumulation of rotting algae in SW corner. Could not identify which plants were decomposing but appeared to be mostly algae. Generally appeared worse than last year. SE corner accumulated debris drying out with no odour.

1989

20/9/89	Complaints about smell.
21/9/89	Smelt
22/9/89	Three complaints about smell, present for the last few days.
2/10/89	Complaint about smell.
9/10/89	Constant smell, getting worse.
	Oct/89 Large areas of algae on the surface, green slimy with long strands. Along Midway Pt. side, near Sorell side and a bit up near the golf course.
16/10/89	Eleven complaints concerning odour since 7/10/89.
17/10/89	Terrible smells the worst in 7 years.
24/10/89	Green algal mat, smell from the lagoon.
25/10/89	Complaint about smell.
31/10/89	Smelt by Sorell residents.
3/11/89	Complaint about smells for past few months.
6/11/89	Individual has made three complaints since 1/9/89.
8/11/89	Smells at Midway Pt..

1990

Jan /90	Foul stenches from the lagoon.
10/1/90	Offensive smells from the lagoon.(D of E. Files, 1972-91)