Nutrient water quality Avon-Heathcote Estuary/Ihutai

Inputs, concentrations and potential effects

Report No. U05/71

Prepared by
Lesley Bolton-Ritchie
Malcolm Main

June 2005

Environment Canterbury
Your regional council

Report U05/71

58 Kilmore Street
PO Box 345
Christchurch
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru
Phone (03) 688 9069
Fax (03) 688 9067

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

Executive Summary

The Avon-Heathcote Estuary/Ihutai is close to Christchurch City and is a place special to the people of this city. This estuary is the natural habitat for a diverse and abundant community of birds and aquatic flora and fauna. It is also a recreational playground for a wide range of water-based (sailing, wind surfing, kite surfing, kayaking, jet skiing, fishing) and shore-based (walking, bird watching, picnicking) activities.

This report focuses on the concentrations of nutrients in the estuary water.

There are numerous sources of nutrients to estuary water. These sources are:

- the effluent discharged from the Bromley sewage treatment works oxidation ponds.
- the toe drains that receive the seepage from the oxidation ponds, land drainage and stormwater.
- the Avon and Heathcote rivers.
- Charlesworth, Lovett's, City Outfall and Estuary drains
- the 67 or more stormwater outlets around the perimeter of the estuary.
- the nutrients stored in the sediments.
- the nutrients released by the decomposition of macroalgae.
- the diverse and abundant community of birds.

The volumes of effluent, toe drain water and river water discharged into the estuary have been well documented while the volumes from the drains and stormwater outlets have not. Nutrient concentrations in the effluent, toe drain water, drain water and river waters have also been well documented. The quantity of nutrients supplied to estuary water from estuary sediments, decomposing macroalgae, stormwater and the birds is unknown.

Nutrient data have been collected from the Avon-Heathcote Estuary/Ihutai by or in association with Environment Canterbury over the periods 1989-1999 and 2002-2005. A high median and large range in concentrations of each nutrient were found at sites in close proximity to one or more large nutrient source/s. At sites further from such nutrient sources the median concentrations were lower and the concentration ranges smaller. The highest medians and largest ranges in nitrate and nitrite-nitrogen (NNN) concentrations occurred at sites close to the Avon and Heathcote river mouths. The highest medians and largest ranges in ammonia-nitrogen (NH_3N), total nitrogen (TN), dissolved reactive phosphorus (DRP) and total phosphorus (TP) concentrations occurred at the site closest to the oxidation ponds.

The ANZECC (2000) NNN, NH_3N, TN, DRP and TP trigger values were exceeded at all sites. However, at sites closer to the mouth of the estuary the trigger values were not exceeded in as many samples as they were in samples collected from sites in proximity to the river mouths and the effluent discharge point. These results indicate that nutrient concentrations in this estuary have the potential for adverse biological effects i.e. excessive growth of phytoplankton and macroalgae.

The green alga *Ulva* spp. and *Enteromorpha* sp. and the red alga *Gracilaria chilensis* often proliferate (form algal mats) in this estuary over the summer. The distribution and abundances of these algae vary considerably between years. In this estuary, the sediment beneath *Gracilaria chilensis* has been found to be anoxic and only inhabited by highly tolerant opportunistic benthic invertebrates. The *Ulva spp.* habitat supports a higher richness of benthic invertebrates than habitats with no macroalgae, which suggests that *Ulva* spp. provides cover and substrate for some species (Bressington, 2003). The seasonal proliferation of these macroalgae leads to the accumulation of decaying, rotting odour-forming algal masses along the shoreline in some areas. The sediment under these rotting masses becomes anoxic and devoid of benthic invertebrates (Bressington, 2003). There is no information on the species of phytoplankton present in this estuary and there are no records of phytoplankton blooms.

There are concentrations of ammonia-nitrogen in some areas of this estuary that are potentially toxic to estuarine life. These potentially toxic concentrations occurred at sampling sites closer to than further away from, the effluent discharge point. The closer the site to the discharge point the higher the percent of samples having concentrations exceeding ANZECC (2000) trigger values and USEPA (1989) criteria continuous concentrations. It is speculated that the high ammonia-nitrogen concentrations could be responsible for the apparent decline in the estuary population of globefish (has no commercial or recreational fishing value) over time. There have also been declines in the abundance of other fish species in this estuary. However there are no data to determine if this effect is caused by high ammonia-nitrogen concentrations.

Table of Contents

List of Figures

List of Tables

1 Introduction

The Avon-Heathcote Estuary/Ihutai is a 720 hectare triangular-shaped, semi-enclosed shallow body of water formed behind an approximately 4km long sand spit (Figure 1.1). The Heathcote River enters at the western apex of the triangle and the Avon River on the northern apex, with the mouth at the eastern apex. The total catchment of this estuary is about 190 km^2. The estuary is tidal with about 8.5 x 10^6 litres of sea water entering on each mean flood tide (Robb, 1976).

The Avon-Heathcote Estuary/Ihutai is the natural habitat for a diverse and abundant community of birds and aquatic flora and fauna. With this estuary being close to Christchurch City (population of 344,100, June 2004), it is also a place special to the people of this city. This estuary is valued by city residents for its open space, the rich variety of bird life, mahinga kai and the marine ecosystem. It is also a recreational playground for a wide range of water-based (sailing, wind surfing, kite surfing, kayaking, jet skiing, fishing) and shore-based (walking, bird watching, picnicking) activities. The downside of its close proximity to a large human population are, with respect to water quality and the health of the estuary, the impacts from stormwater runoff and point discharges and the discharge of large volumes of treated sewage. Such runoff and discharges input nutrients, bacteria and viruses, dissolved metals such as Cr, Cu, Zn, and organic compounds e.g. PAHs, PCBs, pesticides and herbicides, into the estuary water.

This report will focus on the concentrations of nutrients in the estuary water. The first investigation on the nutrient status of this estuary was carried out between December 1950 and December 1951 (Bruce, 1953). This was followed by the work of Hogan and Wilkinson (1959) between February 1955 and March 1956. In 1973, Knox and Kilner, after the collection of water quality data in 1971, completed a comprehensive evaluation of the sources and nutrient status of this estuary. The North Canterbury Catchment Board and Regional Water Board (NCCB) (now Environment Canterbury (ECan)) collected water nutrient data at various sites between February and November 1975 and July and September 1984 (unpublished) and then routinely at seven sites between 1989 and 1999. More recently community group volunteers, in association with ECan, have been collecting water nutrient samples over the summer months.

The primary focus of this document is to present Avon-Heathcote Estuary/Ihutai water nutrient data that have been collected by, or in association with, ECan. This data evaluation provides the basis for the design of the future water quality sampling strategy that ECan will undertake in this estuary. This document will also present information on the present nutrient inputs into the estuary and assess the effects of the current nutrient concentrations on the functioning of the estuary ecosystem. These parts of the report are in line with Goal 2 (and its included targets) in the Ihutai Management Plan, 2004 (Avon-Heathcote Estuary Ihutai Trust, 2004). Thus, this document consists of four parts, these being:

- An assessment of nutrient inputs into the estuary
- A summary and analysis of the nutrient data that have been collected from the Avon-Heathcote Estuary/Ihutai by or in association with Environment Canterbury since 1989. There are two sets of data:
  - Samples collected routinely by ECan staff at seven sites between 1989 – 1999
  - Samples collected routinely by community group volunteers over the summers of 2002-2005
- An assessment of the effects of the nutrient concentrations present on the marine ecosystem (pelagic and benthic) in the estuary
- Proposed future sampling.

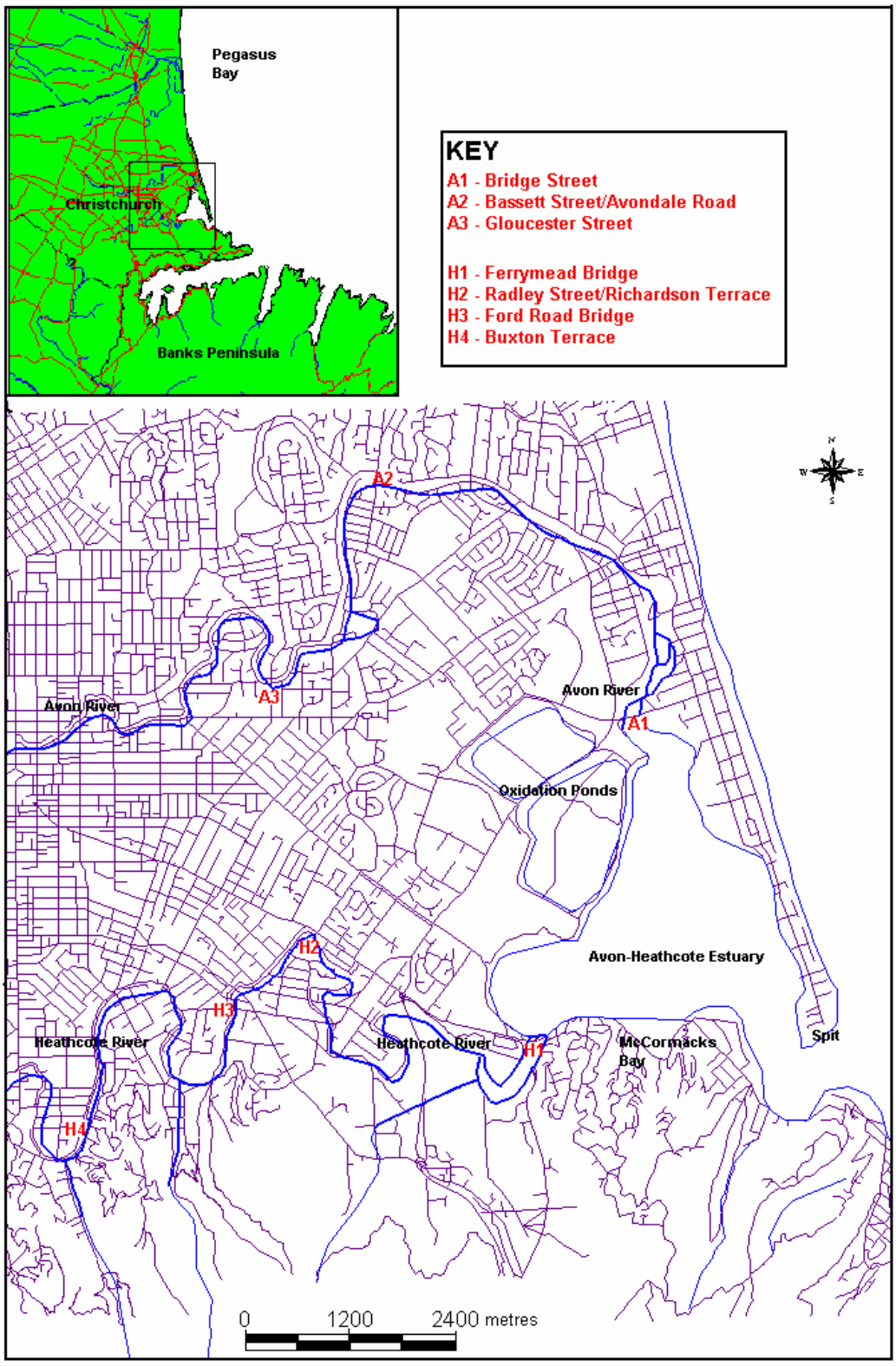


Figure 1.1 The Avon-Heathcote Estuary/Ihutai. Location, rivers and river sampling sites

2 Inputs

2.1 Wastewater treatment plant

2.1.1 Oxidation ponds

Effluent from the Bromley sewage treatment works has always been the largest discharge to the Avon-Heathcote Estuary. The discharge began in 1882, when treatment was by settling ponds and spreading of effluent over paddocks, from where it percolated through the sand to the estuary. Later the settling ponds were replaced by large septic tanks. A plant incorporating settling tanks, trickling filters and oxidation ponds was commissioned in 1962. Improvements to the treatment works, including the oxidation ponds, were completed in 1971, again in 1978, 1996 and 2004.

The effluent from the oxidation ponds (Figure 2.1) has been discharged to the estuary since the ponds were commissioned. Prior to 1973 the discharge from the ponds was continuous, but since July 1973 the effluent has only been discharged into the estuary on the ebb tide. Between 1972 and November 1992 the discharge to the estuary was through two weir structures, one at the northern end of pond 5 and one at the southern end of pond 6. Between November 1992 and March 1994, when pond 6 was out of service, the effluent was discharged through 2 weirs, one at each end of Pond 5. From March 1994 to April 2004 the effluent was discharged from the 2 weirs of Pond 5 and the weir of Pond 6. Following the latest upgrade to pond 6 (in 2004) the effluent is now discharged through one outlet that is located at the southern end of pond 6.

The volume of wastewater discharged from the oxidation ponds has increased steadily since 1962. Over 1995-1996 the mean volume of discharge was 155,000 m^3/day (6 m^3/s), with peak wet weather volumes of up to 450,000 m^3/day (URS, 2001). In 2001 the mean volume was 160,000 m^3/day (6.1 m^3/s) with the mean volume expected to be 200,000 m^3/day (7.6 m^3/s) by 2026 (URS, 2001). At present the existing consent (commenced 23/10/2003) allows for peak wet weather volumes of up to 500,000 m^3/day at a maximum rate of 17.4 m^3/s to be discharged into the estuary for four hours (1 hour before and three hours after high tide) in each tidal cycle (which is approximately 12.5 hours long) (URS, 2004).

Nutrient concentrations, in the Bromley oxidation ponds (from where the effluent is then discharged into the estuary), have been monitored for many years. The data collected (www.ccc.govt.nz/wastewater/treatmentplant/DischargeConsentMonitoring.asp; URS, 2001) by the Christchurch City Council are summarised in Table 2.1. These data indicate that over time there has been an increase in the concentrations of total ammonia-nitrogen (NH_3N), total nitrogen (TN) and total phosphorus (TP), a decrease in the median concentrations of nitrite-nitrogen (NO_2^-), nitrate-nitrogen (NO_3^-) and small changes in dissolved reactive phosphorus (DRP) concentrations in the wastewater discharged. The combination of the increasing volume and the changes in nutrient concentrations means that over time there has been an overall increase in the amount of NH_3N, TN, DRP and TP and an overall decrease in the amount of NO_2^- and NO_3^- discharged into the estuary from the oxidation ponds.

In 1972 Knox and Kilner (1973) and Robb (1973) estimated that the discharged effluent contributed 80% of the nitrogen and 94.4% of the phosphorus input to the estuary. More recently, O'Connor (2001) estimated that the effluent discharged now contributed 90% of the nitrogen and 98% of the phosphorus input to the estuary.

2.1.2 Toe drains

Wastewater from the oxidation ponds seeps through the adjacent land into the toe drains (Northern and Southern toe drains) either side of the oxidation ponds. Land drainage and stormwater from the surrounding areas also enters these drains. The water in these drains then flows into the estuary (Figure 2.1).

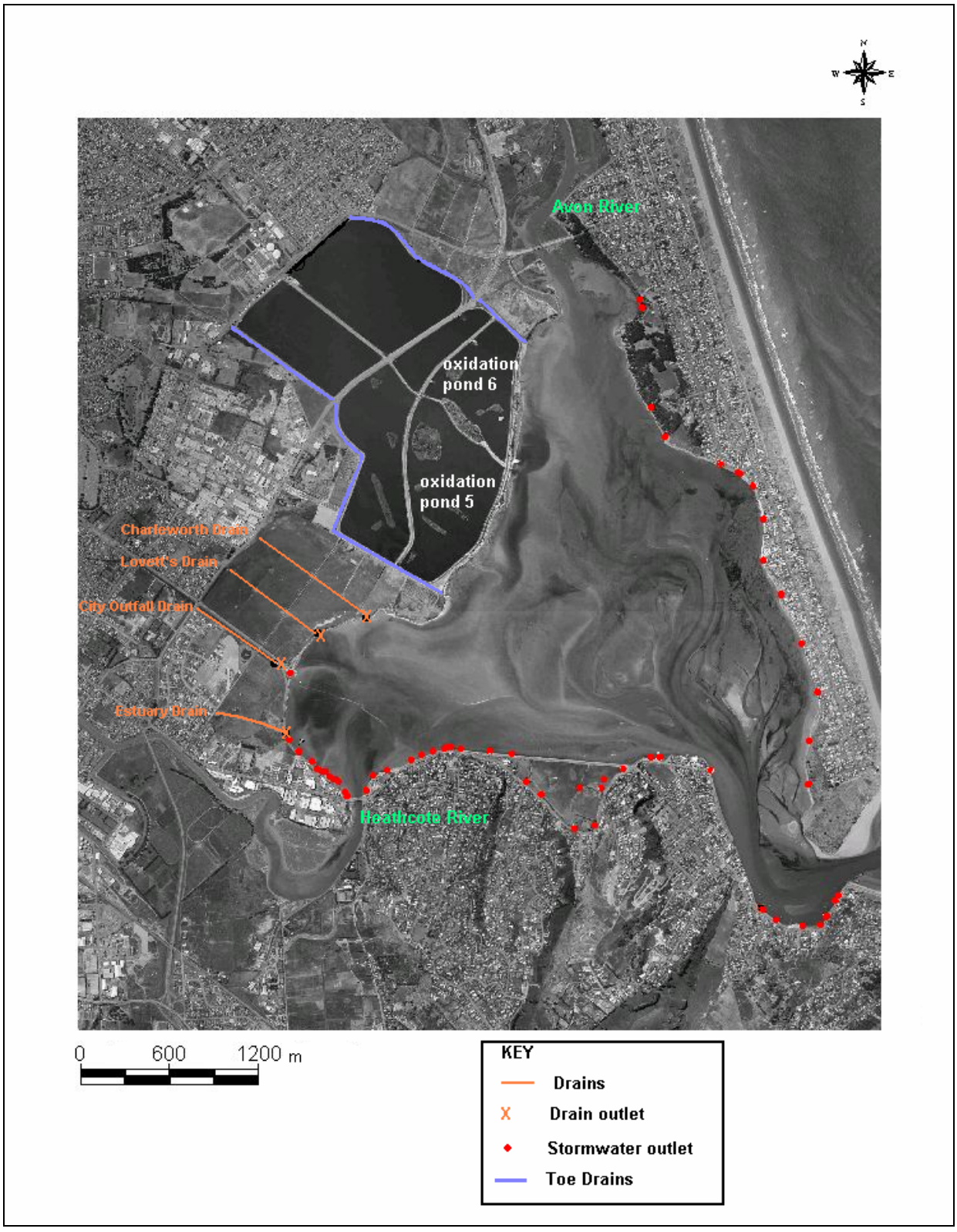


Figure 2.1 **Location of the oxidation ponds and the drain and stormwater outlets around the perimeter of the Avon-Heathcote Estuary/Ihutai**

Table 2.1 Median and maximum concentrations of nutrients from the Bromley oxidation ponds during 1986-1999, 2000 and 2004

n=number of samples

	Units	n	Median	Maximum
1986-1999				
Ammonia-nitrogen	mg/L	216	22.6	43.7
Nitrite-nitrogen	mg/L	135	0.1	4.65
Nitrate-nitrogen	mg/L	135	0.2	5.8
Total nitrogen	mg/L	216	32	56.8
Dissolved reactive phosphorus	mg/L	199	5.2	8.2
Total phosphorus	mg/L	196	6.1	10.6
2000				
Ammonia-nitrogen	mg/L	41	26	33
Nitrite-nitrogen	mg/L	6	0.06	0.42
Nitrate-nitrogen	mg/L	7	0.11	0.52
Total nitrogen	mg/L	37	32.9	44.9
Dissolved reactive phosphorus	mg/L	23	4.3	5.8
Total phosphorus	mg/L	22	6.3	11.7
2004				
Ammonia-nitrogen	mg/L	95	27.8	37.1
Nitrite-nitrogen	mg/L	91	0.03	0.37
Nitrate-nitrogen	mg/L	91	0.14	0.37
Total nitrogen	mg/L	94	33.8	40
Dissolved reactive phosphorus	mg/L	94	5.5	7
Total phosphorus	mg/L	92	6.95	11

Given the variety of sources and the variation in the volume of rainfall, there is a large variation in both the flow and quality of water in these drains. During a dry weather period in March 2001 the flow from the Northern toe drain was 290 m^3/day and from the Southern toe drain was 70 m^3/day. The existing consent (commenced 23/10/2003) has set conditions on these drains so that weir systems are constructed on each drain to ensure that when discharging to the estuary, the northern toe drain retains a flow of 51 L/s and the southern toe drain retains a flow of 12 L/s.

Nutrient concentrations in each toe drain have been monitored by the Christchurch City Council for a considerable period of time (Table 2.2). The concentrations in the toe drains reflect the concentrations in the oxidation ponds.

Table 2.2 Nutrient concentrations in the Northern and Southern toe drains during 1991-1997 * and 1998-2005 **

data from URS, 2001*
data supplied by CCC**

	Units	Northern toe drain		Southern toe drain	
		Median	Maximum	Median	Maximum
1991-1997					
Ammonia-nitrogen	mg/L	43	50	30	39
Nitrate-nitrogen	mg/L	0.2	4.2	0.4	1.9
Dissolved reactive phosphorus	mg/L	0.27	0.82	1.1	2.1
1998-2005					
Ammonia-nitrogen	mg/L	46	52	32.99	41.24
Nitrate -nitrogen	mg/L	0.12	1.15	0.47	2.70
Nitrite-nitrogen	mg/L	0.014	0.054	0.038	0.089
Dissolved reactive phosphorus	mg/L	0.195	1.60	2.13	6.30
Total phosphorus	mg/L	2.8	4	3.8	4.6

2.1.3 Seepage

Wastewater in the oxidation ponds seeps through the land between the oxidation ponds and the estuary. This seepage has the potential to be a small source of nutrients to the Avon-Heathcote Estuary/Ihutai.

2.2 Avon and Heathcote rivers

The Avon and Heathcote rivers are spring-fed, low-gradient, single-thread rivers that rise on the western margin of Christchurch. Both flow in old channels of the Waimakariri River, and the Avon-Heathcote Estuary is their common outlet. The Avon River and tributaries have a predominantly urban (residential and commercial use) catchment of about 85 km^2 and the Heathcote River and tributaries have a rural, hill and urban (residential and industrial) catchment of about 104 km^2. Numerous stormwater drains discharge into both of these rivers and in the past effluents from a wide range of industries also discharged into the Heathcote River in particular (Knox and Kilner, 1973). In the mid-1960s it was estimated that more than 2900 kg/day of BOD_5 was contributed to a 5km reach of the Heathcote River from woollen mills, rubber factories, woolscour, a fellmongery, a soap and candle factory, malt works, gas works, battery manufacturing, abbattoirs, dairy companies and textile industries (Robb, 1976). Stormwater contributes nitrogen and phosphorus compounds along with rubbish, sediments, pathogens, organic matter and chemical contaminants such as heavy metals and organic compounds into the rivers (Vincent and Thomas, 1997).

The flows in the Avon River are dominated by the groundwater source with stormwater runoff making up a very small portion of the total flow (McKerchar, 2001). The annual mean flow of the Avon River has been estimated at 3.2 m^3/s by Mawson (unpublished) cited by Knox and Kilner (1973) and at 2.7 m^3/s by Robb (1976). More recently, recorded monthly mean flows at the Gloucester Street Bridge have ranged from 1.265 m^3/s (March 1992) to 2.805 m^3/s (September 1995) with a median flow of 1.722 m^3/s and flows exceeding 1.26 m^3/s 99% of the time (McKerchar, 2001). However, flows in excess of 5 m^3/s have been recorded at Gloucester Street during high rainfall events (McKerchar, 2001). The estimated average annual flow volume, at Gloucester Street over the period 1991 to 1999, was approximately 60 million m^3 (Pratt, 2000).

The flows in the Heathcote River are dominated by the groundwater source. However, stormwater inputs also have an influence, particularly in winter when there is runoff from the Port Hills (McKerchar, 2001). The annual mean flow in the Heathcote River has been estimated at 1.0 m^3/s by Mawson (unpublished), cited by Knox and Kilner (1973), and at 0.89 m^3/s by Robb (1976). More recently, recorded monthly mean flows at Buxton Terrace have ranged from 0.448 m^3/s (March 1992) to 3.3 m^3/s (August 1992) with a median flow of 0.753 m^3/s and flows exceeding 0.436 m^3/s 99% of the time (McKerchar, 2001). Flows in excess of 6.5 m^3/s have been recorded at Buxton Terrace during high rainfall events (McKerchar, 2001). The estimated average annual flow volume, at Buxton Terrace over the period 1991 to 1999, was approximately 33 million m^3 (Pratt, 2000).

The mean nutrient concentrations recorded from the Avon River at Bassett Street/Avondale Road and from the Heathcote River at Radley Street/Richardson Terrace over the period of 1955 to 1984 are presented in Table 2.3. These sites were selected on the basis that they were unlikely to be influenced by nutrients from the estuary flowing upstream on the incoming tide. From these data, it is evident that the reduction of trade effluent discharged into the Heathcote River by the reticulation of industrial effluents to the trade waste sewer during the early 1970s, resulted in a reduction in nitrate-nitrogen and ammonia-nitrogen concentrations in the river.

The Heathcote River has always had higher mean concentrations of nitrogen than the Avon River. At times this has been attributed not only to the direct discharges to the lower Heathcote, but also to non-point contamination sources as a result of agricultural activity in the upper Heathcote catchment (Hogan and Wilkinson, 1959; Robb, 1973). However, the water in the springs, which are the source of the Heathcote River, has higher concentrations of nitrate-nitrogen than those that feed the Avon River (ECan data). This is possibly because the source of recharge water for the Avon River springs is the Waimakariri River, which in turn has lower concentrations than the groundwater that is believed to feed the Heathcote River source springs.

The Christchurch City Council has sampled both the Avon and Heathcote rivers routinely for some time. These data have been reported as median values by Gilson and Mitchell (1999) and are re-presented in Table 2.4 of this report.

2.3 Drains

The Charlesworth Drain, City Outfall Drain (Canal Reserve Drain), Lovett's Drain and Estuary Drain discharge into the Estuary between the Heathcote River Mouth and Sandy Point (Figures 2.1 and 2.2). The water in these drains has been routinely sampled and analysed for nutrients and other contaminants by the Christchurch City Council since 1998 (Table 2.5). The median and maximum concentrations of each nutrient are drain-specific. Within each drain the median ammonia-nitrogen, nitrite-nitrogen and dissolved reactive phosphorus concentrations are generally higher than the concentrations recorded in the Avon and Heathcote rivers but lower than those in the oxidation ponds. For nitrate-nitrogen, median concentrations within each drain were lower than the concentrations recorded in the Avon and Heathcote rivers but higher than those in the oxidation ponds. There are no data on flow rates and the annual volumes discharged via these drains into the estuary. However, given the concentration of, in particular ammonia-nitrogen, there is a considerable input of nutrients to the estuary from these drains.

2.4 Stormwater

There are at least 67 outlets (Figure 2.1) through which stormwater is discharged directly into this estuary. The outlets come in all shapes and sizes, with some examples of the outlets shown in Figure 2.3 (outlet details in Appendix I). In addition, there are 46 small outlets (6-10 cm diameter) through which it is assumed that stormwater is also discharged. Many of the small outlets originate from private residential properties.

Table 2.3 Mean nutrient concentrations at Bassett Street/Avondale Road on the Avon River (A) and Radley Street/Richardson Terrace on the Heathcote River (H) over various time periods between 1955 and 1984

* Hogan and Wilkinson, 1959
** Webb, 1965
*** Cameron, 1970
\# Knox and Kilner, 1973
NCCB unpublished data

		1955-1956 *		1964 **		1968 ***		1971-1972 #		1975 ##		1984 ##	
	Units	A	H	A	H	A	H	A	H	A	H	A	H
Ammonia- nitrogen	mg/L	0.05	0.3	-	0.23	-	0.25	0.1	0.55	-	0.13	-	0.12
Nitrate-nitrogen	mg/L	-	-	-	3	-	5.1	0.5	1.4	-	2.35	1.19	1.61
Nitrite-nitrogen	mg/L	-	-	-	-	-	-	0.015	0.055	-	0.019	0.017	0.058
Total phosphorus	mg/L	-	-	-	-	-	-	-	-	-	0.25	-	-
Dissolved reactive phosphorus	mg/L	-	-	-	-	-	-	0.05	0.02	-	0.06	-	-

Table 2.4 Summary of nutrient concentrations (mg/L) at Gloucester Street on the Avon River and at Ford Road bridge on the Heathcote River

(Data collected by CCC and reported in Gilson and Mitchell, 1999)
n = number of samples

	Avon River 1991-1997	Heathcote River 1989-1997
Ammonia nitrogen		
Minimum	0.01	0
Median	0.04	0.04
Mean	0.05	0.09
Standard Deviation	0.04	0.17
Maximum	1.9	1.2
Nitrate- nitrogen		
Minimum	0.5	0.3
Median	1.2	1.8
Mean	1.23	1.8
Standard Deviation	0.33	0.53
Maximum	2.1	3.9
Nitrite-nitrogen		
Minimum	0.007	0.005
Median	0.014	0.019
Mean	0.0145	0.0195
Standard Deviation	0.00398	0.00715
Maximum	0.024	0.039
Dissolved reactive phosphorus		
Minimum	0.009	0.008
Median	0.025	0.048
Mean	0.0255	0.0675
Standard Deviation	0.0132	0.0933
Maximum	0.071	0.65
n	**37-39**	**53**

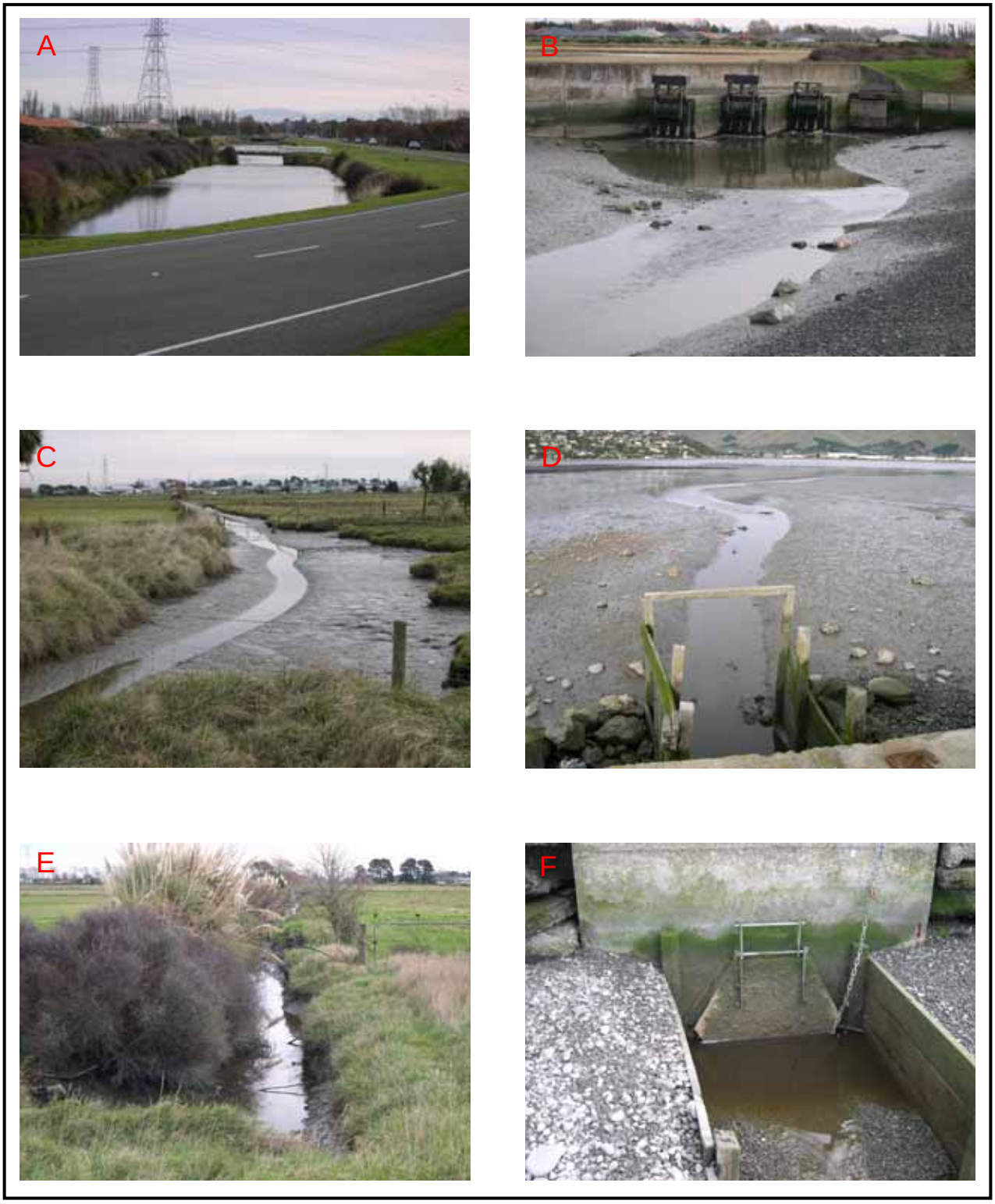


Figure 2.2 **Three of the drains and their outlets into the Avon-Heathcote Estuary/Ihutai**

A – City Outfall drain
B – City Outfall drain outlet into the estuary
C - Charlesworth drain
D – Charlesworth drain outlet into the estuary
E – Lovett's drain
F – Lovett's drain outlet into the estuary

Table 2.5 Nutrient concentrations (mg/L) in the Charlesworth, Lovett's, City Outfall and Estuary Drains from 1998- 2005

Data supplied by CCC
n = number of samples

		n	Median	Maximum
Charlesworth Drain	Ammonia-nitrogen	67	2.50	6.02
	Nitrate-nitrogen	64	0.18	1.90
	Nitrite-nitrogen	65	0.019	0.054
	Dissolved reactive phosphorus	65	0.067	0.357
Lovetts Drain	Ammonia-nitrogen	67	0.80	5.50
	Nitrate-nitrogen	64	0.05	4.17
	Nitrite-nitrogen	65	0.014	0.118
	Dissolved reactive phosphorus	65	0.343	4.284
City Outfall Drain	Ammonia-nitrogen	64	0.36	4.12
	Nitrate-nitrogen	62	0.18	1.67
	Nitrite-nitrogen	63	0.021	0.057
	Dissolved reactive phosphorus	63	0.091	0.409
Estuary Drain	Ammonia-nitrogen	67	6.29	15.30
	Nitrate-nitrogen	65	0.19	12.11
	Nitrite-nitrogen	66	0.215	0.170
	Dissolved reactive phosphorus	66	0.042	0.714

Stormwater contains nitrogen and phosphorus compounds. The concentrations of TN, TP, DRP, NO_3^- and NH_3N in stormwater are highly variable both between catchments and over time (Williamson, 1986; ORC, 1998; Mosley *et al.,* 1997). In urbanised catchments the possible sources of these nutrients include: catchment soils, fertilisers, detergents, animal excretions, plant material and combustion of fossil fuels (Williamson, 1986; Mosley *et al.,* 1997). Nutrient loading in the stormwater from individual rainfall events is likely to be related to a complex mixture of hydrological (rainfall amount and intensity) and meteorological (antecedent length of dry period and antecedent wind conditions) variables.

There are no data on flow rates, annual volumes and nutrient concentrations of stormwater discharged directly into this estuary.

Figure 2.3 **A representative sample of the outlets through which stormwater is discharged directly into the Avon-Heathcote Estuary/Ihutai**

2.5 Natural input of nutrients

The Avon-Heathcote Estuary/Ihutai and Bromley oxidation ponds are recognised as nationally outstanding wildlife areas. One hundred and four species of birds, including 75 wetland/coastal species have been recorded in the Avon-Heathcote Estuary/Ihutai and Bromley oxidation ponds since 1980 (Sagar, 2000). In the early 1990s it was determined that there were 32,000 wetland birds present in the estuary (Crossland 1993, cited in Sagar, 2000).

Bird faeces are a natural source of nutrients and with the abundance of birds present, their contribution to the nutrient load of the estuary and the oxidation ponds cannot be considered to be negligible. It has been estimated that a Canada goose excretes 18 g/day of nitrogen and 6 g/day of phosphorus in its faeces. Given that the mean number of geese counted at the Bromley wildlife refuge from 1985 to 1990 was greater than 1000 (North Canterbury Acclimatisation Society Annual Reports) and that the estuary has a mean high tide volume of 8,332,166 m^3 (Knox and Kilner, 1973), then theoretically geese could contribute up to 0.0022 $g/m^3/day$[1] of nitrogen and 0.00072 g/m^3/day of phosphorus at high tide (these calculations assume that the geese spend all of their loafing time on the estuary, or on the oxidation ponds, which discharge to the estuary). In addition, the other bird species present will be contributing unquantified amounts of nitrogen and phosphorus to the estuary and oxidation ponds.

2.6 Internal nutrient sources

2.6.1 Nutrients within the sediments

Sediment nutrients originate by sedimentation of organic material such as algae, precipitation of chemical compounds and by the adsorption of both organic and inorganic materials to sediment particles. In the Avon-Heathcote Estuary/Ihutai, the relatively enclosed water circulation means that nutrients discharged from the oxidation ponds, rivers and smaller sources, have potentially increased the pool of nutrients within estuary sediments over time.

Knox and Kilner (1973) reported that there was a considerable reserve of both phosphorus and nitrogen present in the sediments of the estuary. They found that the sediment nutrient concentrations of ammonia-nitrogen and total phosphorus corresponded closely with the distribution patterns of organic matter and sediment grain size. In particular, they found that the total phosphorus concentration was significantly correlated ($r = 0.94$) to organic matter content i.e. the higher the organic matter content the higher the total phosphorus content of the sediment. However, the nutrient contribution from the sediments to the water column was related to both grain size and redox potential (a measure of the state of oxygenation) of the sediment. The cycling of the N and P based nutrients between the water column and the sediments and within the sediments (as described in Knox and Kilner, 1973) is summarised in Figures 2.4 and 2.5.

The nutrient content of the sediments of the Avon-Heathcote Estuary/Ihutai have been analysed by Robb (1973) and ECan in 1991 (reported in Gillespie, 1993). Robb found that the highest concentrations of nutrients were in sediments close to the sewage treatment works and near Humphreys Drive. Nutrient concentrations ranged from 0.01 to 25 mg/kg for reactive phosphorus, 216 to 1235 mg/kg for total phosphorus and 44 to 1157 mg/kg for ammonia-nitrogen. Robb estimated that 0.15 kg of phosphorus were released from the tidal flats daily, this quantity being small when compared to the then estimated 429 kg per day from the sewage treatment plant and 25.7 kg per day from the rivers. Robb noted that there was a seasonal variation of nutrients in the sediments, which was related to the seasonal growth and distribution of the algae *Ulva* and *Enteromorpha*. He found that during the period of rapid algal growth between mid spring and late summer, the algae trapped fine suspended material from the water, and this combined with rotting algae produced a silty layer high in nutrients.

[1] g/m^3 is equivalent to mg/L

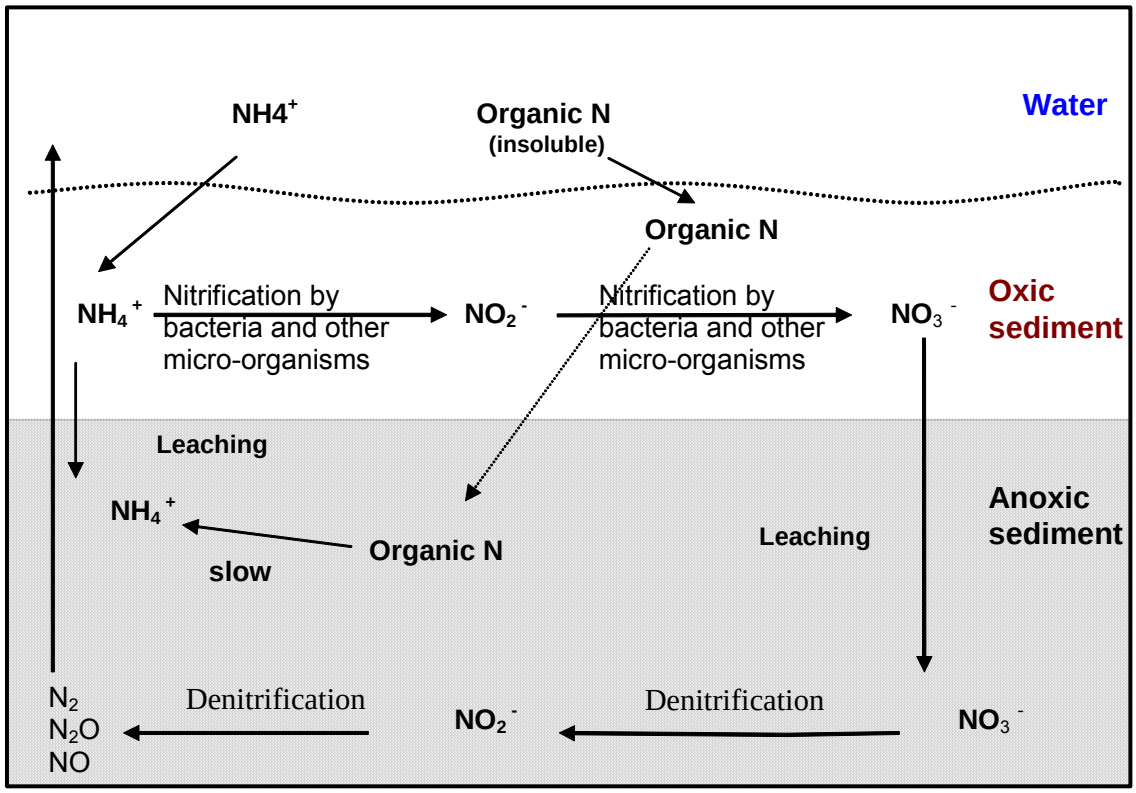


Figure 2.4 **The cycling of the N based nutrients between the water column and the sediments**

(adapted from Knox and Kilner, 1973)

In 1991, sediment nutrient concentrations were measured at 13 sites within the estuary. Nutrient concentrations at these sites ranged from 0.05 to 3.3 mg/kg for reactive phosphorus, 140 to 360 mg/kg for total phosphorus and 3.8 to 963 mg/kg for ammonia-nitrogen. The concentrations at all but one of these sites were within the ranges observed in similar textured sediments from unpolluted sites in other New Zealand inlets. None of the sites showed nutrient enrichment to a level that would indicate a disruption of normal estuarine processes (Gillespie, 1993). The comparison of the 1973 to the 1991 data indicates that over this time period there was a significant reduction in total phosphorus concentrations in the sediments; it is not possible to compare the data for the other determinands.

In a recent study that modelled sea lettuce growth within the estuary, the contribution of the nutrients present within the sediments was not considered (Hawes and O'Brien, 2000). However, these authors noted that the sediments are small net sources of both N and P and quoted unpublished values of 0.5 mg P and 3 mg of N per m^2/hr release from sea lettuce enriched sediments.

2.6.2 Nutrients from the decomposition of algae

According to Bruce (1953), *Ulva,* when growing in nutrient-rich water, is able to concentrate nitrogen in its tissues by absorbing large concentrations of ammonia. Therefore, this alga acts as a store for nitrogen. She found that the mean total Kjehldahl nitrogen content of *Ulva* from the Avon-Heathcote Estuary in 1950-1951 was 3.93% of the dry weight of the alga, whereas Wilkinson (1961) found that it was 4.2% in 1960, and Knox and Kilner (1973) that it was 2.92% in 1969-1970. Thus, the dense beds of decaying *Ulva*, as occur along the South Shore edge of the estuary and in McCormacks Bay at certain times of the year, must be adding considerable quantities of nitrogen to the sediment in these areas.

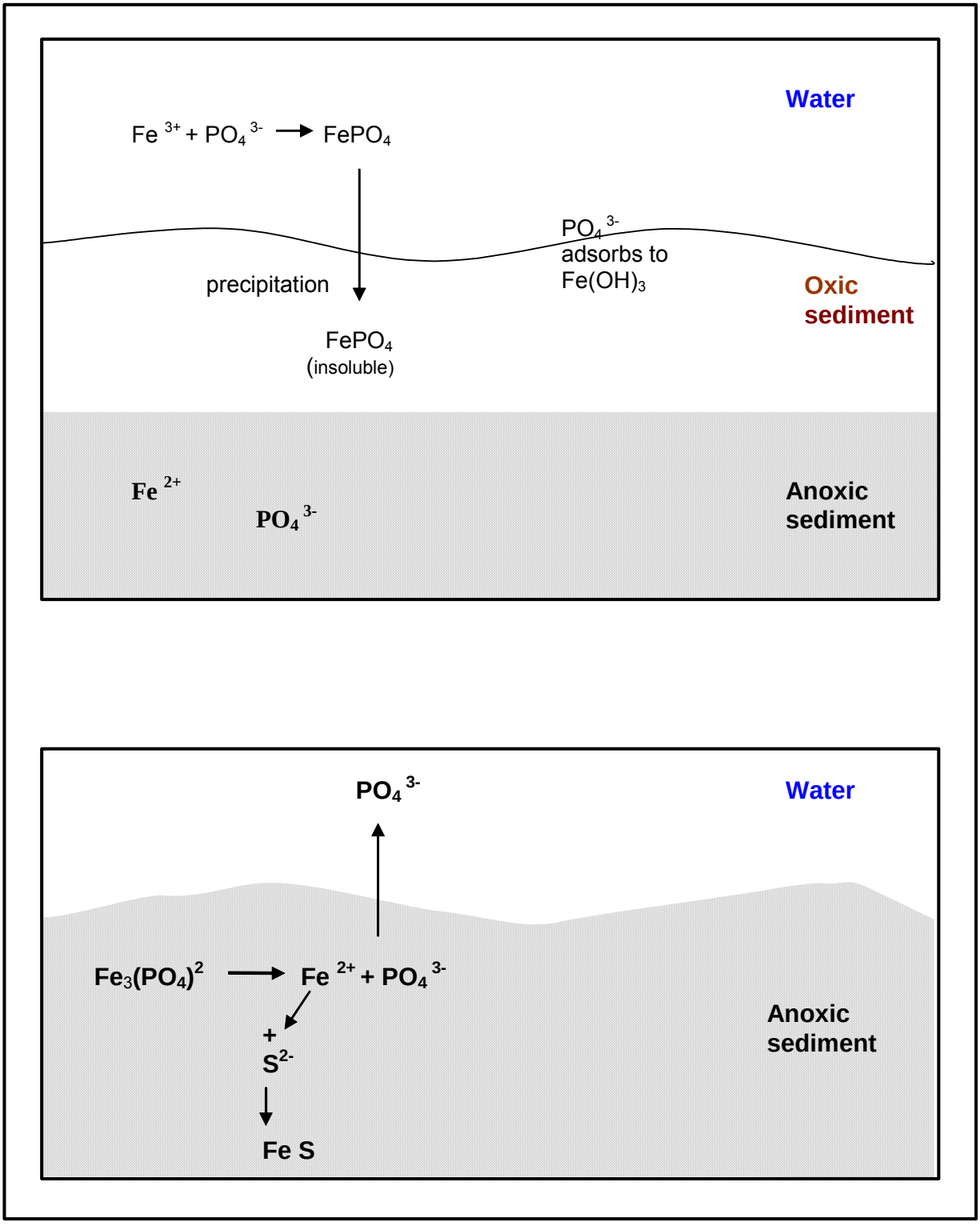


Figure 2.5 **The cycling of the P based nutrients between the water column and the sediments**

(adapted from Knox and Kilner, 1973).

3 Nutrients in the Estuary

In this section, the nutrient data that have been collected by or in association with Environment Canterbury are analysed and discussed.

3.1 Methods

3.1.1 Sites and sampling regime

(a) 1989-1999

Samples were collected from seven sites (C, D, E, G, H, I, K) in the Avon-Heathcote Estuary/Ihutai (Figure 3.1, Appendix II). The sampling at each site was undertaken from January 1989 to September 1999. The number of samples collected in a year varied from 5-12. The intention was to sample on the out-going tide, and the majority of samples were collected between two and four hours after high tide. This was assumed to be the period when the oxidation pond discharge would have the greatest effect on water quality.

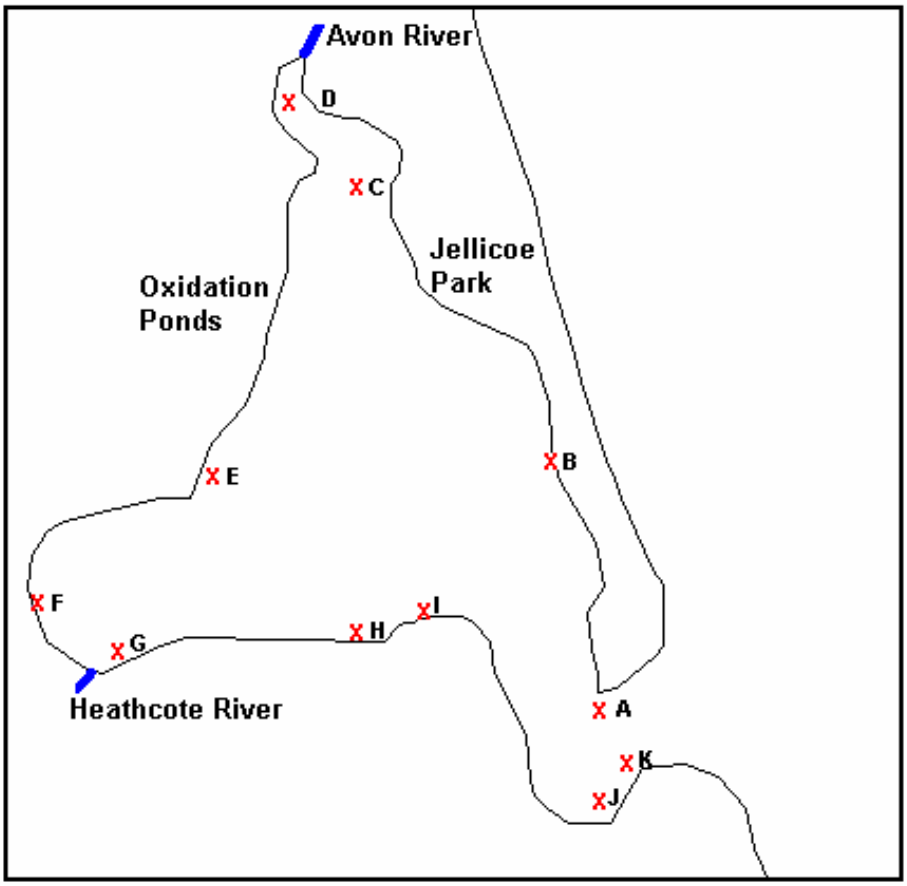


Figure 3.1 Sampling sites in the Avon-Heathcote Estuary/Ihutai

A – South Spit
B – Penguin Street
C – Pleasant Point jetty
D – Pleasant Point Yacht Club
E – Sandy Point
F – Humphries Drive
G – Mt. Pleasant Yacht Club
H – McCormacks Bay outlet
I – Beachville Road
J – Moncks Bay
K – Shag Rock

The samples were collected by staff of the North Canterbury Catchment Board and staff from the Environmental Quality Section of Environment Canterbury. Sampling was carried out from the shore. All water collected was stored in specially prepared bottles provided by the laboratory undertaking the analyses and kept cooled in chilly bins until delivery to the laboratory, in accordance with the ECan Environmental Quality Section Field and Office Procedures Manual (ECan, 1999).

(b) 2002-2005

Samples were collected from seven sites (A, B, D, F, G, I, J) in the Avon-Heathcote Estuary/Ihutai (Figure 3.1, Appendix II). The sampling at each site was undertaken weekly between mid November and the end of February, from November 2002 to February 2005. 14-15 samples were collected at each site over each summer. The samples were collected on the ebb-tide one hour after high tide (two hours after high tide at Lyttelton).

Sampling over a full tidal cycle was undertaken at sites G, H, I and J on one day of each year from 2001 to 2005 (that is: 4.10.2001, 16.01.2002, 19.02.2003, 18.02.2004 and 9.02.2005). At each site, samples were collected every 2 to 2½ hours, with a total of six samples collected over the tidal cycle.

The samples were collected by volunteers who also collected water samples as part of the ECan recreational water quality monitoring programme. Sampling was carried out from the shore. All water collected was stored in specially prepared bottles provided by the laboratory undertaking the analyses and kept cooled in chilly bins until delivery to the laboratory, in accordance with the ECan Environmental Quality Section Field and Office Procedures Manual (ECan, 1999).

3.1.2 Sample analyses

The water samples collected from 1989 to 1999 were analysed for the chemical determinands listed in Table 3.1. The samples collected from 2002 to 2005 were analysed for nitrate and nitrite nitrogen (NNN), ammonia-nitrogen (NH_3N) and pH while the samples collected over a tidal cycle were initially analysed for NH_3N and pH but as of 2003 were analysed for NNN, NH_3N and pH. The 1989, 1990, 1993, 1994, 1997 (from April) and all subsequent samples were analysed by the ECan laboratory. The 1991, 1992, 1995, 1996 and 1997 (first three months) samples were analysed by the Environmental Laboratory of Cawthron Institute of Nelson. Total nitrogen analyses were only carried out from May 1991; prior to this the laboratory did not have the equipment required for the analysis of saline samples. The analytical methods are listed in Appendix III. A detailed description of these determinands is given in Appendix VIII.

Table 3.1 Chemical determinands (nutrients) analysed for in water from the Avon-Heathcote Estuary/Ihutai, 1989-2005

Nitrate and nitrite nitrogen (NNN)
Ammonia nitrogen (NH_3N)
Total nitrogen (TN)
Dissolved reactive phosphorus (DRP)
Total phosphorus (TP)

3.1.3 Data analyses

Microsoft Excel 2000 and Systat (version 9) were used for the production of summary statistics, charts, box plots and all statistical analyses.

The Kruskall-Wallis H statistic test for seasonality was performed on the data collected routinely from 1989 to 1999. Long-term trend analysis of these data was also undertaken. The Mann Kendall trend analysis was performed on the data that showed no statistically significant seasonal pattern. For data that showed significant seasonality, the Seasonal Kendall test, which is an extension of the Mann Kendall test that removes seasonal cycles, was used for trend analysis. The Sen's slope estimator calculated the slope of any trends detected. These analyses were performed using WQstat Plus (v1.5) (IDT, 1998).

While the trend tests can determine the statistical significance of a trend, they do not necessarily indicate environmental significance. For the purposes of this report, a statistically significant trend was considered environmentally significant if the magnitude of the trend was greater than 1% per annum and

the overall change over the monitoring period was greater than the laboratory detection limit (Stansfield, 2000).

Where concentrations of nutrients were less than the analytical limits of detection, the results were reported as 'less than' the detection limit. These non-detect data were converted to a value equal to half the detection limit for the purposes of data analyses.

3.2 Results

The nutrient data from the seven sites sampled from 1989 - 1999 are summarised in Table 3.2. These data are also presented in a series of box plots (Figures 3.2, 3.4, 3.6, 3.7) and line graphs (Appendix IV). The nutrient data from the seven sites sampled from 2002 - 2005 are summarised in Table 3.3. These data are also presented in a series of box plots (Figures 3.2, 3.4) and line graphs (Appendix V).

3.2.1 Nitrate and nitrite nitrogen (NNN)

(a) Between sites
1989-1999
The highest median (0.57 mg/L) and the largest variability (0.17 – 3.45 mg/L) in NNN concentrations were recorded at the Pleasant Point Yacht Club (Table 3.2; Figure 3.2; Appendix IV). However, the median and variability in NNN concentrations at the Pleasant Point Jetty (0.5 mg/L; 0.15 – 3.4 mg/L) were similar to those at the Pleasant Pont Yacht Club. At the Mt. Pleasant Yacht Club the median concentration was 0.35 mg/L and concentrations were very variable (0.02 – 2.7 mg/L). The median NNN concentrations at McCormacks Bay, Beachville Road and Shag Rock were low, being 1/6 to 1/12 of the concentration at the Pleasant Point sites. The median concentration at Sandy Point was approximately half that at the Pleasant Point sites and two-thirds that at the Mt. Pleasant Yacht Club but 3 to 6 times higher than that at McCormacks Bay, Beachville Road and Shag Rock. The variability in concentrations at Sandy Point (0.045 – 2.8 mg/L) was comparable to that at the Mt. Pleasant Yacht Club and the variability in concentrations at McCormacks Bay (0.005 – 0.77 mg/L), Beachville Road (0.01 – 0.83 mg/L) and Shag Rock (0.011 – 0.82 mg/L) were similar.

2002-2004
The highest median (0.355 mg/L) and largest variability (0.086 – 1.3 mg/L) in NNN concentrations were recorded at Humphries Drive. The median concentration at the Pleasant Point Yacht Club (0.29 mg/L) was slightly lower than that at Humphries Drive while the median concentrations at South Spit, Penguin Street, Beachville Road and Moncks Bay were much lower, being 1/12 to 1/20 of that at Humphries Drive.

The median concentration at the Mt. Pleasant Yacht Club was approximately a quarter of that at Humphries Drive and a third of that at the Pleasant Point Yacht Club. The variability in concentrations at the Pleasant Point Yacht Club (0.14 –1.2 mg/L) was lower than at Humphries Drive while the variabilities in concentrations at the Mt. Pleasant Yacht Club (0.003 – 0.49 mg/L), Penguin Street (0.017 – 0.19 mg/L), South Spit (0.005 – 0.043 mg/L), Beachville Road (0.003 – 0.65 mg/L) and Moncks Bay (0.006 – 0.077 mg/L) was much lower than at Humphries Drive.

(b) Over time
Seasonality and trends (1989-1999 data)

Significant seasonality occurred in NNN concentrations at Pleasant Point Jetty, Pleasant Point Yacht Club, McCormacks Bay, Beachville Road and Shag Rock (Table 3.4). Analysis of the raw data determined that NNN concentrations at these sites were lowest during late spring-summer and highest in late autumn. This seasonal variation did not occur at Sandy Point and the Mt. Pleasant Yacht Club.

There was no significant trend, i.e. increase or decrease, in NNN concentrations at any of the sites over time (Table 3.4).

Over a tidal cycle
The relationship between NNN concentrations and the state of the tide at the time of sampling was investigated by plotting the NNN concentrations against the sampling time as number of minutes after high tide in Lyttelton Harbour (Figure 3.3). These plots were generated for all sites except south spit and Penguin Street. At south spit and Penguin Street all samples were collected two after high

Table 3.2 Summary of nutrient concentrations (mg/L) at each site sampled from 1989-1999

Sites: C – Pleasant Point jetty D – Pleasant Point Yacht Club
E – Sandy Point G – Mt. Pleasant Yacht Club
H – McCormacks Bay outlet I – Beachville Road jetty
K – Shag Rock
n = number of samples

	Sites						
	C	**D**	**E**	**G**	**H**	**I**	**K**
DRP							
Minimum	0.061	0.08	0.057	0.011	0.007	0.016	0.007
Median	0.24	0.23	0.51	0.22	0.04	0.04	0.05
Mean	0.26	0.26	0.92	0.22	0.04	0.06	0.09
Standard Deviation	0.15	0.16	0.90	0.10	0.06	0.05	0.08
Maximum	1.1	0.98	3.7	0.48	0.61	0.285	0.38
TP							
Minimum	0.09	0.12	0.08	0.074	0.03	0.02	0.026
Median	0.31	0.30	0.83	0.29	0.06	0.08	0.09
Mean	0.35	0.35	1.40	0.30	0.07	0.11	0.14
Standard Deviation	0.19	0.20	1.33	0.12	0.05	0.10	0.12
Maximum	1.3	1.16	5.5	0.74	0.38	0.63	0.69
NNN							
Minimum	0.15	0.17	0.045	0.02	0.005	0.01	0.011
Median	0.50	0.57	0.24	0.35	0.04	0.06	0.08
Mean	0.60	0.67	0.32	0.46	0.08	0.10	0.12
Standard Deviation	0.48	0.45	0.31	0.40	0.12	0.14	0.13
Maximum	3.4	3.45	2.8	2.7	0.77	0.83	0.82
NH_3N							
Minimum	0.18	0.074	0.24	0.11	0.005	0.0025	0.0025
Median	1.02	0.86	3.25	0.81	0.10	0.12	0.22
Mean	1.14	1.07	5.45	0.94	0.12	0.23	0.40
Standard Deviation	0.85	0.82	6.36	0.52	0.09	0.29	0.42
Maximum	6.4	4.9	38	2.1	0.59	1.68	1.6
n	**100**	**102**	**102**	**102**	**101**	**102**	**102**
TN							
Minimum	0.77	1	0.55	0.35	0.2	0.18	0.18
Median	2.25	2.40	4.70	2.00	0.45	0.49	0.60
Mean	2.39	2.36	7.63	2.13	0.55	0.65	0.93
Standard Deviation	1.11	0.80	7.74	0.96	0.34	0.40	0.75
Maximum	9.4	5.3	39	5.3	1.8	2.3	3.4
n	**80**	**83**	**83**	**83**	**82**	**83**	**83**

Table 3.3 Summary of nutrient concentrations (mg/L) at each site sampled from 2002-2005

Sites: A – South Spit B – Penguin Street
D – Pleasant Point Yacht Club F – Humphries Drive
G – Mt. Pleasant Yacht Club I – Beachville Road jetty
J – Moncks Bay
n = number of samples

	Sites						
	A	**B**	**D**	**F**	**G**	**I**	**J**
NNN							
Minimum	0.005	0.017	0.14	0.086	0.003	0.003	0.006
Median	0.017	0.031	0.29	0.355	0.105	0.023	0.022
Mean	0.018	0.042	0.315	0.384	0.115	0.023	0.024
Standard deviation	0.010	0.032	0.157	0.197	0.076	0.011	0.012
Maximum	0.043	0.19	1.2	1.3	0.49	0.065	0.077
n	**45**	**44**	**45**	**44**	**44**	**45**	**45**
NH_3N							
Minimum	0.003	0.03	0.25	0.12	0.031	0.014	0.01
Median	0.06	0.17	0.56	0.520	0.395	0.081	0.066
Mean	0.079	0.216	0.841	0.807	0.594	0.118	0.078
Standard deviation	0.068	0.171	0.716	0.719	0.487	0.134	0.052
Maximum	0.34	0.89	4	3.5	2.5	0.87	0.22
n	**58**	**57**	**48**	**47**	**46**	**48**	**48**

tide in Lyttelton i.e. on the same state of the tide on all sampling occasions.

At all sites there was considerable variability in NNN concentrations at any particular time of the tide. Hence the following are generalised descriptions of the obvious patterns in NNN concentrations over the tidal cycle.

The obvious patterns in NNN concentrations over the tidal cycle were:

- The lowest concentrations at all sites generally occurred around high tide.
- The concentrations at the Pleasant Point Yacht Club and the Mt Pleasant Yacht Club tended to begin to increase as the tide was ebbing i.e. 120 – 180 minutes after high tide in Lyttelton or 60-120 minutes after high tide in the estuary.
- At the Pleasant Point Yacht club, Beachville Road Jetty and Moncks Bay the NNN concentrations were generally highest at mid-low tide.
- The concentrations at Shag Rock increased steadily as the tide ebbed with the highest concentrations occurring around low tide.

There was no obvious relationship between NNN concentrations and the state of the tide at the time of sampling, at Sandy Point, McCormacks Bay site and at the Pleasant Point Jetty.

The determination of the pattern in NNN concentrations over the tidal cycle at Humphries Drive is complicated by the very high variability in NNN concentrations at one state of the tide and the limited amount of data over the complete tide cycle. However, the available data for this site do indicate that the NNN concentrations increase as the tide starts to ebb but then decrease as the tide continues to ebb increasing again with the rising tide.

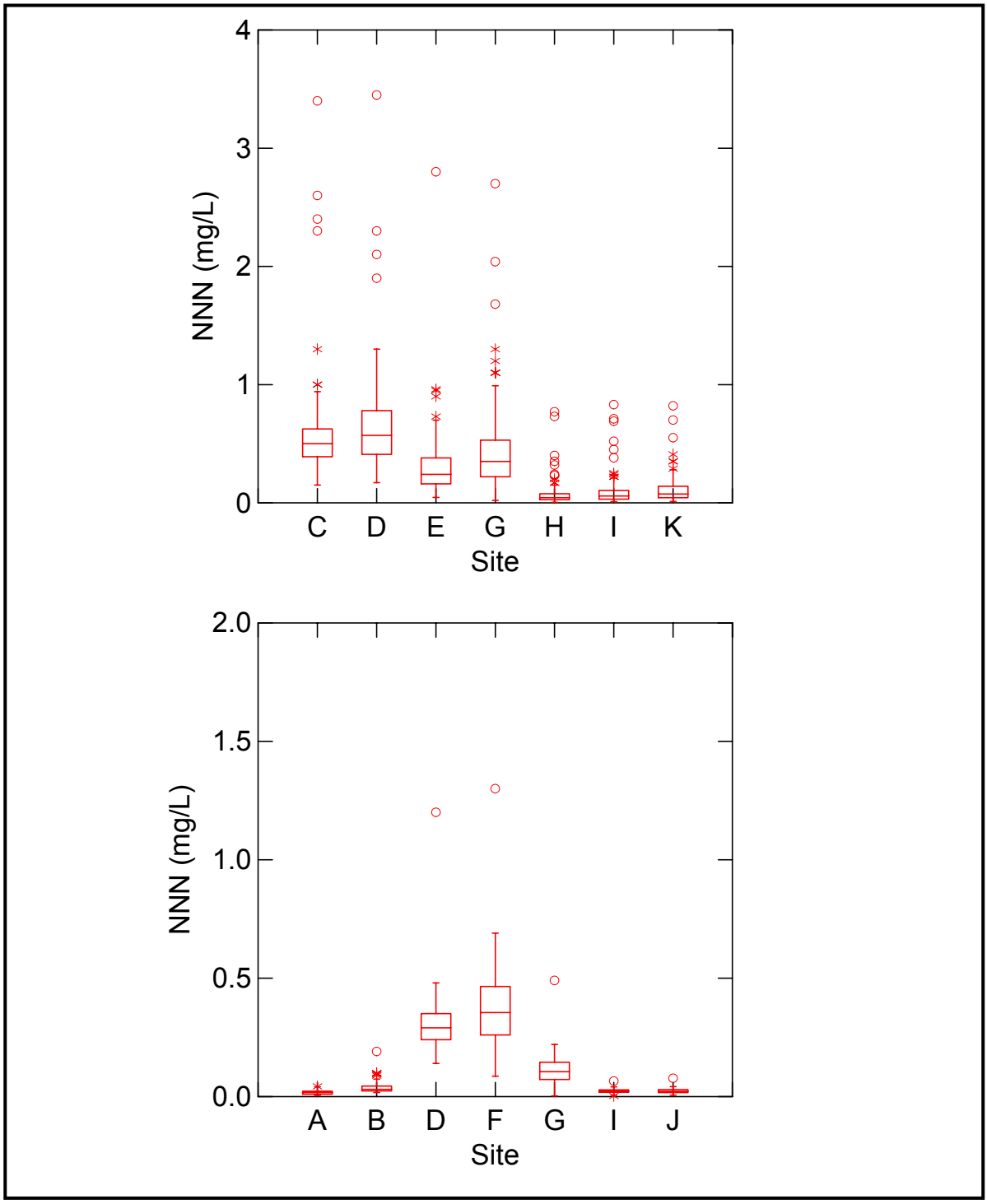


Figure 3.2 **Nitrate and nitrite nitrogen (mg/L) in water at sites in Avon-Heathcote Estuary/Ihutai**

A – sites sampled 1989-1999
B – sites sampled 2002-2005

Note: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95%iles, * and ° indicate outlier and extreme values respectively

Sites

A – South Spit
B – Penguin Street
C – Pleasant Point Jetty
D – Pleasant Point Yacht Club
E – Sandy Point
F – Humphries Drive
G – Mt. Pleasant Yacht Club
H – McCormacks Bay outlet
I – Beachville Road
J – Moncks Bay
K – Shag Rock

Table 3.4 Seasonality and trend analysis of data collected routinely at seven sites in the Avon-Heathcote Estuary/Ihutai over 1989-1999

Seasonality: ✓ - denotes seasonality detected at α = 0.05 x – no seasonality detected
Trend: * Significant at α = 0.05, ** Significant at α = 0.01, x not significant
Down - significant trend of decreasing determinand values over time
up - significant trend of increasing determinand values over time

Site		NH3N	NNN	TN	DRP	TP
Pl. Point Jetty	Seasonality	x	✓	x	x	✓
	Trend	x	x	down**	down**	down*
	Slope (units/year)			-0.138	-0.011	-0.012
	Relative slope (% change per annum)			6.1	4.6	3.9
Pl.Point Yacht Club	Seasonality	x	✓	x	x	x
	Trend	x	x	down**	down*	down*
	Slope (units/year)			-0.119	-0.009	-0.008
	Relative slope (% change per annum)			5.0	3.9	2.7
Sandy Point	Seasonality	x	x	x	✓	✓
	Trend	x	x	x	x	x
	Slope (units/year)					
	Relative slope (% change per annum)					
Mt. Pleasant Yacht Club	Seasonality	x	x	x	✓	✓
	Trend	x	x	down**	down *	down *
	Slope (units/year)			-0.149	-0.0099	-0.0099
	Relative slope (% change per annum)			7.5	4.5	3.4
McCormacks Bay	Seasonality	x	✓	x	x	x
	Trend	up*	x	x	x	x
	Slope (units/year)	0.004				
	Relative slope (% change per annum)	4.0				
Beachville Road	Seasonality	x	✓	x	x	x
	Trend	x	x	x	x	x
	Slope (units/year)					
	Relative slope (% change per annum)					
Shag Rock	Seasonality	x	✓	x	x	x
	Trend	x	x	x	x	x
	Slope (units/year)					
	Relative slope (% change per annum)					

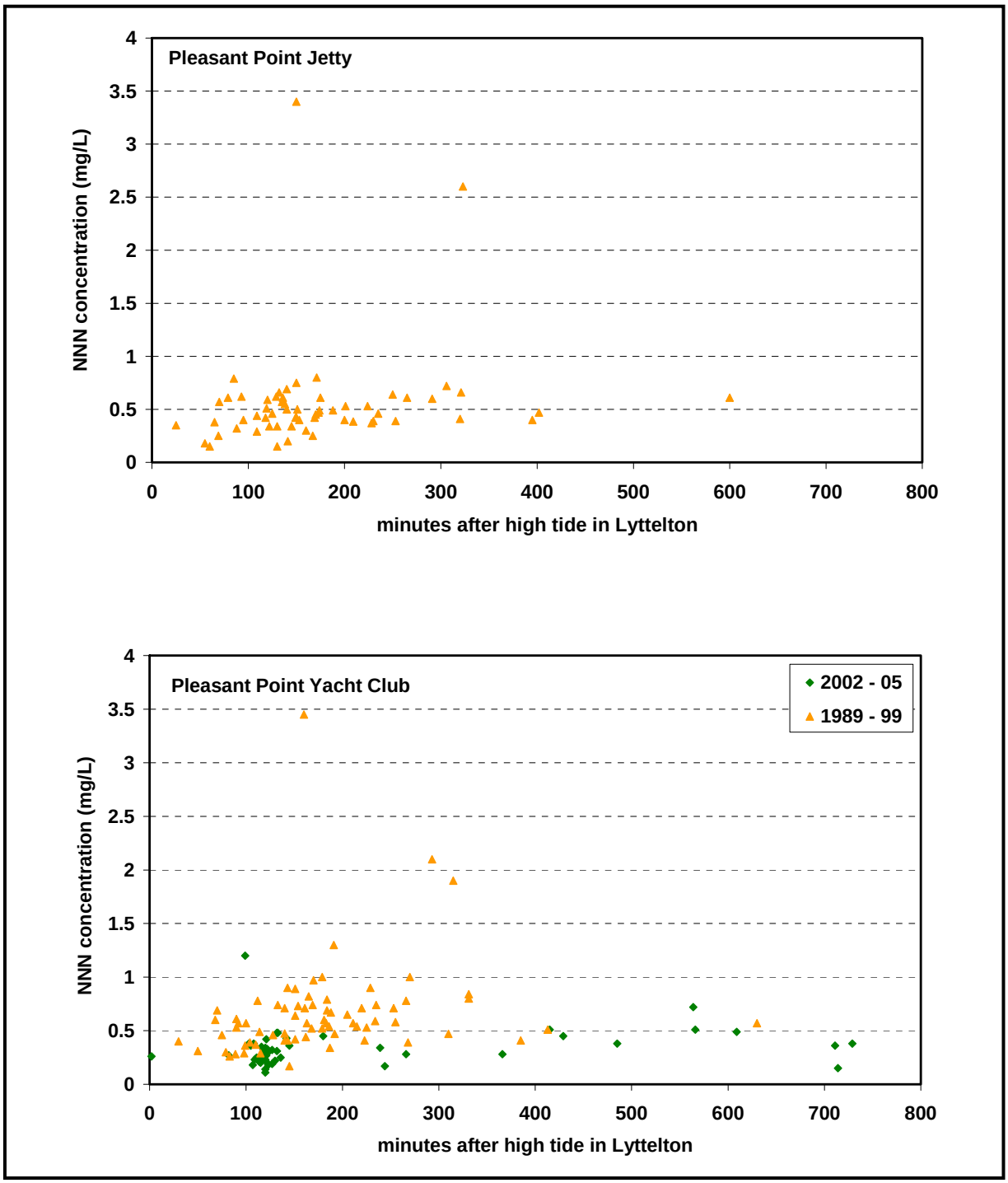


Figure 3.3 **Nitrate and nitrite nitrogen concentrations (mg/L) over the tidal cycle**

Note: differing scales on the y-axis

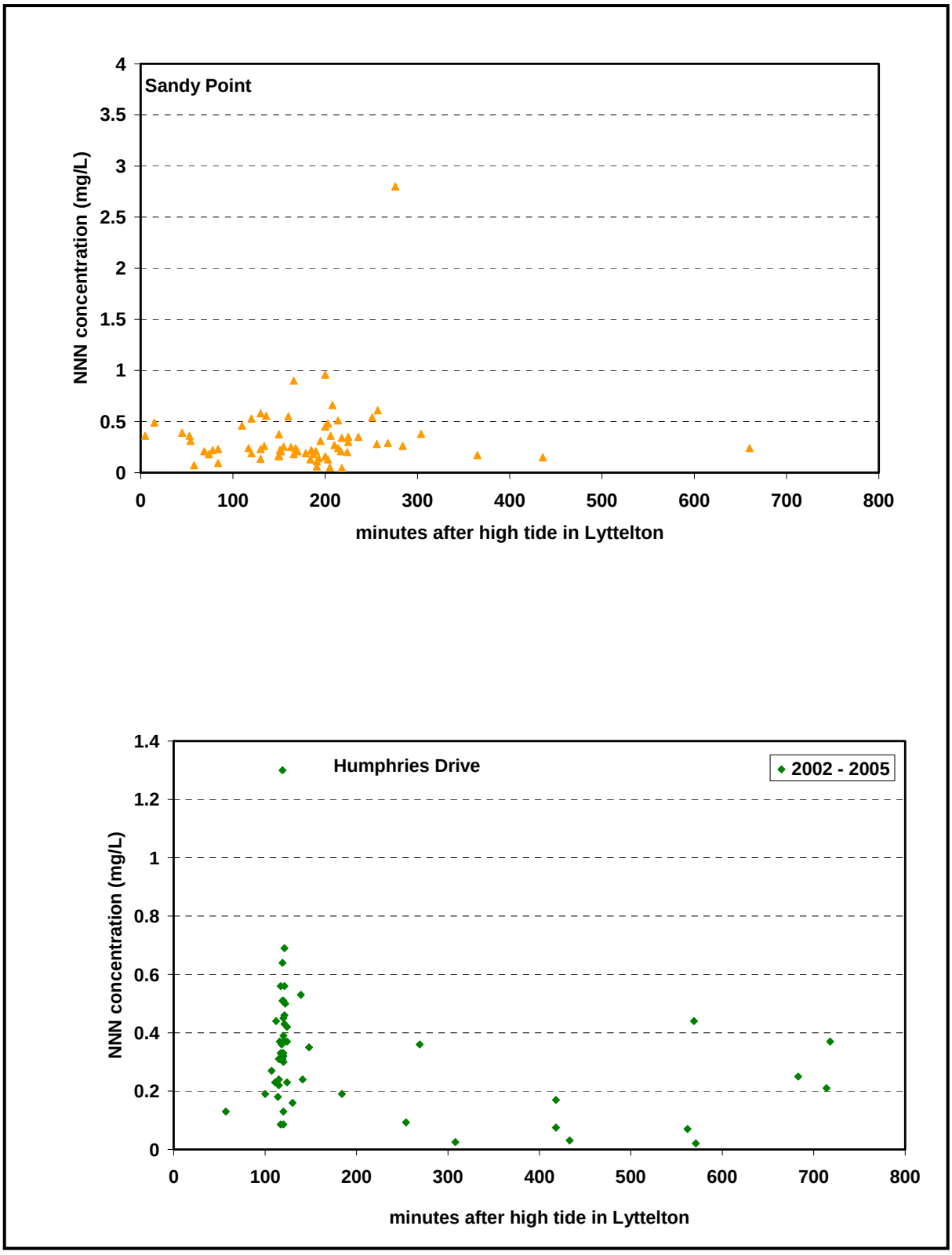


Figure 3.3 continued

Note: differing scales on the y-axis

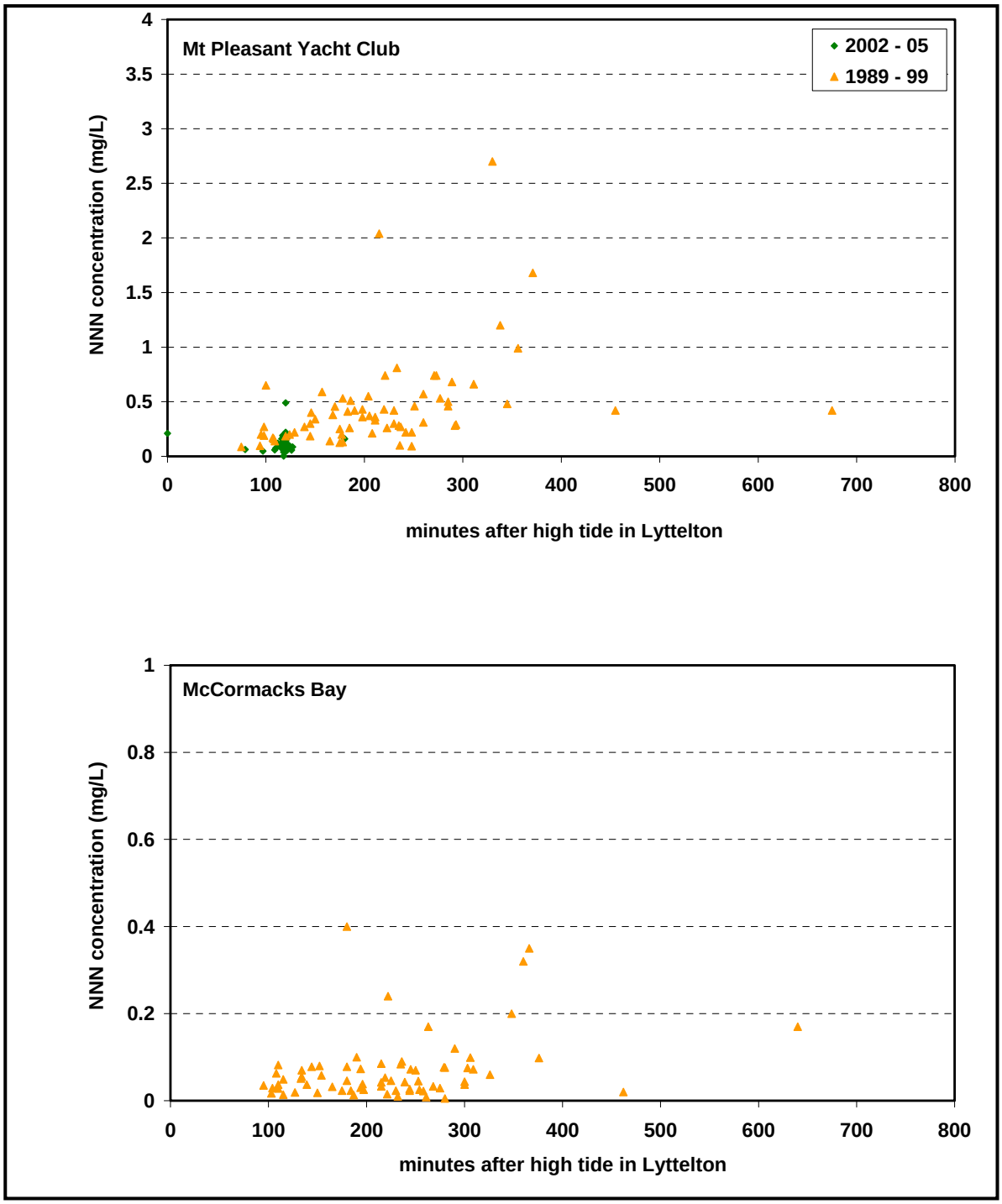


Figure 3.3 continued

Note: differing scales on the y-axis

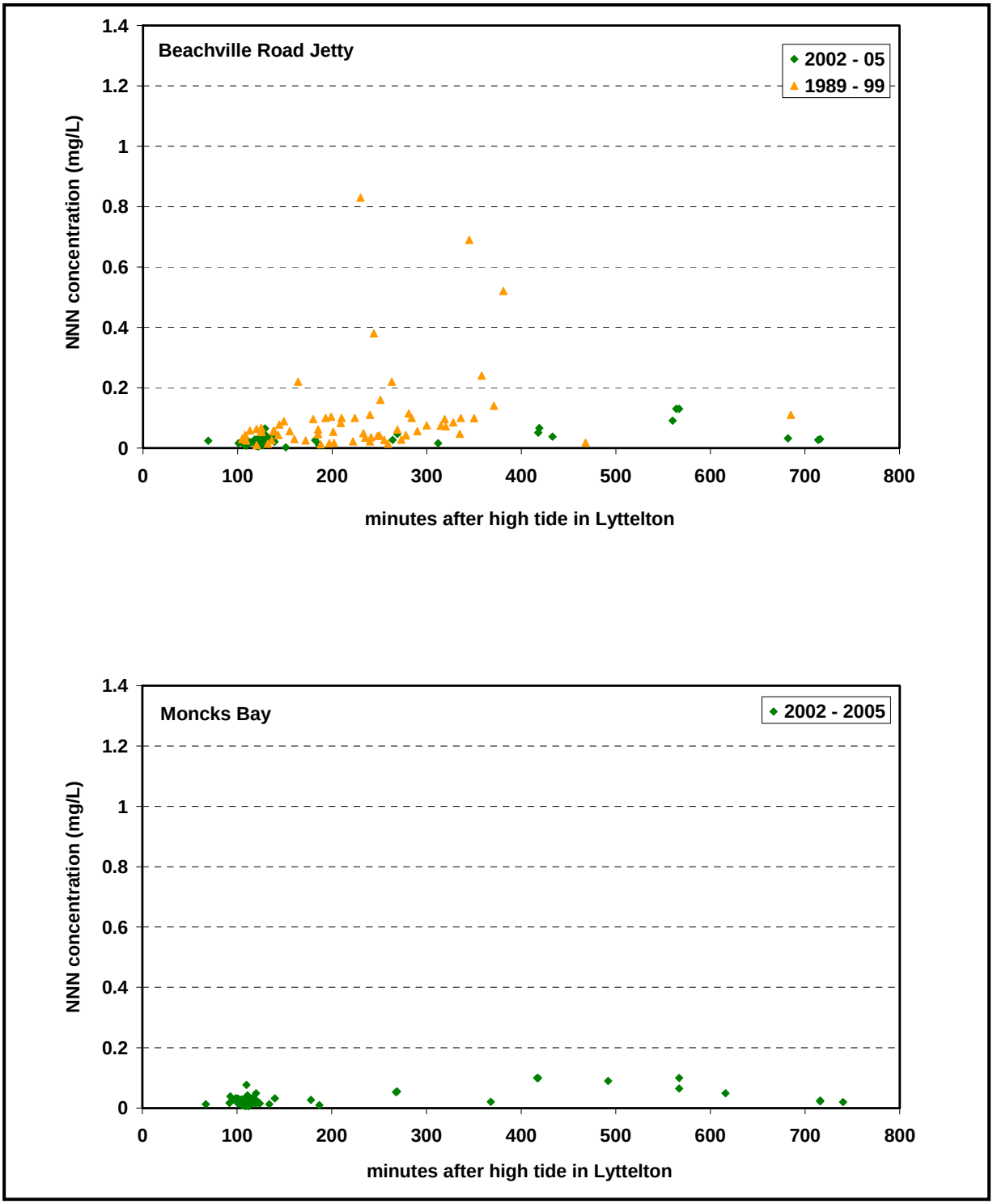


Figure 3.3 continued

Note: differing scales on the y-axis

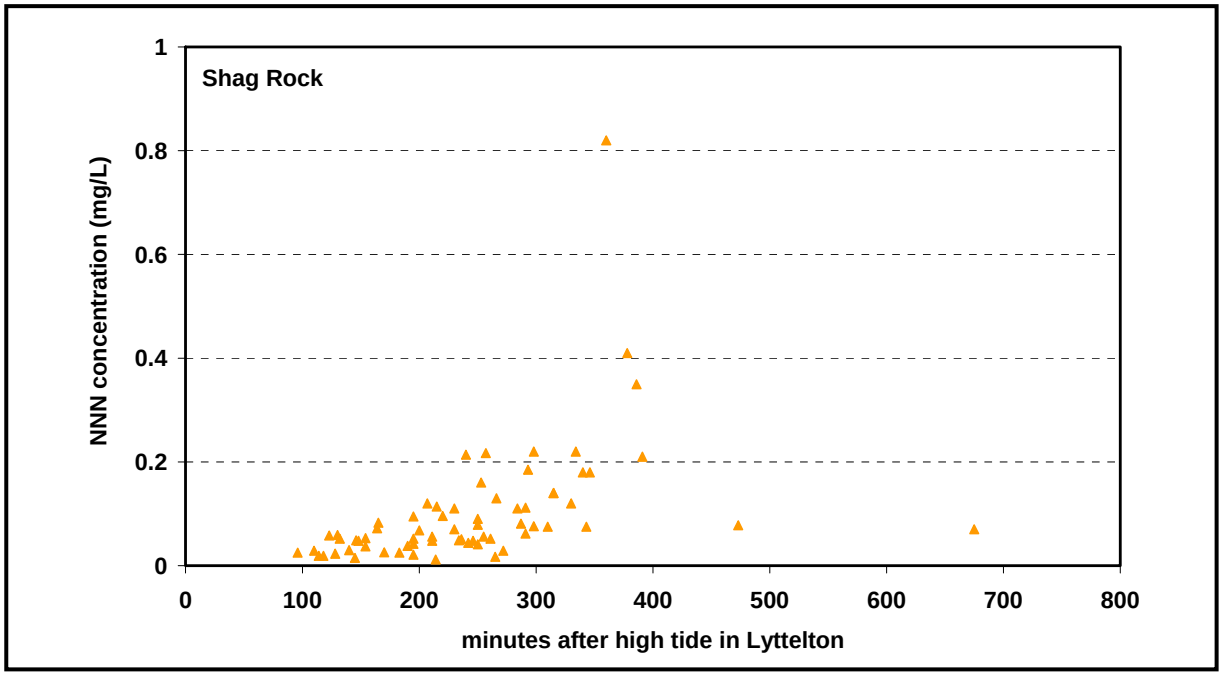


Figure 3.3 continued
Note: differing scales on the y-axis

3.2.2 Ammonia nitrogen (NH_3N)

(a) Between sites

1989-1999

The highest median (3.25 mg/L) and the largest variability (0.24 - 38 mg/L) in NH_3N concentrations were recorded at Sandy Point (Table 3.2, Figure 3.4, Appendix IV). The median concentration at Pleasant Point Jetty was a third, those at Pleasant Point Yacht Club and Mt. Pleasant Yacht Club were a quarter, that at Shag Rock was 1/12, that at Beachville Road was 1/25 and that at McCormacks Bay was 1/33 of the median NH_3N concentration at Sandy Point. The variabilities in NH_3N concentrations at the Pleasant Point Jetty (0.18 – 6.4 mg/L), the Pleasant Point Yacht Club (0.074 – 4.9 mg/L), the Mt. Pleasant Yacht Club (0.11 – 2.1 mg/L), Beachville Road (0.0025 – 1.68 mg/L), Shag Rock (0.0025 – 1.6 mg/L) and McCormacks Bay (0.005 – 0.59 mg/L) were 1/6 to 1/65 of the variability at Sandy Point.

2002-2003

The highest (0.56 mg/L) median and largest variability (0.25 – 4 mg/L) in NH_3N concentration were recorded at Pleasant Point Yacht Club. The median concentration at Humphries Drive was slightly lower (0.52 mg/L) while that at the Mt. Pleasant Yacht Club was 7/10, that at Penguin Street was a third and those at South Spit, Beachville Road and Moncks Bay were one seventh to one tenth of the median NH_3N concentration at the Pleasant Point Yacht Club. The variability in NH_3N concentrations at Humphries Drive (0.12 – 3.5 mg/L) was similar to, while at the Mt. Pleasant Yacht Club (0.031 – 2.5 mg/L), Penguin Street (0.03 – 0.89 mg/L), Beachville Road (0.014 – 0.87 mg/L), South Spit (0.003 – 0.34 mg/L) and Moncks Bay (0.01 – 0.22 mg/L) the variability was smaller than, the variability in NH_3N concentrations at the Pleasant Point Yacht Club.

(b) Over time

Seasonality and trends (1989 – 1999 data)

There was no seasonality in NH_3N concentrations at any of the sites (Table 3.4).

There was a significant increase in NH_3N concentration at the McCormacks Bay site over time (Table 3.4). At McCormacks Bay, the mean and median NH_3N concentrations over 1989-1990 (12 samples) were 0.063 and 0.055 mg/L, whereas by 1998-1999 (12 samples) they were 0.097 and 0.082 mg/L respectively. Even with this increase of 0.004 mg/L or 4 percent per annum, the NH_3N concentrations at McCormacks Bay in 1998-1999 were lower than those at all other sites sampled. There was no significant trend, i.e. increase or

decrease, in NH_3N concentrations at any of the other sites.

Over a tidal cycle

The relationship between NH_3N concentrations and the state of the tide at the time of sampling was investigated by plotting the NH_3N concentrations against the sampling time as number of minutes after high tide in Lyttlelton Harbour (Figure 3.5). These plots were generated for all sites except south spit and Penguin Street. At south spit and Penguin Street all samples were collected two after high tide in Lyttelton i.e. on the same state of the tide on all sampling occasions.

At all sites there was considerable variability in NH_3N concentrations at any particular time of the tide. Hence the following are generalised descriptions of the obvious patterns in NH_3N concentrations over the tidal cycle at each of the sites.

The highest concentrations at the Pleasant Point Yacht Club and the Pleasant Point Jetty occurred on, or 2 –2½ hours after high tide. Concentrations then decreased as the tide ebbed. At the Pleasant Point Yacht Club the lowest concentrations occurred at, or up to four hours after, low tide (Figure 3.5). NH_3N concentrations then increased with the rising of the tide to high.

At Humphries Drive, high NH_3N concentrations occurred at times, one hour after high tide, with lower concentrations occurring over the rest of the tidal cycle. However, there are insufficient data to determine if there was a pattern in NH_3N concentrations over as tidal cycle at this site.

At Beachville Road, Moncks Bay and Shag Rock the NH_3N concentrations generally increased as the tide ebbed, with the highest concentrations occurring at mid-low tide. At Beachville Road and Moncks Bay the NH_3N concentrations then generally decreased with the rising of the tide to high. There are insufficient data to determine if this decrease in concentrations with the rising of the tide occurred at Shag Rock.

There was no obvious relationship between NH_3N concentrations and the state of the tide at the time of sampling, at McCormacks Bay site.

The determination of a tidal cycle pattern in NH_3N concentrations at Sandy Point and the Mt Pleasant Yacht Club is complicated by the very high variability in concentrations at any one state of the tide and the limited amount of data over the complete tide cycle. However at both sites the highest concentrations occurred around and up to 3 –3 ½ hours after, high tide.

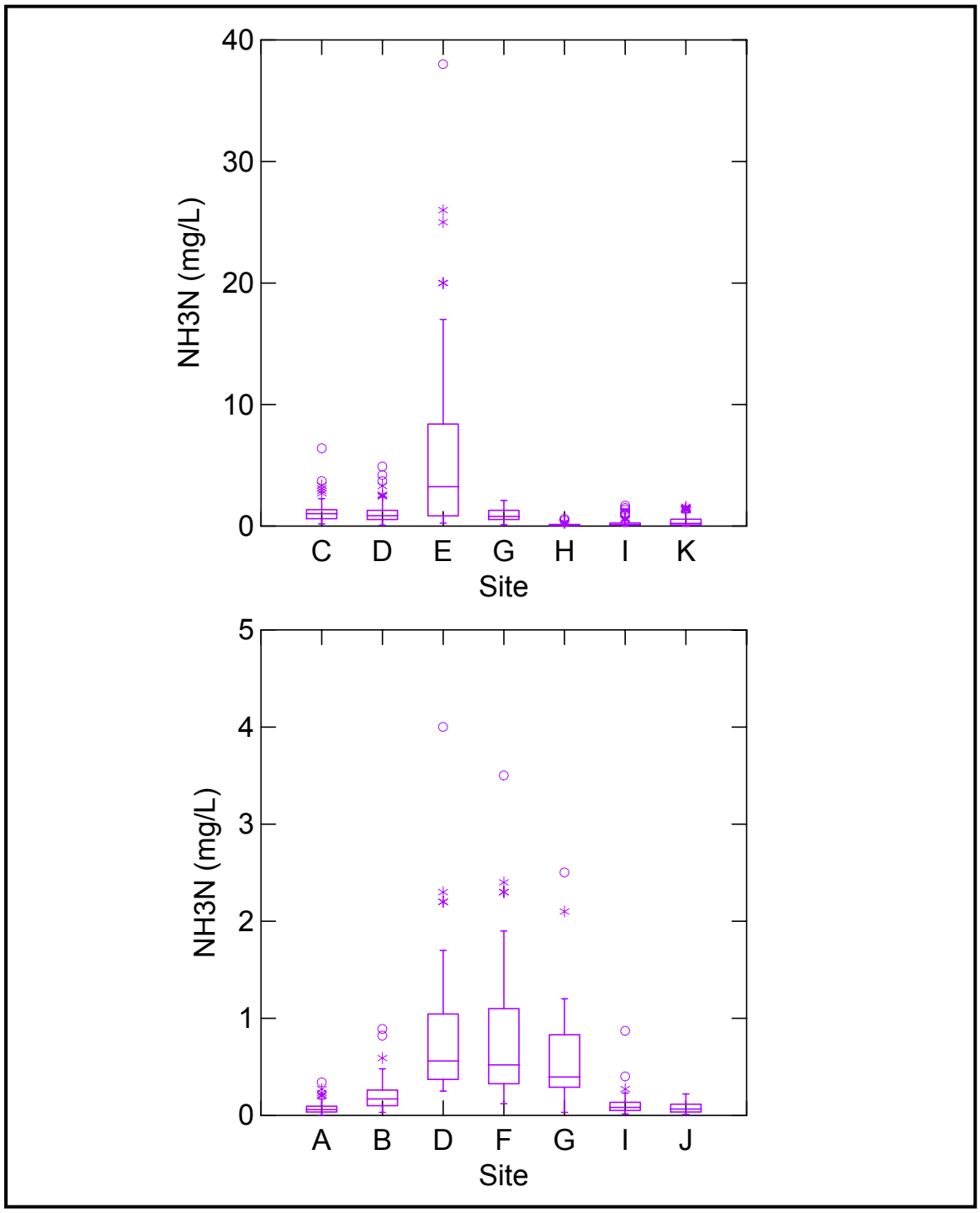


Figure 3.4 **Ammonia-nitrogen (mg/L) in water at sites in Avon-Heathcote Estuary/Ihutai**

A – sites sampled 1989-1999
B – sites sampled 2002-2005

Note: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95%iles,
* and ° indicate outlier and extreme values respectively

Sites

A – South Spit
B – Penguin Street
C – Pleasant Point Jetty
D – Pleasant Point Yacht Club
E – Sandy Point
F – Humphries Drive
G – Mt. Pleasant Yacht Club
H – McCormacks Bay outlet
I – Beachville Road
J – Moncks Bay
K – Shag Rock

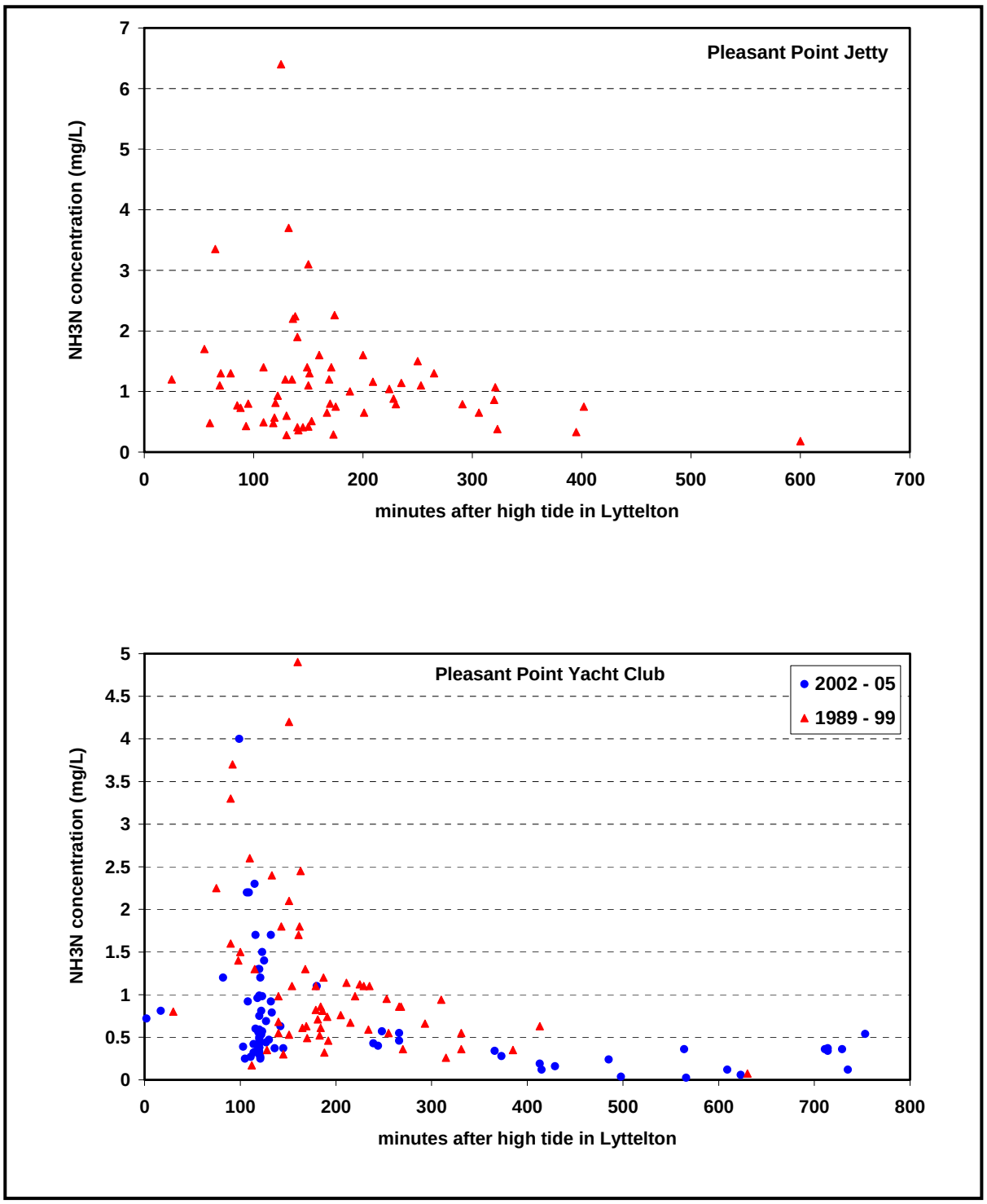


Figure 3.5 **Ammonia-nitrogen concentrations (mg/L) over the tidal cycle**

Note: differing scales on the y-axis

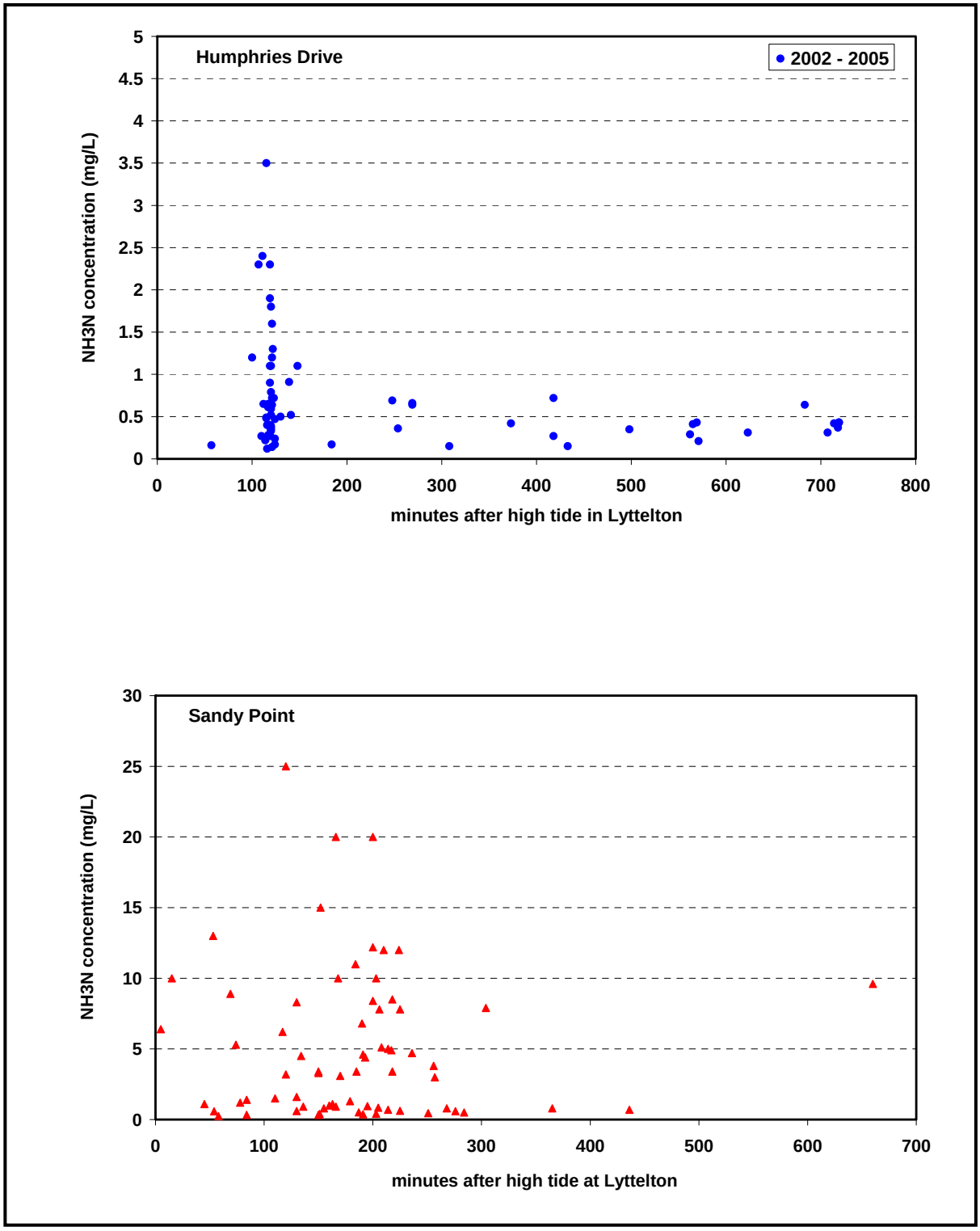


Figure 3.5 continued

Note: differing scales on the y-axis

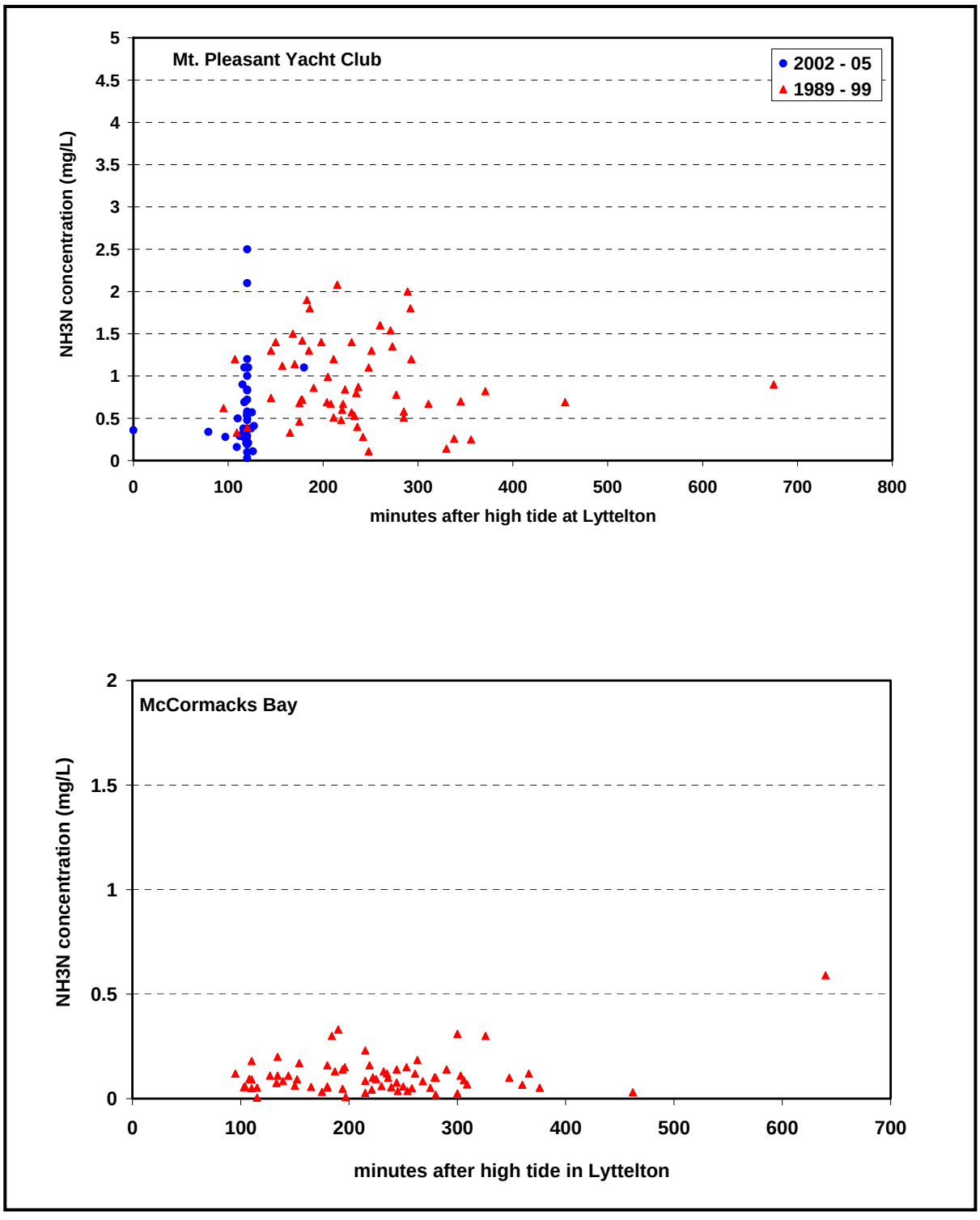


Figure 3.5 continued

Note: differing scales on the y-axis

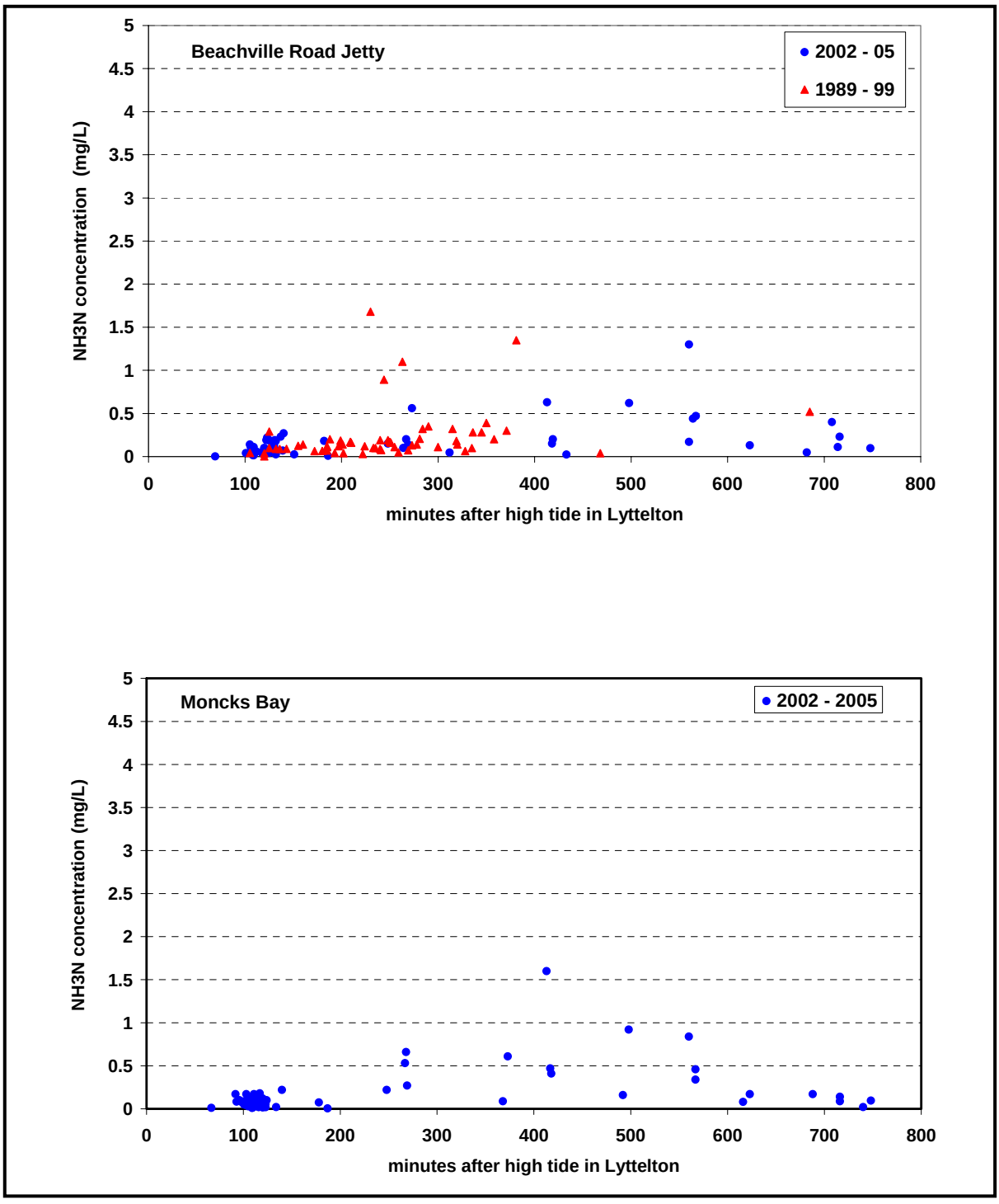


Figure 3.5 continued

Note: differing scales on the y-axis

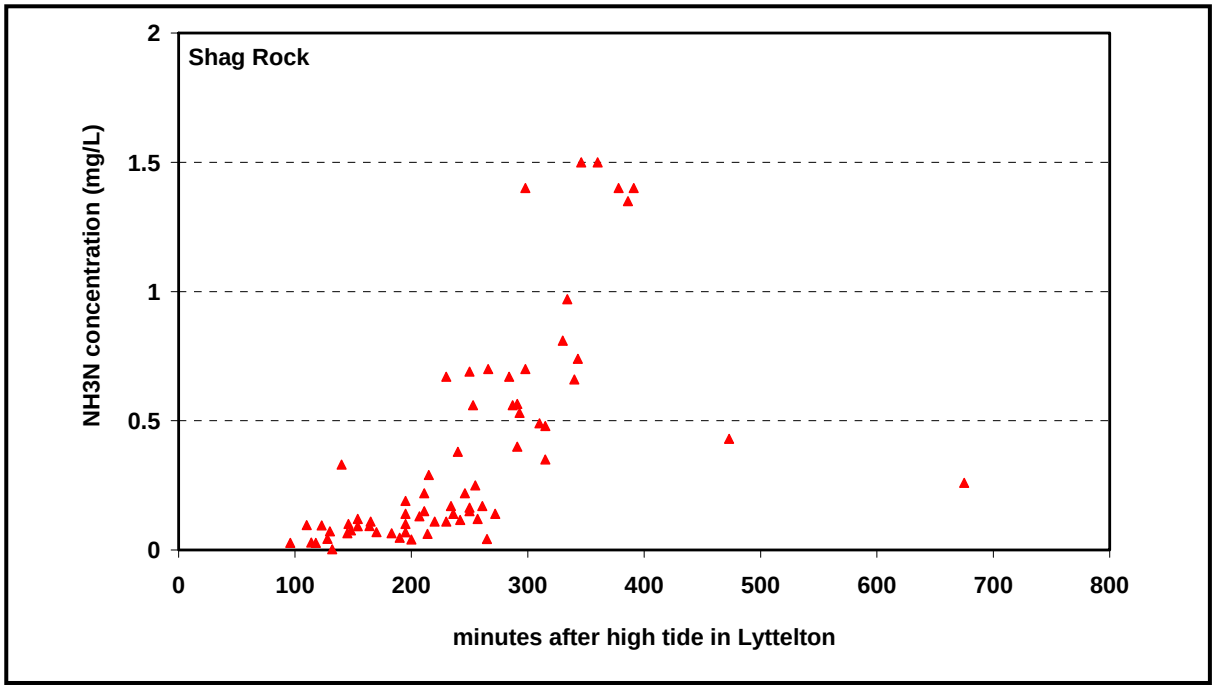


Figure 3.5 continued

Note: differing scales on the y-axis

3.2.3 Total Nitrogen (TN)

(a) Between sites
1989-1999

The highest median (4.7 mg/L) and the largest variability (0.55 - 39 mg/L) in TN concentrations were recorded at Sandy Point (Table 3.2, Figure 3.6, Appendix IV). The median concentrations at Pleasant Point Jetty, Pleasant Point Yacht Club and Mt. Pleasant Yacht Club were approximately a half, that at Shag Rock was one eighth and those at Beachville Road and McCormacks Bay were approximately one tenth of the median TN concentration at Sandy Point. The variability in TN concentrations at the Pleasant Point Jetty (0.77 - 9.4 mg/L), the Pleasant Point Yacht Club (1 - 5.3 mg/L), the Mt. Pleasant Yacht Club (0.35 - 5.3 mg/L), Shag Rock (0.18 - 3.4 mg/L), Beachville Road (0.18 - 2.3 mg/L) and McCormacks Bay (0.2 -1.8 mg/L) were a quarter to 1/24 of the variability at Sandy Point.

(b) Over time
Seasonality and trends

There was no seasonality in TN concentrations at any of the sites (Table 3.4).

There was a significant decrease in TN concentration over time at Pleasant Point Jetty, Pleasant Point Yacht Club and Mt Pleasant Yacht Club (Table 3.4). There was some similarity in the percentage change per annum at the Pleasant Point sites (6.1 and 5.0 %), while that at the Mt Pleasant Yacht Club was higher at 7.5%. At the Pleasant Point Jetty, the mean and median TN concentrations over 1991-1992 (12 samples) were 2.94 and 2.6 mg/L respectively, but by 1998-1999 (12 samples) they had dropped to 1.53 and 1.4 mg/L respectively. At the Pleasant Point Yacht Club the mean and median TN concentrations over 1991-1992 (12 samples) were 2.66 and 2.5 mg/L but by 1998-1999 (12 samples) they were 1.65 and 1.45 mg/L, respectively. At the Mt Pleasant Yacht Club the mean and median TN concentrations over 1991-1992 (12 samples) were 1.93 and 1.65 mg/L, and by 1998-1999 (12 samples) they were 1.19 and 1.1 mg/L, respectively.

There was no significant trend, i.e. increase or decrease, in TN concentrations at Sandy Point, McCormacks Bay, Beachville Road and Shag Rock.

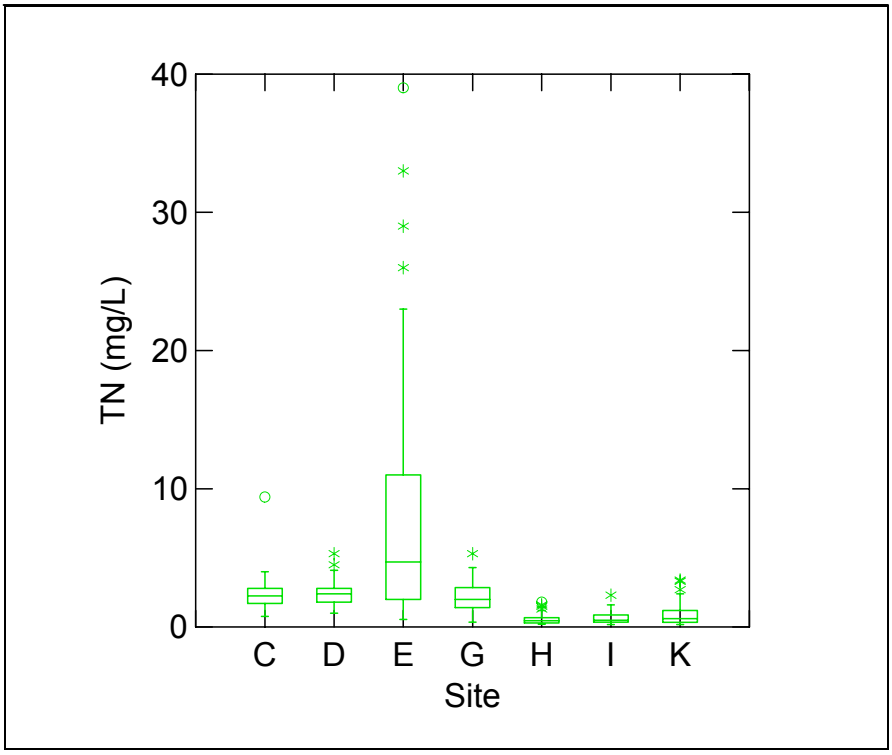


Figure 3.6 Total nitrogen (mg/L) in water at sites in the Avon-Heathcote Estuary/Ihutai, 1989-1999

Note: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95%iles,
* and ° indicate outlier and extreme values respectively

Sites

A – South Spit	B – Penguin Street	C – Pleasant Point Jetty
D – Pleasant Point Yacht Club	E – Sandy Point	F – Humphries Drive
G – Mt. Pleasant Yacht Club	H – McCormacks Bay outlet	I – Beachville Road
J – Moncks Bay	K – Shag Rock	

3.2.4 Dissolved Reactive Phosphorus (DRP)

(a) Between sites
1989-1999
The highest median (0.51 mg/L) and the largest variability (0.057 – 3.7 mg/L) in DRP concentrations were recorded at Sandy Point (Table 3.2, Figure 3.7, Appendix IV). The median concentrations at Pleasant Point Jetty, Pleasant Point Yacht Club and Mt. Pleasant Yacht Club were approximately a half, that at Shag Rock was one tenth and those at Beachville Road and McCormacks Bay were approximately 1/13 of the median DRP concentration at Sandy Point. The variability in DRP concentrations at the Pleasant Point Jetty (0.061 - 1.1 mg/L), the Pleasant Point Yacht Club (0.08 - 0.98 mg/L), the Mt. Pleasant Yacht Club (0.011 - 0.48 mg/L), Shag Rock (0.007 - 0.38 mg/L), Beachville Road (0.016 - 0.285 mg/L) and McCormacks Bay (0.007 - 0.61 mg/L) were a third to 1/14 of the variability at Sandy Point.

(b) Over time
Seasonality and trends
Significant seasonality occurred in DRP concentrations at Sandy Point and the Mt. Pleasant Yacht Club (Table 3.4). Analysis of the raw data determined that DRP concentrations at these sites were generally lowest during late spring-summer and highest in late autumn. This seasonal variation did not occur at any of the other sites.

There was a statistically significant decrease in DRP concentration over time at Pleasant Point Jetty, Pleasant Point Yacht Club and Mt Pleasant Yacht Club (Table 3.4). The percentage decrease (change per annum) at each site was similar (4.6, 3.9 and 4.5 % respectively). At the Pleasant Point Jetty, the mean and median DRP concentrations over 1989-1990 (12 samples) were 0.282 and 0.205 mg/L, by 1998-1999 (12 samples) they were 0.215 and 0.19 mg/L, respectively. At the Pleasant Point Yacht Club the mean and median DRP concentrations over 1991-1992 (12 samples) were 0.32 and 0.198 mg/L, by 1998-1999 (12 samples) they were 0.21 and 0.195 mg/L, respectively. At the Mt Pleasant Yacht Club the mean and median DRP concentrations over 1991-1992 (12 samples) were 0.257 and 0.26 mg/L, by 1998-1999 (12 samples) they were 0.169 and 0.15 mg/L, respectively. These data show that the mean and median DRP concentrations at Mt Pleasant Yacht Club decreased over time, while at the Pleasant Point sites the mean concentrations decreased but median concentrations changed very little, if at all, over time.

There was no significant trend, i.e. increase or decrease, in DRP concentrations at Sandy Point, McCormacks Bay, Beachville Road and Shag Rock.

3.2.5 Total Phosphorus (TP)

(a) Between sites
1989-1999
The highest median (0.83 mg/L) and the largest variability (0.08 - 5.5 mg/L) in TP concentrations were recorded at Sandy Point (Table 3.2, Figure 3.7, Appendix IV). The median concentrations at Pleasant Point Jetty, Pleasant Point Yacht Club and Mt. Pleasant Yacht Club were approximately a third, that at Shag Rock was one ninth, that at Beachville Road was one tenth and that at McCormacks Bay was 1/14 of the median TP concentration at Sandy Point. The variability in TP concentrations at the Pleasant Point Jetty (0.09 - 1.3 mg/L), the Pleasant Point Yacht Club (0.12 - 1.16 mg/L), the Mt. Pleasant Yacht Club (0.074 - 0.74 mg/L), Shag Rock (0.026 - 0.69 mg/L), Beachville Road (0.02 - 0.63 mg/L) and McCormacks Bay (0.03 - 0.38 mg/L) were a quarter to 1/15 of the variability at Sandy Point.

(b) Over time
Seasonality and trends
Significant seasonality occurred in TP concentrations at the Pleasant Point Jetty, Sandy Point and the Mt. Pleasant Yacht Club (Table 3.4). On analysis of the data from each site, the seasonal pattern was apparent for Sandy Point and the Mt. Pleasant Yacht Club but there was no clearly defined pattern for Pleasant Point Jetty. At Sandy Point, TP concentrations were highest in late summer and winter and lowest in autumn and early summer. At the Mt. Pleasant Yacht Club, TP concentrations were highest in late spring and summer and lowest in early spring and autumn. Seasonality in TP concentration did not occur at any of the other sites.

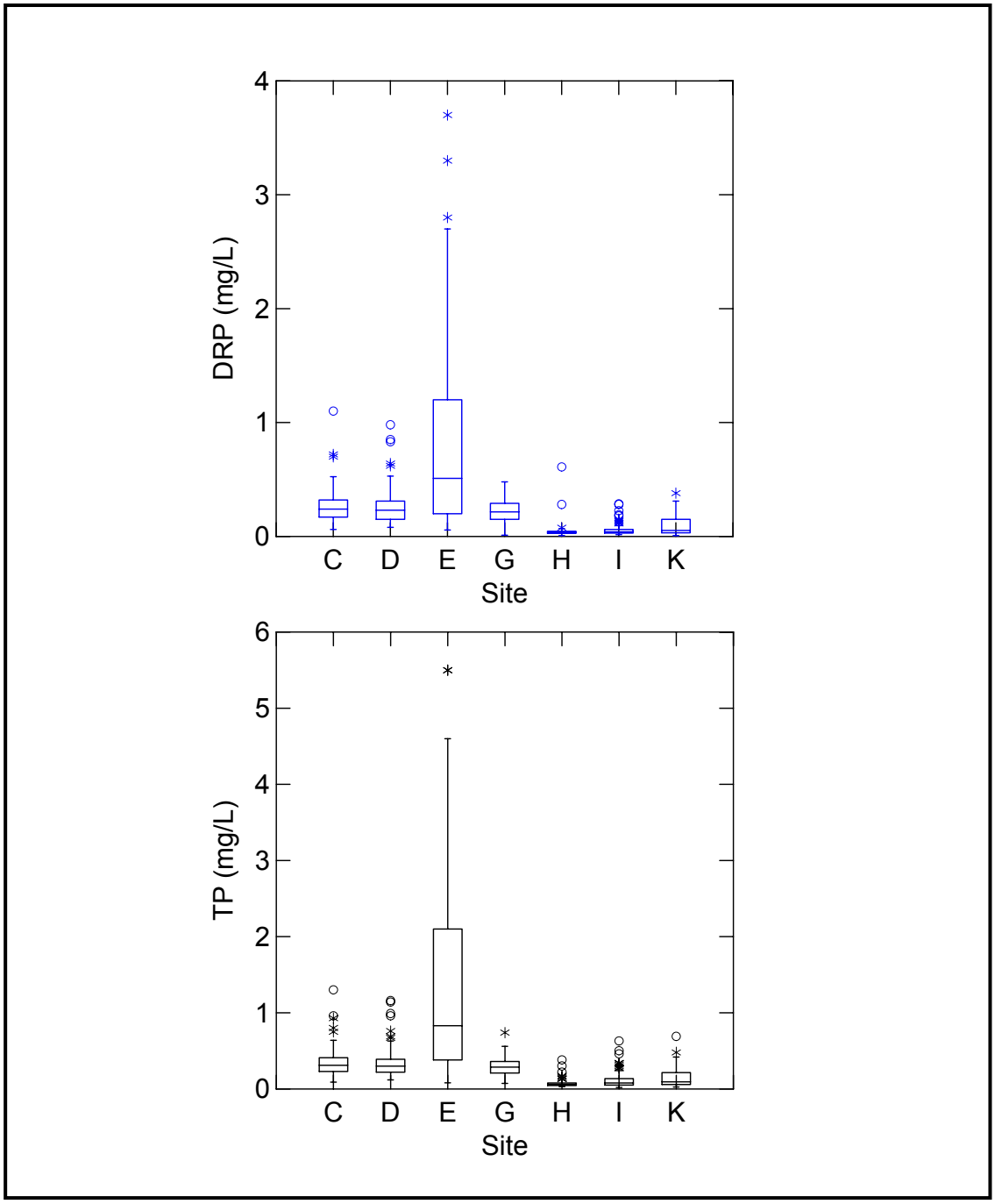


Figure 3.7 Dissolved reactive phosphorus and total phosphorus (mg/L) in water at sites in the Avon-Heathcote Estuary/Ihutai, 1989-1999

Note: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95%iles,
* and ° indicate outlier and extreme values respectively

Sites

A – South Spit	B – Penguin Street	C – Pleasant Point Jetty
D – Pleasant Point Yacht Club	E – Sandy Point	F – Humphries Drive
G – Mt. Pleasant Yacht Club	H – McCormacks Bay outlet	I – Beachville Road
J – Moncks Bay	K – Shag Rock	

There was a significant decrease in TP concentration over time at Pleasant Point Jetty, Pleasant Point Yacht Club and Mt Pleasant Yacht Club (Table 3.4). The percentage decrease (change per annum) was different at each site (3.9, 2.7 and 3.4 % respectively). At the Pleasant Point Jetty, the mean and median TP concentrations over 1989-1990 (12 samples) were 0.388 and 0.283 mg/L, but by 1998-1999 (12 samples) they were 0.278 and 0.27 mg/L, respectively. At the Pleasant Point Yacht Club the mean and median TP concentrations over 1991-1992 (12 samples) were 0.407 and 0.265 mg/L, by 1998-1999 (12 samples) they were 0.303 and 0.25 mg/L, respectively. At the Mt Pleasant Yacht Club the mean and median TP concentrations over 1991-1992 (12 samples) were 0.318 and 0.293 mg/L, by 1998-1999 (12 samples) they were 0.223 and 0.195 mg/L, respectively. These data show that the mean and median TP concentrations at Mt Pleasant Yacht club decreased over time, while at the Pleasant Point sites the mean concentrations decreased, but median concentrations changed very little, if at all, over time.

There was no significant trend, i.e. increase or decrease, in TP concentrations at Sandy Point, McCormacks Bay, Beachville Road or Shag Rock.

3.3 Discussion

3.3.1 Between sites

For NH_3N, NNN, TN, DRP and TP, there were large differences in the median and range in concentration between sites within the estuary. Such differences give an indication of the proximity of each site to a source or sources of each nutrient to the estuary water. Any site with a high median and a large range in concentrations of a nutrient is suggestive of the close proximity of the site to a particular nutrient source. The large variation in the nutrient concentration at a site likely results from fluctuations in the volumes and nutrient concentrations of the input in combination with the hydrological processes within the estuary. A relatively low median and small range in concentrations are considered to be an indication that the site is not close to a significant nutrient source.

The nitrate and nitrite-nitrogen concentrations in the estuary between 1989-1999 were highest at the Pleasant Point Yacht Club, Pleasant Point Jetty and Mt Pleasant Yacht Club sites. These sites are in close proximity to the rivers that flow into this estuary. That is, the results indicate that the Avon and Heathcote rivers are a large source of estuary NNN. The larger range and higher median concentrations at the Pleasant Point Yacht Club and Pleasant Point Jetty compared to those at Mt. Pleasant Yacht Club indicate that the Avon River contributes more NNN to the estuary than does the Heathcote River. This difference between the rivers, in NNN contribution, is most likely a function of the volume of inflow rather than the NNN concentration in the river water. This is because NNN concentrations are higher in the Heathcote River than the Avon River (Tables 2.3-2.5), but the Avon River discharges a greater volume of water into the estuary than does the Heathcote River. Rivers have been found to be a large contributor of NNN to estuaries elsewhere in New Zealand; for example, Park (1994) found that a large percentage of the nitrate-nitrogen within Tauranga Harbour comes from the Wairoa River. In contrast, the NNN concentration in oxidation pond effluent is always low (e.g. Hickey, *et al*., 1989).

The lower NNN concentration at Sandy Point, 1.2 km from a river mouth, than at sites closer to a river, suggests that the concentration of NNN in the estuary is a function of distance from a river mouth. However, while the rivers are large sources of NNN to the estuary, there is still an input of NNN from the oxidation pond effluent even though the NNN concentration in oxidation pond effluent is relatively low compared to that in the Avon and Heathcote rivers (Tables 2.2-2.5). In addition, the ammonia-nitrogen in the oxidation pond effluent will begin to oxidise to NNN on reaching the aerobic estuarine water. Therefore, it is possible that the NNN present at Sandy Point is a mix of that from the Heathcote River and the oxidation ponds, with this site being between both sources. The lowest NNN concentrations in the estuary occurred at the sites (McCormacks Bay, Beachville Road, Moncks Bay, Shag Rock, Spit Tip and Penguin Street) 1.8 km or more away from the river mouths and the oxidation ponds. That is, these sites are not close to a significant NNN source, with the lower NNN

concentrations due to the dilution of the river water and effluent by the sea water.

Over 2002-2005 the NNN concentrations were higher at Humphries Drive than at sites in closer proximity to the rivers, i.e., the Mt. Pleasant Yacht Club and the Pleasant Point Yacht Club. The Humphries Drive site, while more than 500 m from the low tide Heathcote River channel, was found to have water with a salinity range of 14 to 33 ppt (sea water has a salinity of 35 ppt) at high tide. At this site there was a significant inverse relationship between salinity and NNN concentration, with the lower salinity water containing higher concentrations of NNN than the higher salinity water, e.g. at 16 ppt, the NNN concentration was 0.69 mg/L, while at 33 ppt it was 0.086 mg/L. The NNN rich fresh water affecting this site most likely originates from the Heathcote River and the oxidation pond discharge, but other sources such as the City Drain and stormwater outlets cannot be discounted. This combination of sources is likely because:

- concentrations at Humphries Drive were higher than those at Mt. Pleasant Yacht Club.
- it has been found that oxidation pond effluent moves into the Humphries Drive area on a flood tide (Lincoln Environmental, 1994).
- it has also been found that microbiological water quality at this site is highly influenced by rainfall, which suggests that this site is influenced by the discharge from the drains and stormwater outlets in the vicinity.

Concentrations of NH_3N, TN, DRP and TP, are higher in the oxidation ponds than in the Avon and Heathcote rivers and therefore the effluent discharged from the oxidation ponds is considered the largest source of these nutrients to the estuary water. Of the sites sampled in the estuary, the highest median and largest range in concentrations of each of these nutrients occurred at Sandy Point. The Sandy Point site is close to, and downstream from, the sewage treatment plant outfall. Dye tracing by Knox and Kilner (1973) and Lincoln Environmental (1994) has shown that under the prevailing north-easterly wind, effluent flows close to this site. Thus, the effluent is primarily responsible for the high NH_3N, TN, DRP and TP concentrations at this site. Dye tracking studies (Knox and Kilner, 1973; Lincoln Environmental, 1994) have also shown that the effluent moves up the Heathcote low tide channel (and hence in proximity to the Mt. Pleasant Yacht Club), into the Humphries Drive area and into the Pleasant Point area (in proximity to the Pleasant Point Jetty and Pleasant Point Yacht Club), on the flood tide. This accounts for the concentrations of NH_3N, TN, DRP and TP being higher at these sites than at the sites further away from the oxidation ponds and closer to the mouth of the estuary.

The somewhat elevated NH_3N concentrations at Penguin Street (there are no data for TN, DRP or TP at this site), compared to concentrations at South Spit, Beachville Road and Moncks Bay, may also originate from the oxidation pond discharge. Lincoln Environmental (1994) reported that under south-westerly conditions, effluent released one hour before high tide moves to the area in front of Jellicoe Park (north of Penguin Street). Given that Jellicoe Park is 'upstream' from Penguin Street, elevated NH_3N concentrations at Penguin Street could result from the effluent off Jellicoe Park being transported downstream in the Avon River channel on the outgoing tide. It is also possible that in westerly conditions, effluent could move to the Penguin Street area of the spit.

The concentrations of NH_3N, TN, DRP and TP at the McCormacks Bay outfall and Beachville Road sites were consistently low. This is probably because any effluent reaching these sites is highly diluted. Dye tracing work by Knox and Kilner (1973) and Lincoln Environmental (1994) showed that the effluent flowed down the Heathcote River low-flow channel on the out-going tide at the same time that water was exiting McCormacks Bay. On the incoming tide, any effluent which did not leave or which re-entered the Estuary, appeared to flow up the Avon River low-flow channel with the water in McCormacks Bay and the vicinity of Beachville Road being influenced by sea water that entered the Estuary later on the incoming tide.

3.3.2 Over Time

(a) Long Term

The comparison of data collected by differing workers over time, is complicated by variations in the determinands analysed, analytical methods, sampling sites, and sampling times

relative to the stage of the tide. A change in the latter variable alone can result in a large variation in the nutrient concentration measured. Nonetheless, it is possible to make a broad comparison of the data collected by other workers (Appendix VI) to that collected by and in association with Environment Canterbury (Tables 3.2 and 3.3).

At the sites that were sampled in both 1950-51 and 1970-71 there were changes in the concentrations of NH_3N and nitrite (NO_2^-) over time. For NH_3N there was a three fold (approximately) increase in concentration at Sandy Point, Ferrymead Bridge and the site opposite McCormacks Bay, a two fold increase in concentration at Beachville Road and an eight fold increase (approximately) in concentration at Shag Rock over time. These increases may have been the result of the installation of the oxidation ponds (1962), as present records show that NH_3N concentration in the ponds is high. For NO_2^- there was little change in concentration over time at Sandy Point and opposite McCormacks Bay while there was a four fold increase in concentration at the Ferrymead Bridge and a two fold increase at Beachville Road and Shag Rock. This increase in NO_2^- concentration at Ferrymead Bridge most likely resulted from an increase in the number of stormwater and industrial discharges into the Heathcote River over this time.

Between 1970-71 and 1989-99 the mean concentrations of all of the nutrients at Bridge Street/Pleasant Point Yacht Club, Sandy Point and Ferrymead Bridge/Mt Pleasant Yacht Club appear to have increased, whereas mean concentrations either declined slightly or remained about the same at the McCormacks Bay outlet, Beachville Road and Shag Rock. These results suggest that while the oxidation pond effluent and river inputs increased the nutrient concentrations at estuary sites adjacent to these sources, the volume of sea water that enters the estuary with each tide was sufficient to dilute the nutrients to low concentrations at sites some distance away from the sources. That is, the input of increased nutrient concentrations and likely increased effluent discharge volumes did not result in increased concentrations at sites 1.8 km or more away from the sources.

No comparison has been made between the 1989-99 and 2002-05 data because:

1. over 1989-99 sampling was year round while over 2002-05 sampling was only over summer and therefore the 2002-05 data are unlikely to cover the range of rainfall and other meteorological events that the 1989-99 data do.
2. over 1989-99 sampling was undertaken 2-4 hours after high tide while over 2002-05 sampling was undertaken one hour after high tide, and as shown in Figures 3.3 and 3.5, nutrient concentrations at a site do vary over a tidal cycle.

(b) Seasonality and trends

Over 1989-99, significant seasonality occurred in NNN concentrations at 5 sites, in DRP concentrations at 2 sites and in TP concentrations at 3 of the 7 sites. The concentrations of NNN and DRP were found to be lowest during late spring-summer and highest in late autumn. This seasonal pattern reflects the uptake of these nutrients by marine plant life (phytoplankton and macroalgae) in late spring-summer and the release of nutrients back into the water column in late autumn. This seasonal NNN and DRP pattern is a well-recognised phenomenon of marine and freshwater environments. For NNN, this seasonal pattern did not occur at Sandy Point or the Mt. Pleasant Yacht Club, whereas the seasonal pattern for DRP only occurred at these two sites. This result suggests that NNN seasonality at these sites is masked by the continual input of NNN from the Heathcote River and/or the oxidation pond effluent. The seasonality of DRP suggests that given the continual inputs of NNN, marine plant production (uptake of nutrients) at these sites is limited by the concentration of DRP. At the Pleasant Point Jetty, Pleasant Point Yacht Club, McCormacks Bay, Beachville Road and Shag Rock sites, there was a seasonal pattern for NNN but not one for DRP. This suggests that given the DRP concentrations at these sites the marine plant production could be limited by the supply of NNN. However, this is unlikely to be the situation at the Pleasant Point Yacht Club and Pleasant Point Jetty, given the input of high concentrations of NNN to these sites via the Avon River.

The seasonality of TP at Pleasant Point Jetty, Sandy Point and Mt. Pleasant Yacht Club is unusual because TP does not typically exhibit seasonality in marine and freshwater ecosystems. With between-site differences in

the seasonal pattern, it is possible that the apparent seasonal TP concentrations result from seasonal variations in TP inputs from either the oxidation pond discharge and/or the Heathcote River. A Kruskall-Wallis H statistic test for seasonality was performed on recent (October 2003 – June 2005) TP concentrations in the oxidation ponds. This revealed that there was significant seasonality in TP concentrations in the ponds over this time period (Appendix VII), with TP concentrations being higher over summer and autumn than over winter. This seasonal pattern for TP in the ponds is different to that found at Sandy Point and the Mt. Pleasant Yacht Club in the estuary (at Sandy Point, TP concentrations were highest in late summer and winter and lowest in autumn and early summer while at the Mt. Pleasant Yacht Club, TP concentrations were highest in late spring and summer and lowest in early spring and autumn). The seasonality differences in TP concentrations between the ponds and sites in the estuary could be because:

- the seasonality of TP has varied over time (the data from the ponds were from a different time period (2003-05) to that from the estuary (1989-99)).
- The seasonality of TP at sites in the estuary results from seasonality in TP concentrations in the ponds and the Heathcote River

Over the time period from 1989 to 1999, there was a significant decrease in the concentration of TN, DRP and TP at the Pleasant Point Jetty, Pleasant Point Yacht Club and the Mt. Pleasant Yacht Club. Given the proximity of these sites to the Avon and Heathcote rivers, these results suggest that there has been a decrease in the concentration of these nutrients in river water over this time period. While it is not possible to pinpoint this decrease in river nutrient concentrations to any particular change in activities within the Avon and Heathcote catchments, possibilities include; reduced industrial discharges into the rivers, improved stormwater quality and a reduction in the use of fertilisers.

There was a significant increase in NH_3N concentration at the McCormacks Bay outlet only, from 1989 to 1999. This result suggests that the source of the NH_3N over this period was localised i.e., from McCormacks Bay. Even with the increase in concentration over time, the NH_3N concentrations at McCormacks Bay were lower than those at all other sites sampled over 1998-1999.

(c) Over a tidal cycle

The differences in the concentrations of NH_3N and NNN over a tidal cycle at the different sites within the estuary are a function of:

1. The proximity of the site to the predominant source/s of the nutrient
2. The direction of the ebb and flood tide flows in the estuary
3. Wind direction

The tidal cycle pattern in NNN concentrations at the Pleasant Point Yacht Club, Beachville Road, Moncks Bay and Shag Rock, i.e. higher concentrations at mid to low tide and lower concentrations at high tide, occurred because the predominant NNN sources are the Avon and Heathcote rivers. At these sites the NNN from the river is much diluted by sea water at high tide, while at low tide the water sampled is predominantly river water.

The data indicate that the tidal cycle pattern in NNN concentrations at Humphries Drive likely consisted of the concentration increasing as the tide begins to ebb but then decreasing as the tide continues to ebb, increasing again with the rising tide. At this site the highest NNN concentrations occurred in 22-34 ppt sea water and the lowest concentrations generally occurred in 5.2-12.9 ppt sea water (but one low concentration was at 34 ppt sea water). This suggests that the NNN at this site is not primarily from a river but from a number of sources, with the likely sources being the Heathcote River, the effluent discharged from the oxidation ponds and the four drains in the vicinity of this site. Knox and Kilner (1973) reported that the north-east wind caused the effluent to stay close to the western shore and that oxidation pond effluent moves into the Humphries Drive area on a flood tide. The NNN concentrations over the tidal cycle at Humphries Drive highlight the complexity of factors affecting the water in this part of the estuary.

At the Pleasant Point Yacht Club and the Pleasant Point Jetty NH_3N concentrations were highest on or 2-2½ hours after high tide and then decreased as the tide continued to ebb. At the Pleasant Point Yacht Club the lowest concentrations occurred at or up to four hours after low tide. Concentrations then increased as the tide rose to high. This tidal cycle pattern

is consistent with the finding of Knox and Kilner (1973), who reported that on the flood tide the pond effluent starts to be carried towards the Avon River, and from mid-flood tide can be seen flowing close to the shoreline towards the river. The pond effluent has been observed moving some distance up the Avon River (Knox and Kilner, 1973). Lincoln Environmental (1994) also found that strong (relatively undiluted) residual effluent moved into the Pleasant Point area on the flood tide. The occurrence of high concentrations at 2-2½ hours after high tide could result from the flow of the NH_3N pushed up the Avon River on the flood tide flowing back down the river on the ebb tide and past the sampling site.

At Sandy Point and the Mt Pleasant Yacht Club the data indicate that the highest NH_3N concentrations occurred around and up to 3 - 3½ hours after, high tide. At Beachville Road, Moncks Bay and Shag Rock, NH_3N concentrations increased with the ebbing of the tide and highest concentrations occurred at mid to low tide. These tidal cycle patterns in NH_3N concentrations at these sites likely result from the discharge regime for the oxidation pond effluent. The effluent is discharged into the estuary for four hours on each tidal cycle – one hour before and three hours after high tide. Thus the change in NH_3N concentrations at each site as the tide ebbs reflects the time that it takes for the effluent, through tidal and wind generated flow, to reach the various sites as it moves towards the mouth of the estuary.

At Humphries Drive there was no clear relationship between NH_3N concentration and the state of the tide. This most likely results from the multiple sources (oxidation pond effluent and drains) of NH_3N in this area, in combination with the effect of the wind and tide on the estuary water. Again, this highlights the complexity of factors affecting the water in this part of the estuary.

4 Potential effects of nutrient concentrations on the estuarine ecosystem

The potential effects of high concentrations of one or more of the nitrogen and phosphorus based nutrients on the estuarine ecosystem are:

1. The excessive growth of aquatic plants (phytoplankton, cyanobacteria, macro-algae) i.e. eutrophication
2. Possible changes in the relative abundance of phytoplankton species without an overall increase in primary productivity
3. Toxicity to pelagic and benthic species

4.1 Macro-algae

4.1.1 Estuary nutrient concentrations compared to guideline values

The ANZECC (2000) guidelines have been used to assess the potential for the nutrient concentrations in the estuary to cause adverse biological effects, i.e. excessive growth of aquatic plants. The concentrations of the nutrients recorded in the Avon-Heathcote Estuary/Ihutai were compared to the ANZECC (2000) trigger levels for 'slightly disturbed estuarine water' (south–east Australia). When concentrations are below the trigger levels the risk of adverse biological effects is low while at concentrations above the trigger level there is a potential water quality issue and the potential for adverse biological effects (ANZECC, 2000). At all sites the ANZECC (2000) trigger values ('slightly disturbed estuarine water') for NNN, NH_3N, TN, DRP and TP were exceeded (Table 4.1). At Penguin Street, the Pleasant Point Jetty, the Pleasant Point Yacht Club, Sandy Point and Humphries Drive, the concentrations of all nutrients measured exceeded guideline values in all samples. At South Spit,

McCormacks Bay, Beachville Road, Moncks Bay and Shag Rock the guideline values for one or more nutrients was not exceeded in all samples. That is, at sites closer to the mouth of the estuary, trigger values were not exceeded as frequently as they were in samples collected in proximity to the river mouths, the oxidation ponds discharge and in the middle parts of this estuary.

It is important to note that, to date, marine trigger values have not been developed for New Zealand and the guidelines suggest the comparison of New Zealand values to those for south-east Australia. As a consequence the guideline values, which are for the low-nutrient (oligotrophic) waters of south-east Australia, are conservative for the nutrient concentrations in New Zealand estuarine waters which tend to be naturally higher than those on which the guidelines were based. This could, in part, account for the high percentage of samples from this estuary for which the guideline values were exceeded.

Table 4.1 Percentage of samples at each site exceeding ANZECC (2000) estuarine trigger values for each nutrient

TRIGGER VALUES: NOx (oxides of nitrogen) ≡ NNN - 0.015 mg/L
NH_4^+ (ammonium) ≡ NH3N - 0.015 mg/L
TN - 0.3 mg/L
FRP (filterable reactive phosphorus) ≡ DRP - 0.005 mg/L
TP - 0.03 mg/L

Sites

A – South Spit	B – Penguin Street	C – Pleasant Point Jetty
D – Pleasant Point Yacht Club	E – Sandy Point	F – Humphries Drive
G – Mt. Pleasant Yacht Club	H – McCormacks Bay outlet	I – Beachville Road
J – Moncks Bay	K – Shag Rock	

SITE	NNN		NH3N		TN	DRP	TP
	1989-1999	2002-2005	1989-1999	2002-2005	1989-1999	1989-1999	1989-1999
A		63		90			
B		100		100			
C	100		100		100	100	100
D	100	100	100	100	100	100	100
E	100		100		100	100	100
F		100		100			
G	100	98	100	100	100	100	100
H	95		98		79	100	100
I	92	84	99	98	87	100	97
J		87		98			
K	97		99		84	100	98

Table 4.2 Percentage of samples at each site exceeding the water quality criteria mooted by Knox and Kilner (1973) for DIN and TP

Criteria : DIN (+ NNN + NH3N) - > 0.5 mg/L
TP - > 0.1 mg/L

SITE	DIN		TP
	1989-1999	2002-2005	1989-1999
A		0	
B			
C	99		99
D	99	100	100
E	95		98
F		89	
G	89	50	99
H	5		11
I	16	2	38
J		0	
K	38		46

In 1973, Knox and Kilner referred to nutrient criteria (i.e., concentrations that should not be exceeded) developed for reversing the eutrophication process in the Potomac Estuary (Jaworski *et al.,*1972, as cited in Knox and Kilner, 1973), as possible water quality criteria for this estuary. These criteria were 0.3-0.5 mg/L for dissolved inorganic nitrogen (DIN =NNN + NH3N) (i.e. at least ten times higher than the trigger level in the ANZECC (2000) guidelines) and 0.03 to 0.1 mg/L for TP (i.e. comparable to, to 3.33 times higher than the trigger level in the ANZECC (2000) guidelines). The DIN and TP concentrations present at all sites in the estuary are evaluated against these U.S. criteria (Table 4.2). The criterion for TP was exceeded at all sites. At the Pleasant Point Jetty, the Pleasant Point Yacht Club, sandy Point and the Mount Pleasant Yacht Club a high percentage, at McCormacks Bay a low percentage, and at Beachville road and Shag Rock a moderate percentage, of samples contained concentrations that exceeded the criterion. The criterion for DIN was exceeded at all sites except South Spit and Moncks Bay. At the Pleasant Point Jetty, the Pleasant Point Yacht Club, Sandy Point, Humphries Drive and the Mount Pleasant Yacht Club a high percentage, at McCormacks Bay and Beachville Road a low percentage and at site Shag Rock a moderate percentage, of samples contained DIN concentrations that exceeded the criterion. That is, at sites closer to the mouth of the estuary, the criteria were not exceeded in as many samples as they were in samples collected in proximity to the river mouths, the oxidation ponds discharge and in the middle parts of this estuary.

These results suggest that nutrient concentrations in this estuary could result in excessive growth of aquatic plants.

4.1.2 Macroalgal growth in this estuary

The green algae *Ulva* spp. and *Enteromorpha* spp. and the red alga *Gracilaria chilensis* often proliferate on the estuary mudflats in summer.

Ulva spp. are the principal macroalgae that proliferate in this estuary. *Ulva* has a world-wide distribution and while once considered opportunistic, it is now considered a persistent seaweed that is capable of rapid growth responses when conditions are favourable (Park, 1994). It appears that *Ulva* was uncommon in the estuary in the late 1920s,

because Thompson (1930) (as cited in Knox and Kilner, 1973) reported only that there was "... a little *Ulva* in sheltered rock pools and on muddy sand banks." By 1946 *Ulva* was becoming abundant and in the summer of 1950-1951 it was reported to be growing over most of the mudflats, with medium to dense concentrations in Humphreys Drive Basin and along the Heathcote channel (Bruce, 1953) (Figure 4.1). It seems that *Ulva* became less abundant about 1962-1963 (Rosenberg, 1963). However, by 1968 it appeared that its density had increased markedly over previous years (Knox and Kilner, 1973) (Figure 4.1). Between 1972 and the present day there has been considerable variation in the density of *Ulva* on the mudflats. For example:

- in the summer of 1997-98 (a summer of serious drought in Canterbury) there was, after many years of low sea lettuce growth, a large bloom of *Ulva.*
- Bressington (2003) reported differences in the distribution and abundance of *Ulva* spp. between the summer of 2001/2002 and the summer of 2002/2003 (Figure 4.2).

The dense growths of *Ulva* typically occur on the mud flats fronting the oxidation ponds, and on both sides of the McCormacks Bay embankment, as well as in the Humphreys Drive area (Figures 4.1 and 4.2). The dislodged, drifting algae usually accumulate on the South Shore edge of the estuary and in McCormacks Bay. The biomass of *Ulva* spp. is seasonal, peaking in December or January with almost no biomass in autumn and winter (Bressington, 2003).

Gracilaria chilensis is not as widespread as *Ulva* spp. and predominates in the south-western corner of the estuary near Humphries Drive and near the Avon River low flow channel opposite the oxidation ponds outfall (Figure 4.3). Where this alga occurs, the mats can cover over 75% of the mudflat (Bressington, 2003). The biomass of *Gracilaria chilensis* peaks in December and is maintained over the summer but declines slightly in autumn with a moderate biomass throughout the winter (Bressington, 2003).

The factors that favour the prolific growth of *Ulva* spp. in the summer are the subject of some debate, but the principal ones appear to be a large starting biomass (resulting from a mild winter prior to the growing season to allow for the over-wintering of plantlets), suitable sites for zoospore settlement in sheltered sites, light penetration of the water and temperature (Hawes and O'Brien, 2000). Nutrient concentrations do have a part to play in the abundance of the algae over the summer growing season. Bruce (1953) concluded that proliferation of algae in the estuary was caused by the nutrient status of the estuary, but that the greatest growth occurred where there were hollows that allowed the algae to become attached and where permanent water lay. However, Knox and Kilner (1973) suggested that the nutrient status was of overriding importance to the growth of *Ulva,* and cited Waite and Mitchell (1972), who found that growth of this alga was stimulated at ammonia and total phosphorus concentrations of up to 0.7 and 0.5 g/m^3 respectively. This view was disputed by Robb (1976) who considered that the green algae domination of the mud flats was partly a result of modifications to the composition, levels and drainage patterns of the mud flats, and partly a result of natural plant succession. It is worth noting in this regard that the nutrient status of McCormacks Bay has been cited as the cause of sea lettuce proliferations there, yet nutrient concentrations in the outflow from the bay (Figures 3.2, 3.4, 3.6 and 3.7) have been relatively low compared with the remaining estuary sites. Millhouse and Knox (1976) made the same observation during the mid-1970s, and suggested that physical factors such as wave action and river scouring, and exposure to wind, limit sea lettuce growth in the rest of the estuary but not in McCormacks Bay, which is sheltered from the influence of those factors. Needless to say, *Ulva* growth is stimulated by nutrient enrichment. A nitrate-nitrogen (NO_3-N) concentration of 0.18 g/m^3 and an ammonia-nitrogen (NH_3N) concentration of 0.09 g/m^3 are growth saturating for *Ulva* (Pedersen and Borum, 1977) and small concentration increases in NO_3-N and NH_3N can result in massive growth. A doubling in NO_3-N concentration from 1.4 to 2.8 mg/m^3 has been found to result in a many-fold increase in biomass (Harlin and Thorne-Miller, 1981). This alga can use either NH_3N or NO_3-N and has the ability to use both nitrogen species simultaneously (Rosenberg and Ramus, 1984). In addition, *Ulva* can also take up and store nitrogen (Fujita *et al.,* 1988, 1989) giving individuals the ability to grow in N-free medium for some 9 days (Fujita, 1985).

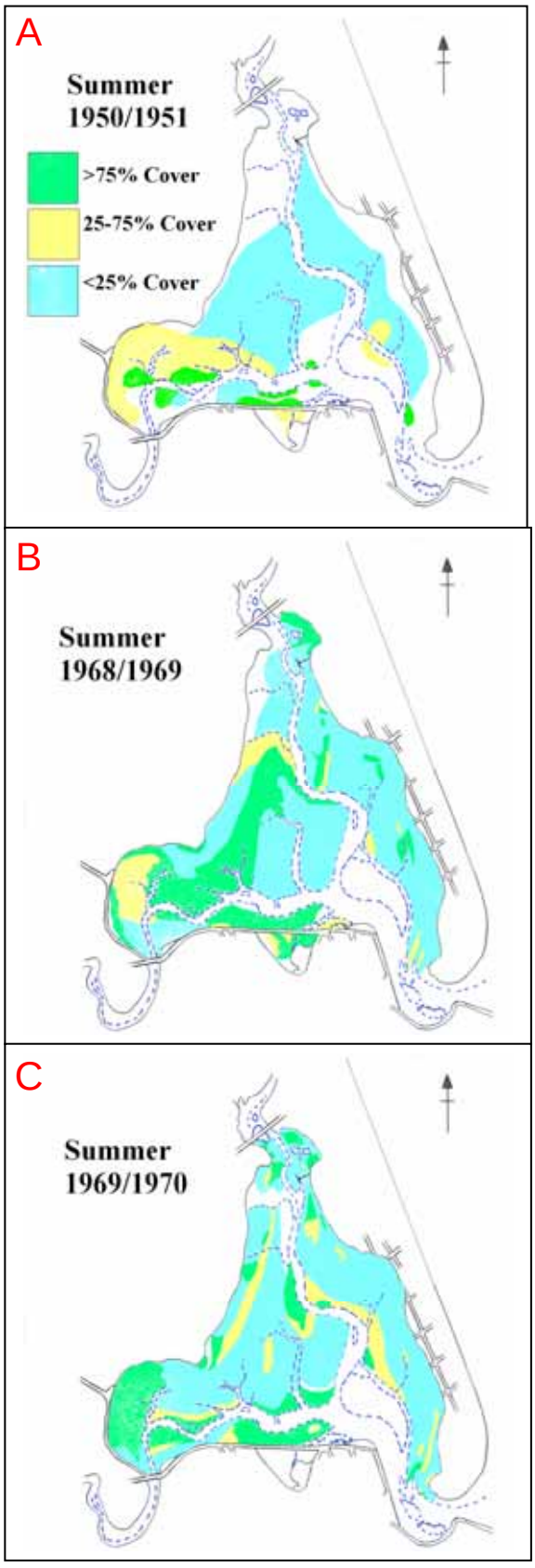


Figure 4.1 **Percentage cover and distribution of *Ulva* spp. around the Avon-Heathcote Estuary/Ihutai over various years** **(Categories for percentage cover as for A)**

A – Bruce (1953) referenced from Knox and Kilner (1973)
B – Referenced from Knox and Kilner (1973)
C – Referenced from Knox and Kilner (1973)
Adapted maps supplied by M. Bressington (from Bressington, 2003)

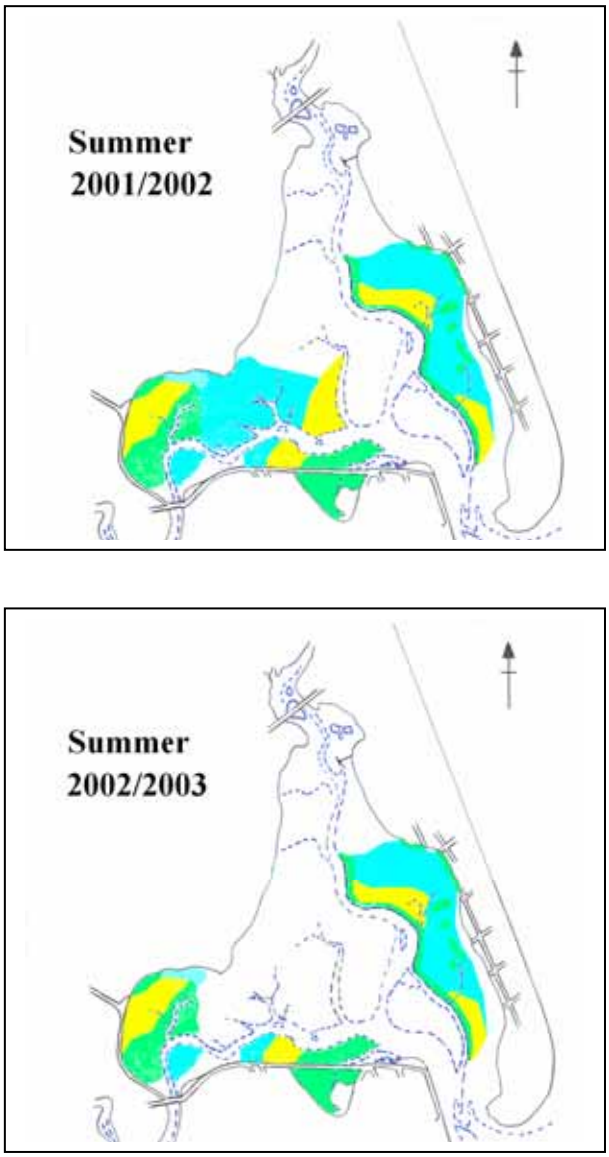


Figure 4.2 Percentage cover and distribution of *Ulva* spp. around the Avon-Heathcote Estuary/Ihutai over two summers (Categories for percentage cover as for A in Figure 4.1)

Maps supplied by M. Bressington (from Bressington, 2003)

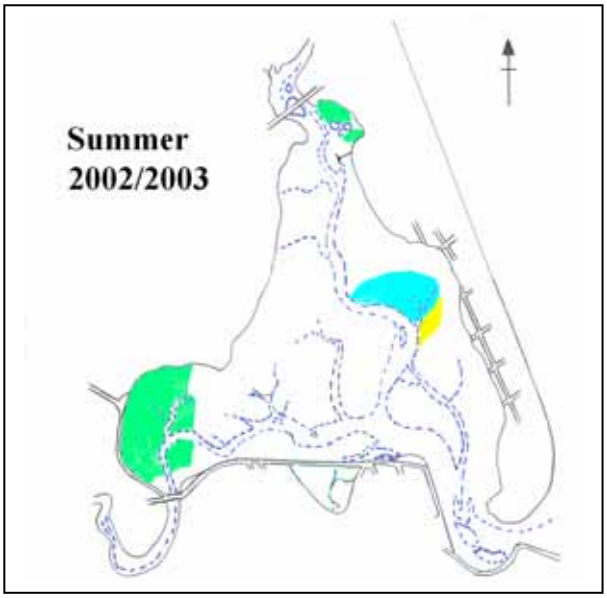


Figure 4.3 Percentage cover and distribution of *Gracilaria chilensis* around the Avon - Heathcote Estuary over the summer of 2002/2003

(Categories for percentage cover as for A in Figure 4.1)

Map supplied by M. Bressington (from Bressington, 2003)

Algal mats can result in the displacement of naturally occurring species, affect the survival of species present and prevent recruitment of polychaete and bivalve larvae. These impacts on the biota can result from:

- reduced/no water circulation at the sediment surface (this reduces the food supply to filter feeders).
- physical interference of the algae (to surface feeding of deposit feeders and to new recruits).
- de-oxygenation of the water and sediments.
- build up of toxic hydrogen sulphide concentrations in the sediment.
- organic enrichment of the sediment.

Bressington (2003) found that in the Avon-Heathcote Estuary/Ihutai, the species richness of the benthic fauna was higher in the *Ulva* spp. habitats than in the *Gracilaria chilensis* habitats or where there were no macroalgae at all. This result suggests that the *Ulva* spp. provides cover and substrate for some species. Bressington (2003), found the lower species richness in the *G. chilensis* habitat was because the sediment was anaerobic and thus only inhabited by highly tolerant opportunistic species.

When the macroalgal blooms occur in the Avon-Heathcote Estuary/Ihutai, large quantities become dislodged from the bottom. This results in a living/growing mobile drift population as well as the accumulation of decaying, rotting algal masses along the shoreline in some areas. The decomposition of the algal masses produces unpleasant odours, of which residents living near the estuary complain. In this estuary these shoreline mats have caused the sediments to become anoxic and devoid of fauna (Bressington, 2003). Such mats can also smother shellfish beds, undermine food chains and cause deterioration of the substrate (Hawes, 1994).

4.1.3 Phytoplankton

In the marine environment nitrogen is the critical limiting nutrient for phytoplankton (plant plankton) growth (NRC, 2001; Rosenberg, 1985; Valiela, 1995). Under optimal conditions, phytoplankton will take up nutrients in the ratio C:N:P of 106:16:1 (Redfield *et al,* 1963), i.e. when the nutrients are available in this ratio phytoplankton growth will not be limited. If the ratio of N:P is less than 16:1 then growth is nitrogen-limited and if it is greater than 16:1 growth is phosphorus limited (NRC, 2001).

The ratio of DIN:DRP (N:P) was calculated for the samples collected between 1989-1999 (Figure 4.4). The N:P ratio of 16:1 was

exceeded in at least one sample at each site and overall in 3.5% of samples collected. That is, based on this ratio, the nutrient primarily limiting phytoplankton growth in the estuary is nitrogen. However, given the high concentrations of DIN and DRP in this estuary, this evaluation of the N:P ratio when considering the potential for excessive phytoplankton growth may well be of limited value.

There is no available information on the species of phytoplankton present in this estuary or phytoplankton growth, and there are no records of phytoplankton blooms.

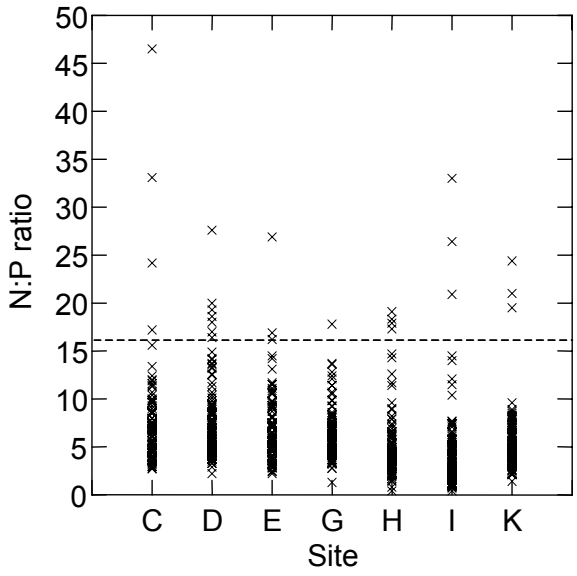


Figure 4.4 **N:P ratio in water sampled at seven sites in the Avon-Heathcote Estuary/Ihutai, 1989-1999**

4.2 Toxicity

4.2.1 Ammonia-nitrogen in the estuary

Ammonia is a non-persistent and non-cumulative toxicant to aquatic life (ANZECC, 2000). The term ammonia-nitrogen (NH_3N) refers to two chemical species that are in equilibrium in water: the un-ionised ammonia NH_3 and the ionised ammonium ion NH_4^+. The proportion of these chemical forms in water is dependent on the pH, temperature and the ionic composition (salinity) of the water. The toxicity is primarily attributed to the concentration of NH_3. However, the ammonium ion can also contribute significantly to ammonia toxicity under certain conditions. The effect of pH and temperature on the toxicity of ammonia is well understood while the effect of salinity on toxicity is not so well understood.

To assess the potential for the NH_3N concentrations in the estuary to cause adverse biological effects, i.e. be toxic to estuarine life, the concentrations recorded have been compared to ANZECC (2000) trigger values (0.5, 0.91, 1.2, 1.7 mg/L respectively) that provide for 99, 95, 90 and 80 percent protection of species in marine water (there are no values given for estuarine water). The above trigger values do not take into account the pH of the water, hence for samples in which both pH and NH_3N concentrations were recorded, the concentrations have also been compared to a different set of trigger values within the AZECC (2000) guidelines. In addition, the 2002-2005 data have been compared to the USEPA water quality criteria for saltwater aquatic life. Comparisons have been made to both the criteria maximum concentrations (acute toxicity) and the criteria continuous concentrations (chronic toxicity). The USEPA guidelines incorporate pH, temperature and salinity into the criteria concentrations; all of these parameters were recorded over 2002-2005 but not all were recorded over 1989-99.

Comparison with the ANZECC (2000) values

Over 1989-1999 (Tables 4.3 and 4.4) the NH_3N concentrations:

- in most samples from Sandy Point exceeded those likely to be toxic to 1-5 % of species.
- at the Pleasant Point Jetty, Pleasant Point Yacht Club and Mt. Pleasant Yacht Club were likely to be toxic to 1% of the species in approximately 80% of the samples and toxic to 5% of the species in approximately half of the samples.
- at Beachville Road and Shag Rock were likely to be toxic to 1% of species in some samples, with concentrations toxic to 10% of species occurring in less than 10% of the samples.
- at the McCormacks Bay outlet were unlikely to reach those toxic to more than 1% of the species.
- likely to be toxic to 20% of species were exceeded at the Pleasant Point

Jetty, Pleasant Point Yacht Club, Sandy Point and Mt. Pleasant Yacht Club.

Over 2002-2005 (Tables 4.5 and 4.6) the NH_3N concentrations:

- in all samples from South Spit and Moncks Bay were below the trigger values.
- in less than 5% of samples from Penguin Street and Beachville Road, exceeded those likely to be toxic to 1-5 % of species.
- in at least half of the samples at the Pleasant Point Yacht Club and Humphries Drive exceeded concentrations likely to be toxic to 1% of the species and concentrations in 13.6% of samples exceeded those considered toxic to 20% of the species.
- in less than half of the samples at the Mt. Pleasant Yacht Club exceeded concentrations likely to be toxic to 1% and concentrations in less than five percent of samples exceeded those considered toxic to 20% of the species.

Table 4.3 Percentage of samples exceeding ANZECC (2000) trigger values for four different levels of protection of marine species (unadjusted for pH) at sites sampled in the Avon- Heathcote Estuary/Ihutai, 1989-1999

n= number of samples

		Level of protection			
	n	**99%**	**95%**	**90%**	**80%**
Pleasant Point Jetty	100	83	55	40	13
Plesant Point Yacht Club	102	80.4	48	28.4	15.7
Sandy Point	101	91.1	75.2	69.3	58.4
Mt. Pleasant Yacht Club	101	80.2	44.6	36.6	12.9
McCormacks Bay	101	1	0	0	0
Beachville Road	101	8.8	4.9	2.9	0
Shag Rock	102	29.4	13.7	8.8	0

Table 4.4 Percentage of samples exceeding the ANZECC (2000) trigger values for 95% protection of marine species (adjusted for pH) at sites sampled in the Avon-Heathcote Estuary/Ihutai, 1989-1999

n= number of samples

	n	**95%**
Pleasant Point Jetty	21	52.4
Plesant Point Yacht Club	21	52.4
Sandy Point	21	90.5
Mt. Pleasant Yacht Club	21	57.1
McCormacks Bay	21	0
Beachville Road	21	9.5
Shag Rock	21	4.8

Table 4.5 Percentage of samples exceeding ANZECC (2000) trigger values for four different levels of protection of marine species (unadjusted for pH) at sites sampled in the Avon-Heathcote Estuary/Ihutai, 2002-2005

n= number of samples

		Level of protection (% species)			
	n	99%	95%	90%	80%
South Spit	44	0	0	0	0
Penguin Street	43	4.7	0	0	0
Pleasant Point Yacht Club	44	54.5	34.1	22.7	13.6
Humphries Drive	44	54.5	29.5	22.7	13.6
Mt. Pleasant Yacht Club	43	44.2	18.6	7	4.7
Beachville Road	45	2.2	0	0	0
Moncks Bay	45	0	0	0	0

Table 4.6 Percentage of samples exceeding the ANZECC (2000) trigger values for 95% protection of marine species (adjusted for pH) at sites sampled in the Avon-Heathcote Estuary/Ihutai, 2002-2005

n= number of samples

	n	95%
South Spit	44	0
Penguin Street	43	0
Pleasant Point Yacht Club	44	29.5
Humphries Drive	44	34.1
Mt. Pleasant Yacht Club	43	11.6
Beachville Road	45	2.2
Moncks Bay	45	0

Comparison with the USEPA (1989) guideline values

Over 2002-2005 (Table 4.7) the criteria maximum concentrations (acute toxicity) did not occur at any of the sites. However, the criteria continuous concentrations (chronic toxicity) were exceeded at four sites. At each of the four sites the percentage of samples in which the criteria continuous concentrations were exceeded is similar to the percentage of samples exceeding the ANZECC (2000) trigger values giving 95% protection of species, when adjusted for pH.

The 2002-2005 samples were collected one hour after high tide, but as shown by the sampling over a tidal cycle, the NH_3N concentrations at:

- the Pleasant Point Yacht Club were highest on or up to 2½ hours after high tide
- Humphries Drive had no defined relationship to the state of the tide. On most occasions the highest concentrations occurred around high tide or as the tide was ebbing while on one occasion it occurred around low tide.
- Beachville Road were highest at mid-low tide.

Table 4.7 Percentage of samples exceeding the USEPA (1989) criteria maximum concentrations and criteria continuous concentrations for saltwater aquatic life, at sites sampled in the Avon-Heathcote Estuary/Ihutai, 2002-2005

	Criteria maximum	Criteria continuous
South Spit	0	0
Penguin Street	0	0
Pleasant Point Yacht Club	0	27.27
Humphries Drive	0	34.1
Mt. Pleasant Yacht Club	0	18.6
Beachville Road	0	2.2
Moncks Bay	0	0

Given these results, it is likely that both the USEPA (1989) continuous criteria concentrations and the ANZECC (2000) trigger values giving 95% protection of species (when adjusted for pH) are exceeded not just at high tide but at other states of the tide as well at these three sites. This could also be the situation at the Mt. Pleasant Yacht Club site although there is no sampling over the tidal cycle to verify this.

These results suggest that NH_3N concentrations in some areas of this estuary are likely to be toxic to some marine species at times.

4.2.2 Fish diversity and abundance

Studies (as reported in the ANZECC (2000) guidelines) have found that in freshwater ecosystems, invertebrates are generally more tolerant to ammonia than fish, and phytoplankton and aquatic vascular plants are more tolerant again. Acute toxicity in fish has been found to manifest itself in various ways, such as: a loss of equilibrium, hyper-excitability and increased breathing rate, cardiac output and oxygen output, and in extreme cases convulsions, coma and death. Chronic toxicity to fish has been found to manifest itself in ways such as: a reduction in breeding success, reduction in growth rate and morphological development and pathological changes in gill, liver and kidney tissue. The assumption is that ammonia toxicity in the marine environment will be similar to that in the freshwater environment and hence the focus here is on the fish of the Avon-Heathcote Estuary/Ihutai.

The fish resources of this estuary were surveyed intensively by Webb in 1965-66 (as cited in James, 1999). Following on from this, Mundy (1968) (as cited in James, 1999), in his PhD research, carried out a detailed study of sand flounder populations in the Estuary and off the Canterbury Coast and Kilner (1973) carried out feeding and salinity studies on the 0-group sand flounders in the estuary for his thesis. For his thesis in 1998, Nairn undertook work on the fish populations in the estuary, but because of major sampling problems associated with the large quantities of sea lettuce present, the data obtained were not able to be compared to those collected by Webb in 1965-66. Thus, there are no recent quantitative data on the abundance of fish species that can be compared to the data collected 40 or so years ago.

Thirty-four species of fish have been recorded from the Estuary (James, 1999). In the comparisons that were made between the data collected by Webb over 1965-66 and those collected by Nairn in 1998, it does appear that the abundance of some fish species has declined since the initial survey. Kahawai and globefish, both abundant over 1965-66, were not recorded in the estuary in 1988, and the abundance of sand flounder, common sole and red cod was much lower in 1988 than in 1965-66. Apart from globefish, all of these fish are fished commercially, with fishing pressure a possible contributing factor if the apparent decline is in fact real (James, 1999). Globefish have no commercial or recreational fishing value and therefore the apparent decline in this population over time could be due to a variety

of causes other than fishing, including the toxins (such as ammonia) present in the effluent discharged from the sewage treatment plant. There is no cause and effect information to ascertain if this assumption is correct. However, it is speculated that a high ammonia concentration in, in particular, the low tide channels where fish aggregate at low tide, could kill the individuals present. Hence, the more frequent the occurrence of high concentrations of ammonia in the estuary channels and estuary water at high tide, the more fish that will be affected.

5 Future water quality monitoring and investigations

5.1 Monitoring

Water quality monitoring is the routine sampling of the water at sites over time.

5.1.1 Objectives of water quality (nutrient concentrations) monitoring in the estuary

The objectives of the water quality (nutrient concentrations) monitoring within the estuary are:

1. To measure the ambient water quality in the estuary
2. To identify long–term changes in water quality in the estuary
3. To compare estuary water quality to guidelines values and assess the potential for adverse ecological effects
4. To characterise the nutrient contributions from the rivers, drains and sewage treatment plant effluent to the water quality of the estuary.

(a) Measuring ambient water quality
The data collected will be regularly checked for high values. This will result in an assessment of the likely source/cause of such values.

(b) Identifying long-term changes
Routine sampling over a long period of time will allow for trend analyses of the data.

(c) Potential for adverse ecological effects
The data collected will be evaluated against ANZECC (2000) and USEPA (1989) guideline values.

(d) Characterise nutrient inputs
The sampling sites will be located throughout the estuary. By strategically locating some sites in proximity to the major influences on estuary water quality e.g. rivers and drains it will be possible to compare nutrient concentrations between sites. From the between-site comparisons the effects of the various inputs on estuary water quality can be measured.

The routine collection of data will be valuable given the expectation that effluent from the sewage treatment plant will not be discharged into this estuary come 2009 (approximately). Following the cessation of this discharge the expectation is for statistically significant decreases in the concentration of some of the nutrients. Routine sampling over a period of at least 10 years will allow for a statistically rigorous assessment of any changes in nutrient concentrations on cessation of this discharge into the estuary.

5.1.2 Methods

(a) Sites
It is recommended that routine sampling be undertaken at nine sites (Figure 5.1) for at least the next ten years. These nine sites have all been sampled at various times in the past.

(b) Sampling regime
Samples should be collected on the ebb-tide, one to two hours after high tide (i.e., three to four hours after NZST high tide at Lyttelton). Sampling should be undertaken monthly.

(c) Sample analyses
Each sample is to be tested for:

pH
Salinity
Dissolved oxygen
Total nitrogen
Nitrate-nitrite nitrogen
Ammonia nitrogen
Dissolved reactive phosphorus
Total phosphorus

At the time of sampling, water temperature will be measured and recorded.

(d) Sample collection

The samples could be collected by, either community volunteers or ECan staff.

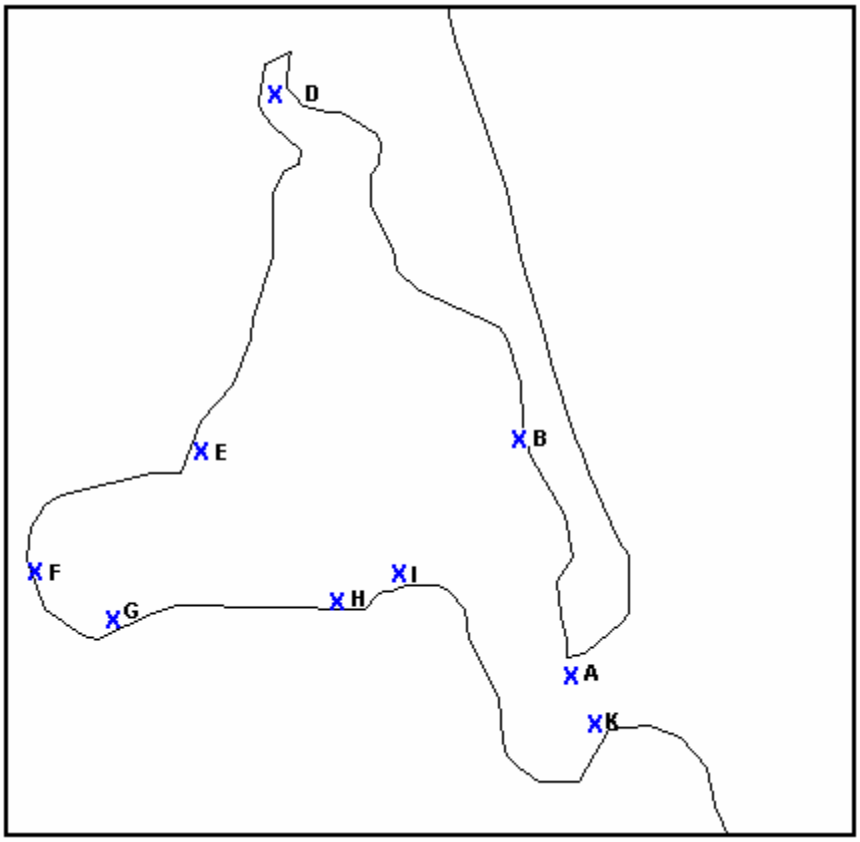


Figure 5.1 Recommended sites for future water quality monitoring

A – South Spit
B – Penguin Street
D – Pleasant Point Yacht Club
E – Sandy Point
F – Humphries Drive
G – Mt. Pleasant Yacht Club
H – McCormacks Bay outlet
I – Beachville Road
K – Shag Rock

5.2 Recommended investigation

Investigations are specific sampling programmes aimed at providing answers to a specific question.

5.2.1 Impact of stormwater discharge

(a) Question

What impact does the stormwater discharging directly into the estuary, have on estuary water quality (nutrient concentrations)?

(b) Investigation

It is recommended that an investigation be undertaken to measure the nutrient concentrations in the stormwater that is discharged directly into the estuary via the stormwater outlets. This would be a complex investigation and given the number of stormwater outlets around the perimeter of the estuary, ten or so representative outlets could be studied.

The following information would be required as part of this investigation:

1. Rainfall throughout the year
2. Size and land use in the catchment area of each stormwater outlet
3. Water flow in the selected outlets
4. Routine auto-sampling of the stormwater in the pipe during rainfall events
5. Analysis of samples for suspended solids, faecal coliforms, DRP, TP, TN, NNN, and NH_3N (and dissolved and total Pb, Cu and Zn).

Such an investigation would be expensive and will only be possible if funds are available.

The details of such an investigation should be developed in consultation with a New Zealand expert on stormwater and staff from the Christchurch City Council.

6 Acknowledgements

The authors wish to thank Julie Edwards, Shirley Hayward and other staff of the Canterbury Regional Council and all the community volunteers who collected the samples. The samples were analysed by the laboratory staff of the North Canterbury Catchment Board, Cawthron Institute and ECan. We greatly appreciate the help of Mike Bourke and Darren Handiforth from the Christchurch City Council; they have willing answered queries and supplied data. We are grateful that Melanie Bressington provided us with, and allowed us to include, the maps she used in her thesis. This report was reviewed by Dr. Paul Gillespie from the Cawthron Institute and edited by Ken Taylor from Environment Canterbury.

7 References

ANZECC (Australia and New Zealand Environment and Conservation Council) 2000: *Australian and New Zealand Guidelines for fresh and marine waters.* Australia and New Zealand Environment and Conservation Council. Melbourne

APHA (American Public Health Association). 1998. *Standard methods for the examination of water and wastewater.* 20th edition. American Public Health Association, Washington.

Avon-Heathcote Estuary Ihutai Trust, 2004. Ihutai Management Plan 2004. 30pp.

Brandvold, D.K., Popp, C.J., and Brierley, J.A., 1976. Waterfowl refuge effect on water quality: II. Chemical and physical parameters. *Journal of the Water Pollution Control Federation* 48: 680-687.

Bressington, M. 2003. The effects of macroalgae mats on the marine benthic fauna in the Avon-Heathcote Estuary. M.Sc. thesis in Environmental Science, University of Canterbury.

Bruce, A., 1953. Report on a biological and chemical investigation of the waters in the estuary of the Avon and Heathcote Rivers. Report to the Christchurch Drainage Board.

Cameron, J., 1970. Biological aspects of pollution in the Heathcote River, Christchurch, New Zealand. *N.Z. Journal of Marine and Freshwater Research* 4: 431-444.

Chapman, D., 1992: *Water Quality Assessments.* Chapman and Hall Ltd, London.

ECan, 1999. Surface water quality, Ground water quality, biological and habitat assessment field and office procedures manual. Draft Environment Canterbury Technical Report.

Fujita, R.M. 1985. The role of nitrogen status in regulating transient ammonium uptake and nitrogen storage by macroalgae. *Journal of Experimental Biology and Ecology* 92:283-301

Fujita, R.M., Wheeler, P.A. and Edwards, R.L. 1988. Metabolic regulation of ammonium uptake by *Ulva rigida* (Chlorophyta): A compartmental analysis of the rate-limiting step for uptake. *Journal of Phycology* 24:560-566.

Fujita, R.M., Wheeler, P.A. and Edwards, R.L. 1989. Assessment of macroalgal nitrogen limitation in a seasonal upwelling region. *Marine Ecology Progress Series* 53:293-303

Gillespie, P.A., 1993. The enrichment status of the Avon-Heathcote sediments collected December 1991. Cawthron Report No. 208. 12pp.

Gilson, M. and Mitchell, K. 1999. Christchurch City. Surface water quality data 1995-97. Water quality trends 1986-97. Report prepared for the Christchurch City Council. 253pp.

Harlin, M.M. and Thorne-Miller, B. 1981. Nutrient enrichment of seagrass beds in a Rhode Island coastal lagoon. *Marine Biology* 65:221-229

Hawes, I. 1994. Sea Lettuce: a 'blooming" nuisance. *Water and Atmosphere* 2(4): 20-22

Hawes, I. and O'Brien R. 2000. Contribution to the assessment of the effects of the Bromley oxidation ponds effluent on the Avon-Heathcote estuary: modelling the growth of sea lettuce in the estuary. *NIWA Client Report CHC00/19 prepared for Woodward-Clyde Consultants Ltd.* 22pp.

Hickey, C.W., Quinn, J. M., Davies-Colley, R. J. 1989. Effluent characteristics of domestic sewage oxidation ponds and their impacts on rivers. *N.Z. Journal of Marine and Freshwater Research* 23:585-600.

Hogan, D.J. and Wilkinson, L., 1959. A survey of pollution in the Avon and Heathcote Rivers, Christchurch, New Zealand. *N.Z. Journal of Science 2:* 506-529.

IDT (Intelligent Decisions Technologies), 1998: Wqstat Plus. Intelligent Decisions Technologies Ltd, Longmont.

James, G. 1999. Fish resources of the Avon-Heathcote Estuary and inshore Pegasus Bay: current knowledge and assessment of effects of treated effluent discharges. NIWA Client Report CHC99/36. 19pp.

Kilner, A.R. 1973. The biology of the 0-group sand flounder (*Rhombosolea plebeian*) in the Avon-Heathcote Estuary. Unpublished M.Sc. thesis, Zoology Department, Canterbury University.

Knox, G.A. 1992. The ecology of the Avon-Heathcote Estuary. A Report Prepared for the Christchurch City and Canterbury Regional Councils.

Knox, G.A. and Kilner, A.R., 1973. The ecology of the Avon-Heathcote Estuary. Unpublished report to the Christchurch Drainage Board by the Estuarine Research Unit, Department of Zoology, University of Canterbury. 358 pp.

Lincoln Environmental. 1994. Avon-Heathcote Estuary Dye Study. Lincoln Environmental Report 2481/2. 60 pp.

Milhouse, D. and Knox, G.A. 1976. Seasonal micronutrient variation in the Avon-Heathcote Estuary. *Estuarine Research Unit Report No. 6.*

Mosley, L., Ho, F., Peake, B.M. and Corson, J. 1997. *A Characterisation of the runoff in the Kaikorai catchment, Dunedin*. Report prepared for the Dunedin City Council, New Zealand. 53pp.

Nairn, H.J. 1998. Fish fauna of the Avon-Heathcote Estuary, Christchurch. Unpublished M.Sc. thesis, Zoology Department, Canterbury University.

NRC, 2001. *Clean Coastal Waters: Understanding and reducing the effects of nutrient pollution.* National Academy Press, Washington D.C.

Otago Regional Council (ORC) 1998. *Otago Harbour. An investigation of sediment in the upper harbour basin and Andersons Bay Inlet.* Otago Regional Council, Dunedin, New Zealand. 137pp.

Park, S., 1994. Environment B.O.P. natural environment regional monitoring network coastal and estuarine ecology programme 1992/93. *Environment B.O.P. Environmental Report No. 94/6.* 137pp.

Pedersen, M. F. and Borum, J. 1997. Nutrient control of estuarine macroalgae: growth strategy and the balance between nitrogen requirements and uptake. *Marine Ecology Progress Series* 161:151-163

Pratt, C. 2000. Assessment of the Avon and Heathcote River contaminant mass load. Prepared for the Christchurch City Council.

Redfield, A.C., Ketchum, B.H. and Richards, F.A. 1963. in: *The Sea: Ideas and Observations on Progress in the Study of the Seas,* ed. M.N. Hill. Vol. II. Pp 26-77. Interscience, New York.

Robb, J.A., 1973. An ecological study of the Bromley oxidation ponds and surrounding environs. Ph.D. thesis in Zoology, University of Canterbury. 206pp.

Robb, J.A., 1976. The Avon-Heathcote Estuary: A current appraisal. *Wastewater Treatment Plant Operators Newsletter, 1976:* 48-52.

Rosenberg, D.R., 1963. Report on biological investigation of the Avon and Heathcote Rivers. Christchurch Drainage Board.

Rosenberg, G. and Ramus, J. 1984. Uptake of inorganic nitrogen and seaweed surface area: volume ratios. *Aquatic Botany* 19:65-72.

Rosenberg, R. 1985: Eutrophication – the future marine coastal nuisance? *Marine Pollution Bulletin* 16 (6): 227-231

Sagar, P. 2000. Christchurch wastewater treatment plant: assessment of environmental effects: birdlife. NIWA Client Report CHC00/72.

Stansfield, B. 2000. *Wellington Regional Council annual freshwater quality report 1998/99.* Wellington Regional Council Publication No. WRC/RINV-G-99/20.

URS. 2001. Assessment of Environmental Effects for Christchurch wastewater discharge. Prepared for the Christchurch City Council.

URS, 2004. Assessment of Environmental Effects: Christchurch City Council Ocean Outfall Pipeline. Prepared for the Christchurch City Council.

USEPA, 1989. Ambient water quality criteria for ammonia (saltwater) – 1989. EPA Report 440/5-88-004. 59pp.

Valiela, I. 1995. *Marine Ecological Processes*. Springer-Verlag, NY. Inc.

Vincent, V.C and Thomas, M.P. 1997. Urban runoff pollution: An Overview. *Environmental Education and Information* 16(2): 185-196.

Waite, T.D. and Mitchell,R. 1972. The effect of nutrient fertilisation in the benthic alga *Ulva lactuca* . *Botanica marina* 15:151-156.

Webb, B.F., 1965. Report on a biological investigation of the estuary of the Avon and Heathcote Rivers, Christchurch, New Zealand. Christchurch Drainage Board.

Wilkinson, L., 1961. Nitrogen transformations in a polluted estuary. *International Journal of Air and Water Pollution 7:* 737-752.

Williamson, R.B. 1986. Urban stormwater quality II. Comparison of three New Zealand catchments. *New Zealand Journal of Marine and Freshwater Research* 20:315-328.

Appendix I: Stormwater outlets discharging into the Avon-Heathcote Estuary/Ihutai

Easting	Northing	Diameter of outlet (cm)	Size of channel in estuary	Comments
2487972	5738806	30	small	
2488076	5738566	60	medium	
2488062	5733545	57	large	
2487934	5738536	46	large	
2487712	5738768	38	large	
2487608	5738851	120	large	Two identical pipes that run under road
2487520	5739044	55	-	Metal door in front and cage/grill around front
2487376	5739054	15	-	
2487172	5739074	54	small	
2487080	5739082	110x30	small	
2487066	5739079	38	-	
2487109	5739080	18	-	
2486989	5739056	30	-	
2486913	5739030	23	-	Metal door on front
2486842	5738995	38	small	
2486683	5738932	75	large	
2486588	5738894	23	-	
2486543	5738797	17	-	
2486026	5739583	22	-	goes into channel from City Outfall drain
2486021	5739137	25	-	Broken rim, 30cm below roadway
2486088	5739057	70	-	
2486092	5739054	90	-	Concrete cover with metal hinges
2486167	5738991	21	-	at base of the wall
2486172	5738986	26	-	30 cm from top of wall
2486208	5738944	41	-	pipe extends ~50 cm from the wall, covered with ice plant
2486241	5738922	26	-	metal cover
2486247	5738921	36	-	
2486265	5738921	25.5	-	
2486300	5738885	17	-	
2486316	5738872	22.4	small	Cover missing, pipe structure beside it
2486327	5738868	15	-	
2486360	5738852	30	-	
2486404	5738783	28	-	
2486413	5738767	42	small	metal cover, hidden by ice plant

Easting	Northing	Diameter of outlet (cm)	Size of channel in estuary	Comments
2487972	5738806	30	small	
2488076	5738566	60	medium	
2488062	5733545	57	large	
2487934	5738536	46	large	
2487712	5738768	38	large	
2487608	5738851	120	large	Two identical pipes that run under road
2487520	5739044	55	-	Metal door in front and cage/grill around front
2487376	5739054	15	-	
2487172	5739074	54	small	
2487080	5739082	110x30	small	
2487066	5739079	38	-	
2487109	5739080	18	-	
2486989	5739056	30	-	
2486913	5739030	23	-	Metal door on front
2486842	5738995	38	small	
2486683	5738932	75	large	
2486588	5738894	23	-	
2486543	5738797	17	-	
2486026	5739583	22	-	goes into channel from City Outfall drain
2486021	5739137	25	-	Broken rim, 30cm below roadway
2486088	5739057	70	-	
2486092	5739054	90	-	Concrete cover with metal hinges
2486167	5738991	21	-	at base of the wall
2486172	5738986	26	-	30 cm from top of wall
2486208	5738944	41	-	pipe extends ~50 cm from the wall, covered with ice plant
2486241	5738922	26	-	metal cover
2486247	5738921	36	-	
2486265	5738921	25.5	-	
2486300	5738885	17	-	
2486316	5738872	22.4	small	Cover missing, pipe structure beside it
2486327	5738868	15	-	
2486360	5738852	30	-	
2486404	5738783	28	-	
2486413	5738767	42	small	metal cover, hidden by ice plant

Appendix II: Details of each sampling site in the Avon-Heathcote Estuary/Ihutai

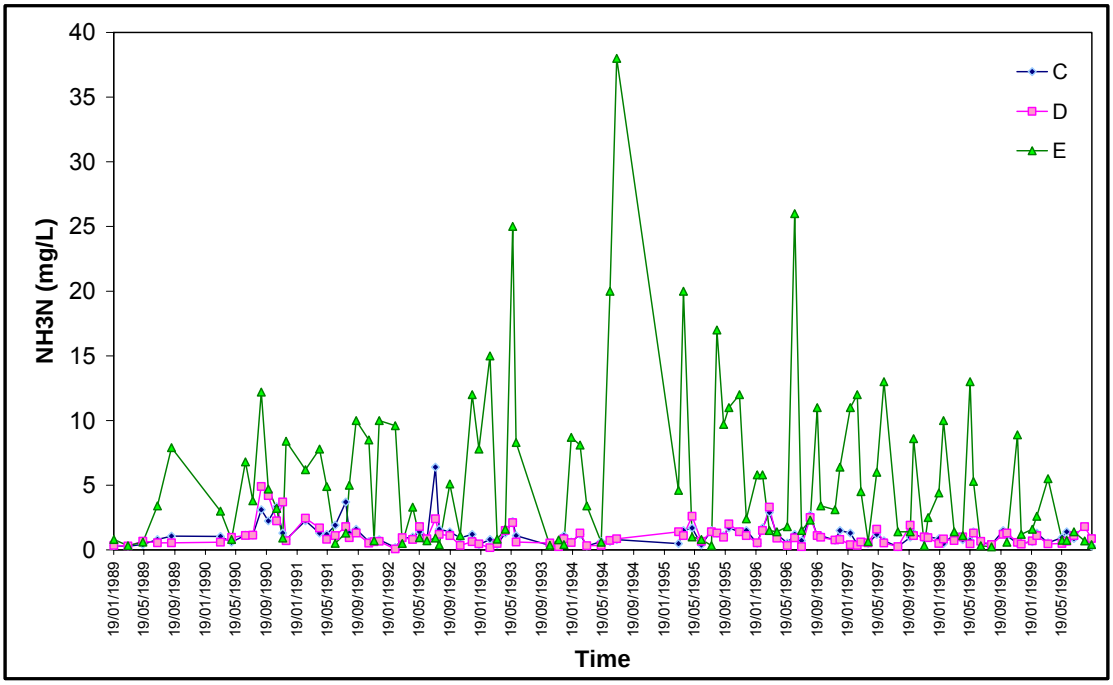
Site Label	Site Description	Grid reference NZMS 260 map series
A	South Spit	M36:897-384
B	Penguin Street	M35:893-401
C	Pleasant Point Jetty	M35:881-418
D	Pleasant Point Yacht Club	M35:878-424
E	Sandy Point	M36:872-400
F	Humphries Drive	M36:861-395
G	Mount Pleasant Yacht Club	M36:866-389
H	McCormacks Bay	M36:881-390
I	Beachville Road	M36:885-391
J	Moncks Bay	M36:896-380
K	Shag Rock	M36:897-382

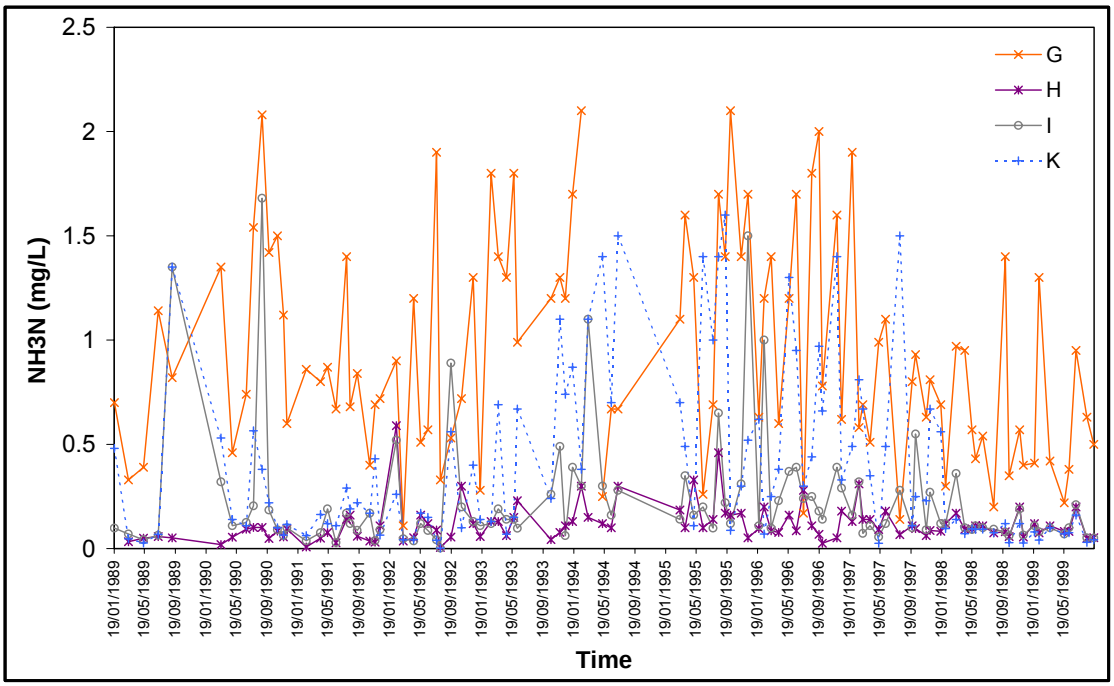
Appendix III: Details of the analytical methods used

Determinand	Analysis provider	Method	Time Period	Detection Limit	Units
Nitrate/nitrite nitrogen (NNN)	CIN Laboratory	APHA 418C Cawthron method	1989-1992	0.005	mg/L
	CIN Laboratory	APHA 4500 NO_3 E.	1992-1997	0.005	mg/L
	CRC laboratory	Cadmium reduction by CFA	1989-1999	0.01	mg/L
	ECan laboratory	APHA 4500 NO_3 - F (20^{th} ED)	2002-2005	0.005	mg/L
Total ammonia-nitrogen (NH_3N)	CIN Laboratory	Limnology and Oceanography 1969, using indophenol blue	1991-1997	0.003	mg/L
	CRC laboratory	Indophenol Blue colorimetry, Water and Soil No.38	1989-1999	0.005	mg/L
	ECan laboratory	APHA 4500 NH3-F - modified (20^{th} ED)	2002-2005	0.005	mg/L
Total nitrogen (TN)	CIN Laboratory	Chem. Div. Photo-oxidation method	1991-1997	0.02	mg/L
	CRC laboratory	APHA 4500-NN.SFA. Persulphate digestion ((19^{th} ED)	1991-1999	0.05	mg/L
	ECan laboratory	APHA 4500-N C modified (20^{th} ED)	2002-2005	0.08	mg/L
Dissolved reactive phosphorus (DRP)	CIN Laboratory	APHA 424 C & F modified Cawthron method	1989-1992	0.002	mg/L
	CIN Laboratory	APHA 4500-P, E	1992-1997	0.002	mg/L
	CRC laboratory	Ascorbic Acid Mo-Sb reagent, Water and Soil No 3	1989-1999	0.003	mg/L
	ECan laboratory	APHA 4500-P B, E modified (20^{th} ED)	2002-2005	0.001	mg/L
Total phosphorus (TP)	CIN Laboratory	APHA 424F Persulphate Digest Cawthron method	1989-1991	0.002	mg/L
	CIN Laboratory	APHA 4500-P B, E	1991-1997	0.002	mg/L
	CRC laboratory	H2SO4/K2S2O8 digestion Mo-Sb reagent	1989-1999		mg/L
	ECan laboratory	APHA 4500-P B (20^{th} ED)	2002-2005	0.008	mg/L

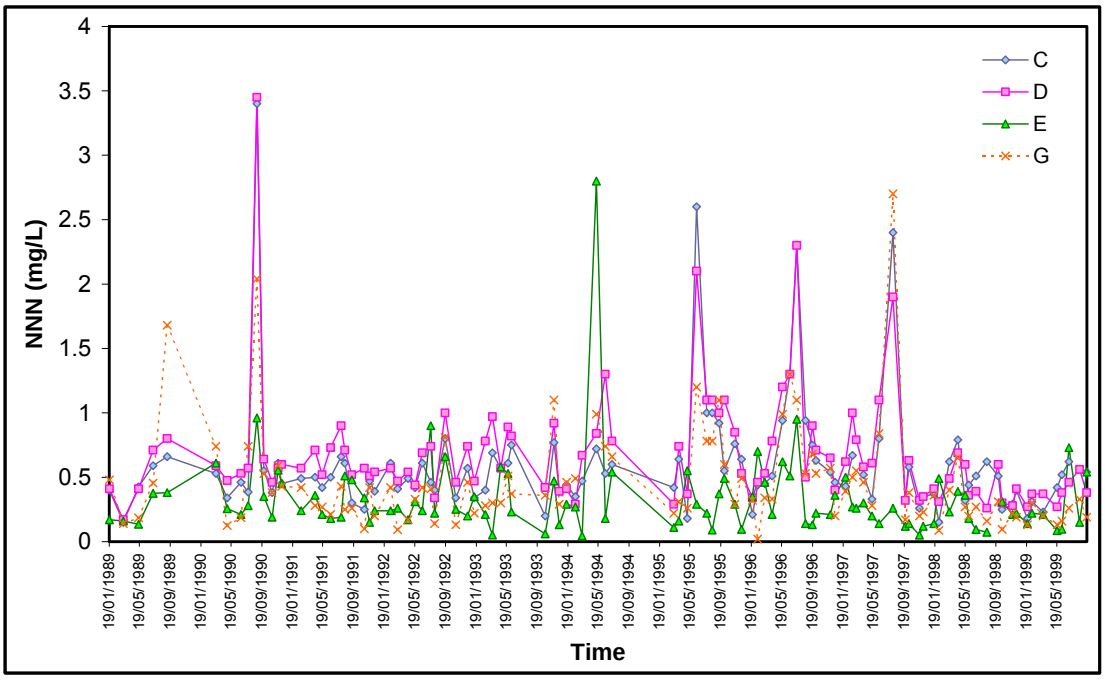
Appendix IV: NH_3N, NNN, TN, DRP and TP concentrations in estuary water over time at sites sampled from 1989-1999

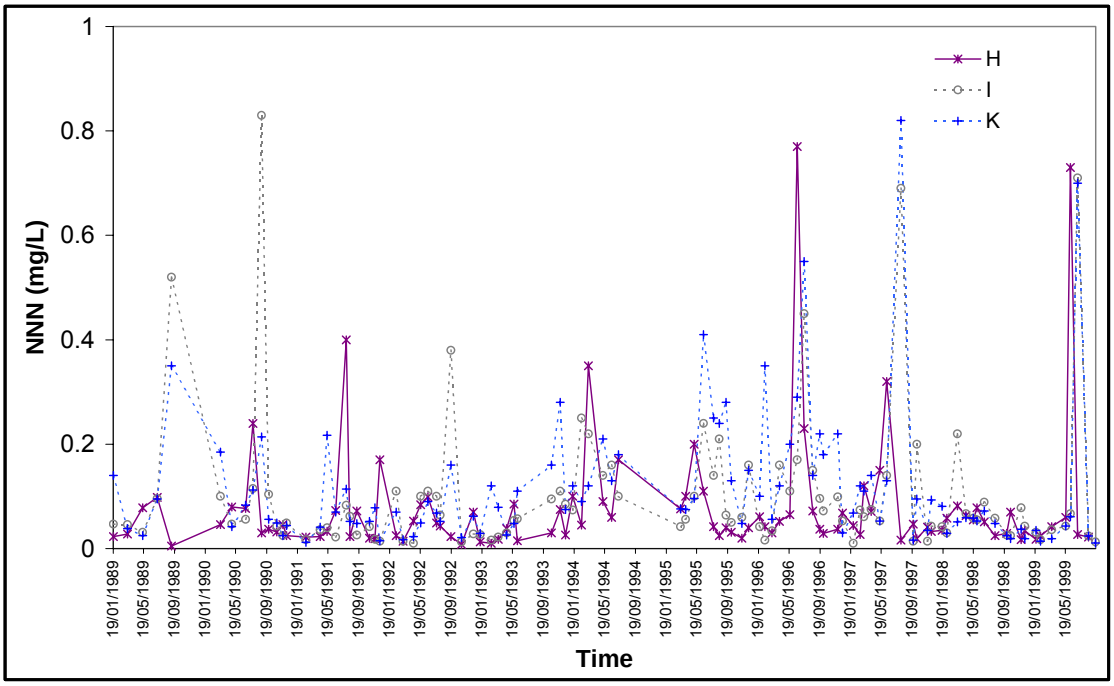
SITES
A – South Spit
B – Penguin Street
C – Pleasant Point jetty
D – Pleasant Point Yacht Club
E – Sandy Point
F – Humphries Drive
G – Mt. Pleasant Yacht Club
H – McCormacks Bay outlet
I – Beachville Road
J – Moncks Bay
K – Shag Rock



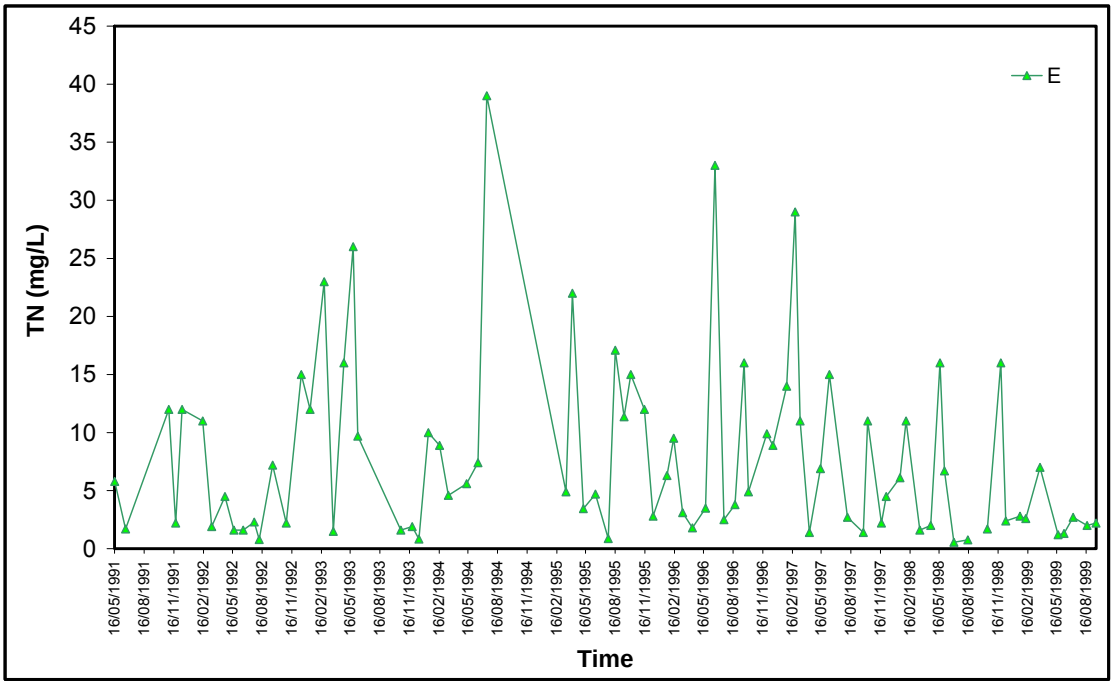


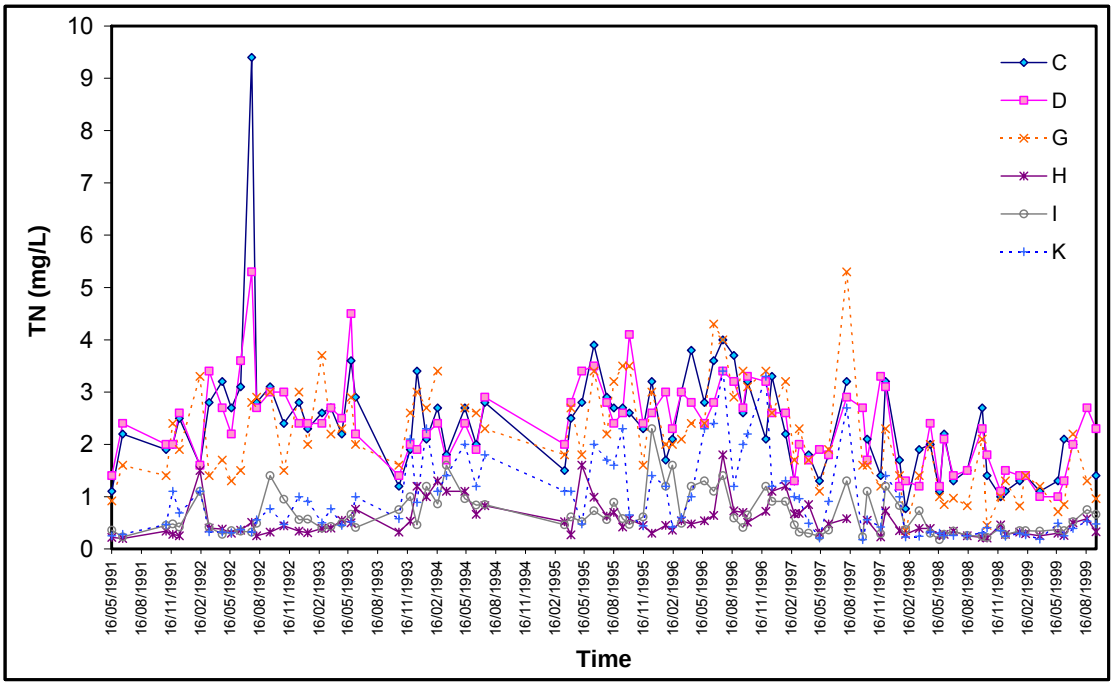
NOTE: differing scales on the y-axis of these two graphs



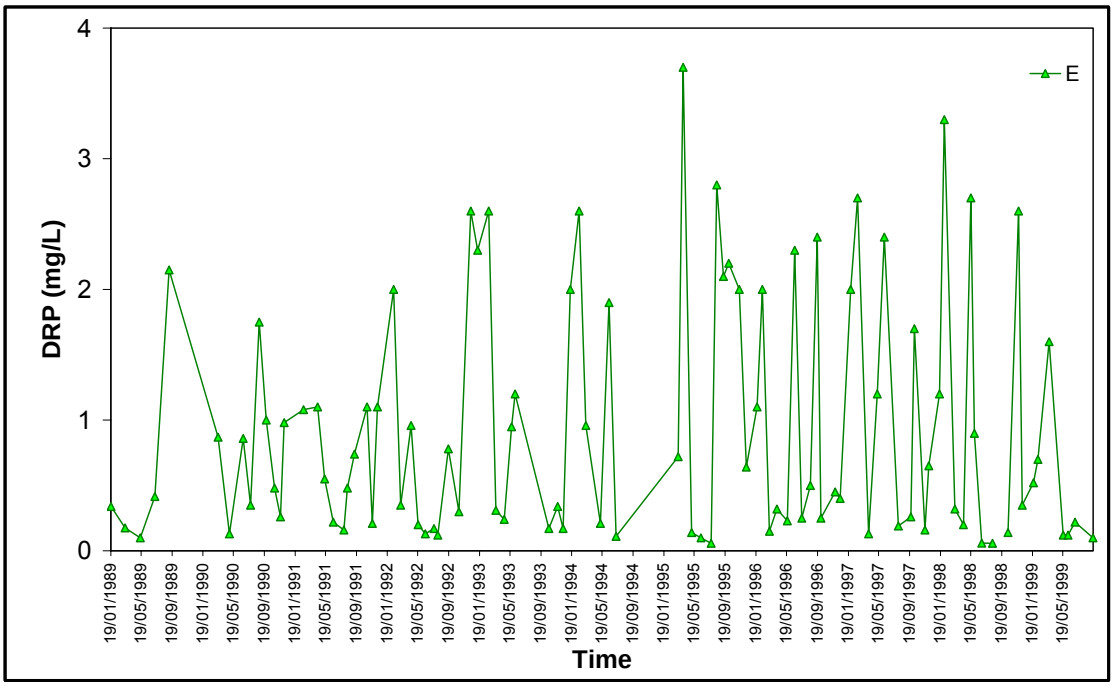


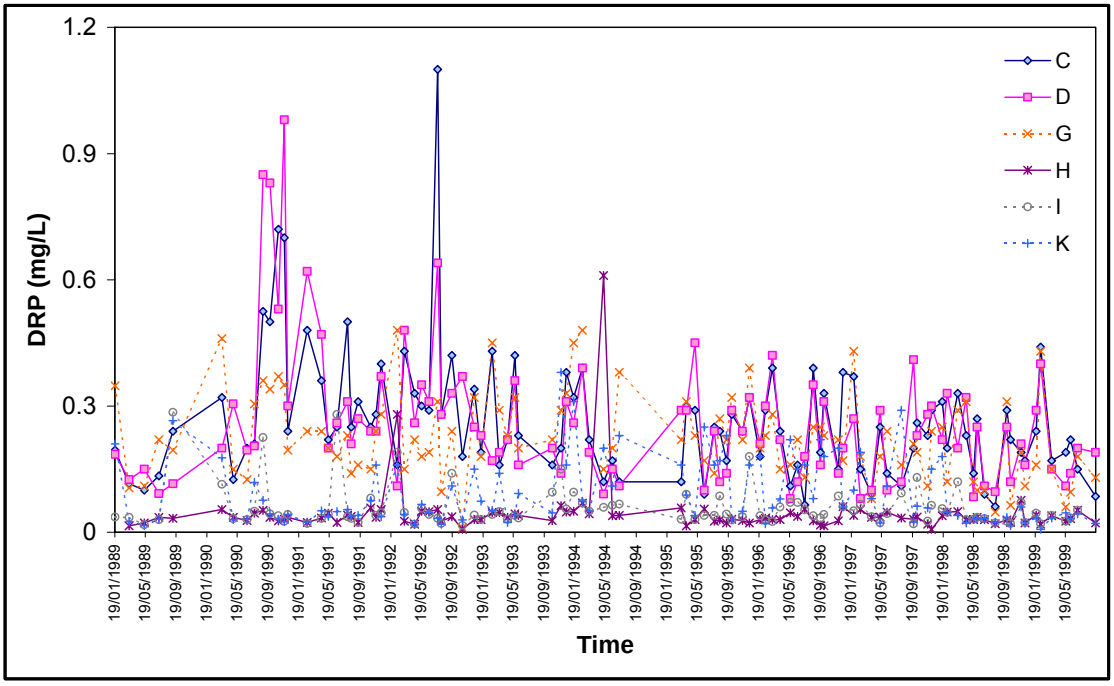
NOTE: differing scales on the y-axis of these two graphs



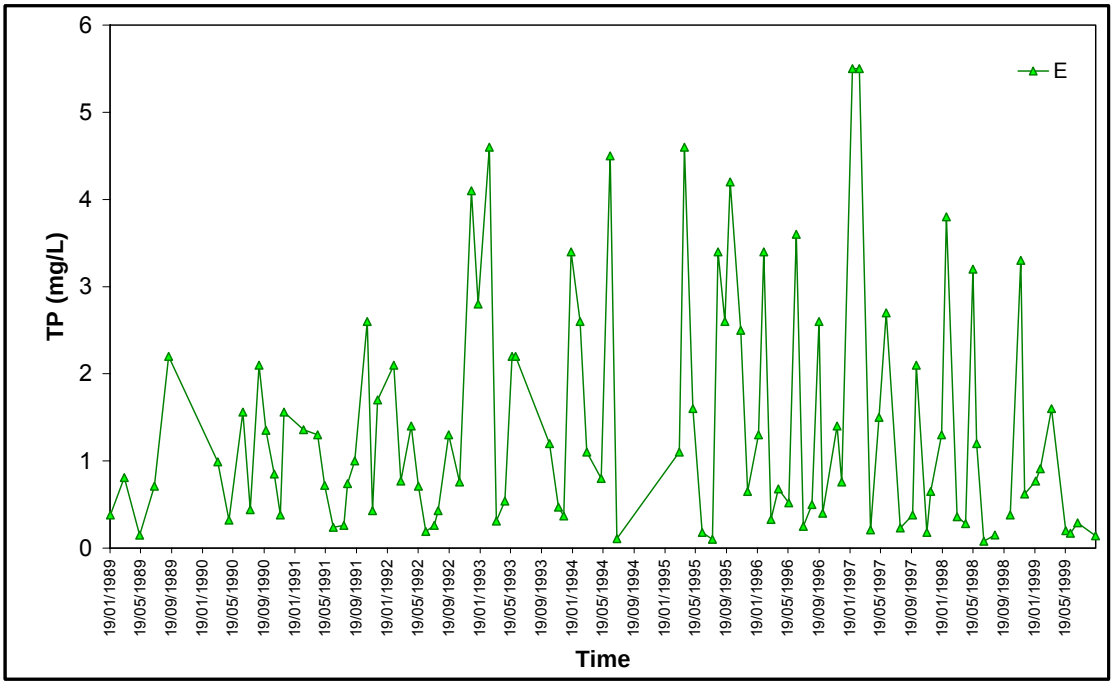


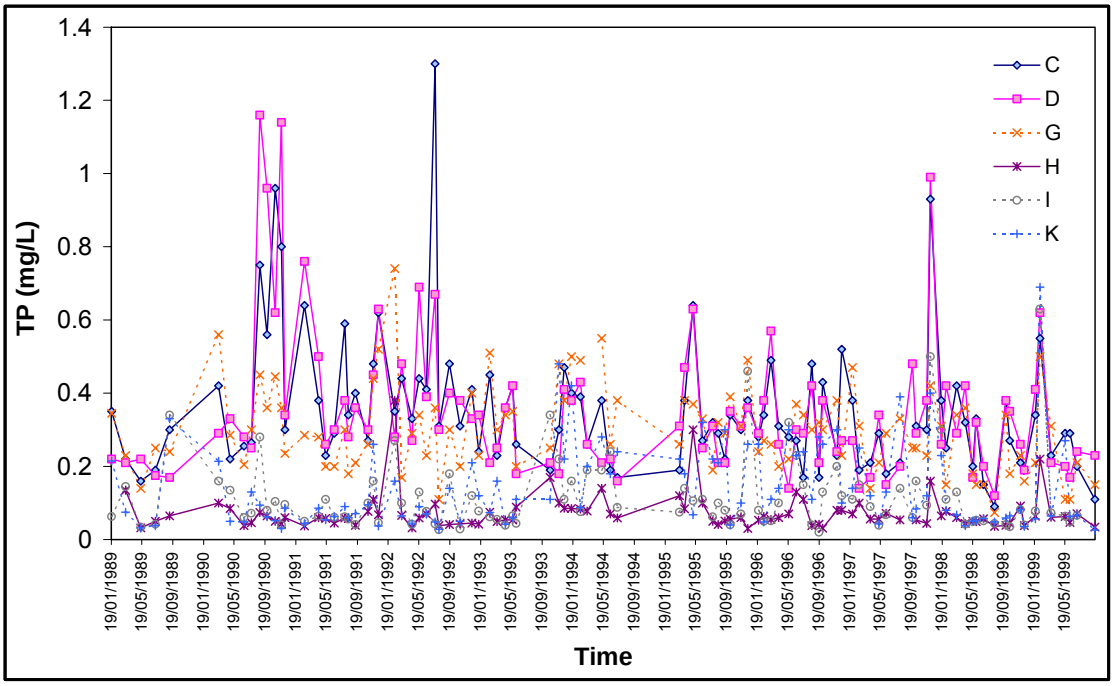
NOTE: differing scales on the y-axis of these two graphs





NOTE: differing scales on the y-axis of these two graphs

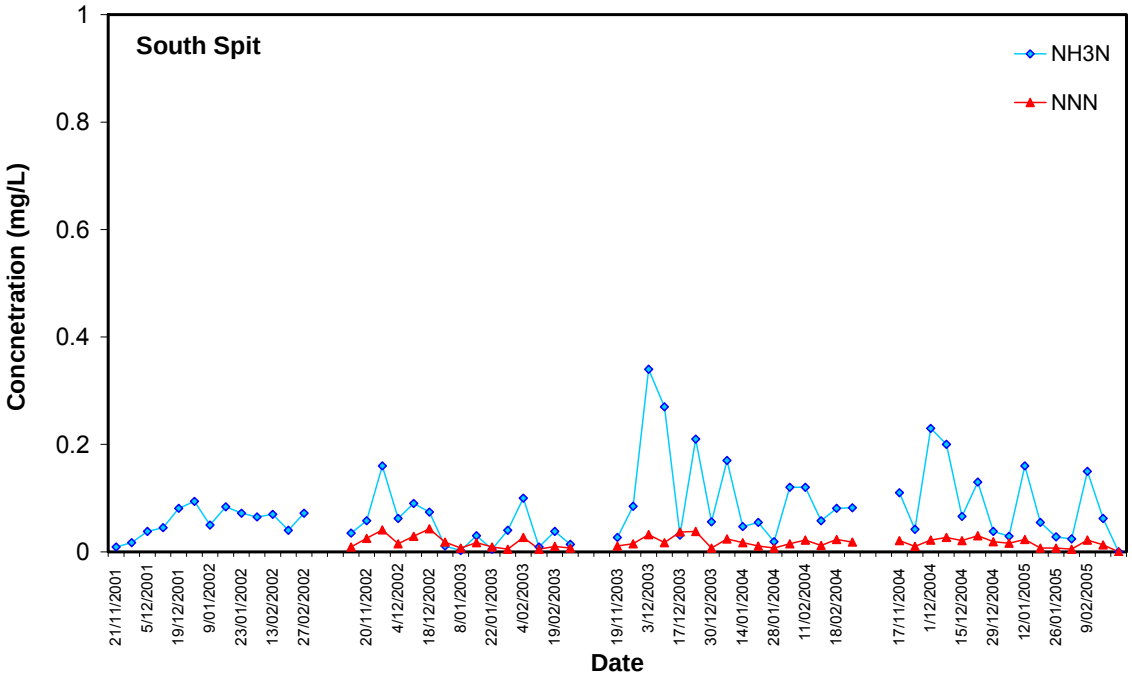


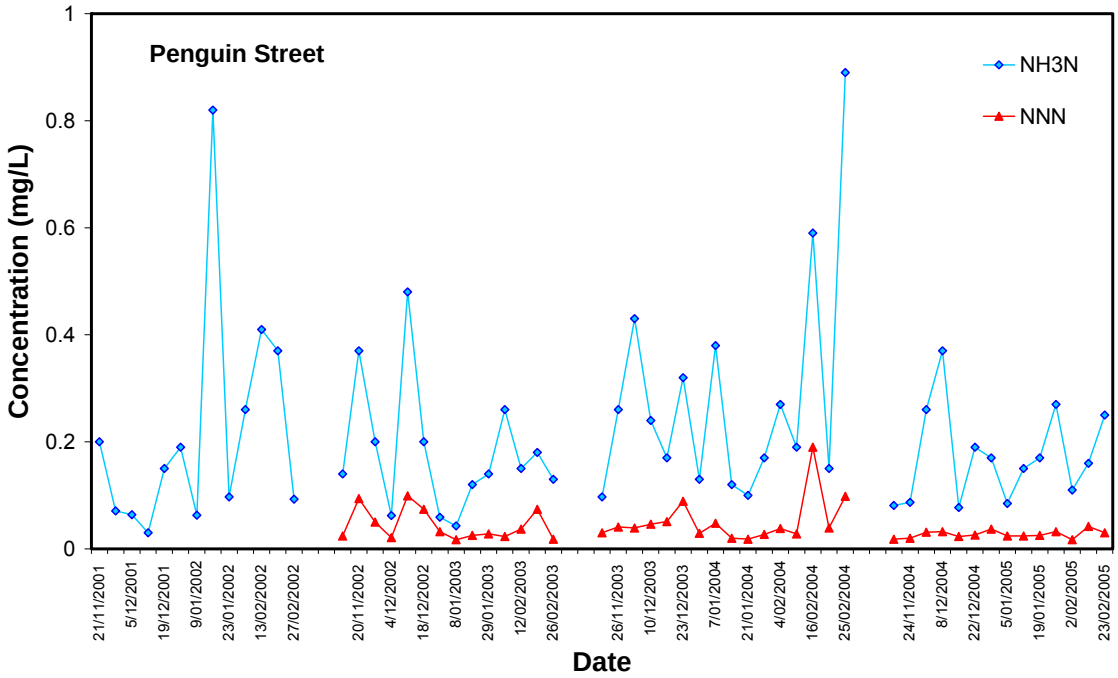


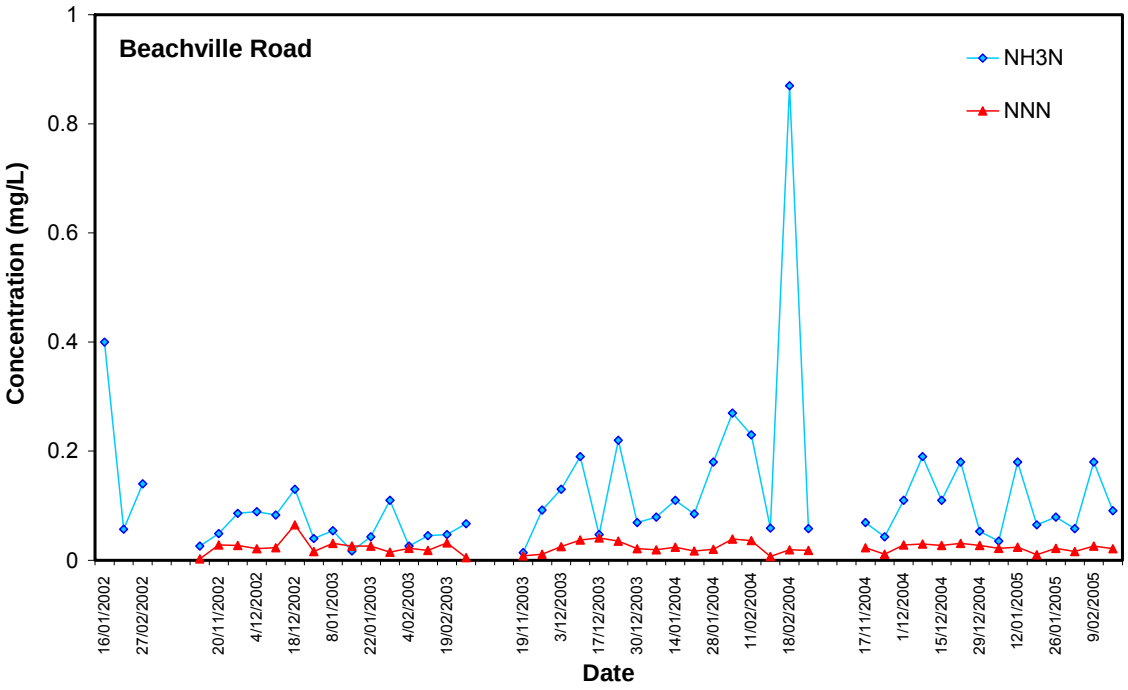
NOTE: differing scales on the y-axis of these two graphs

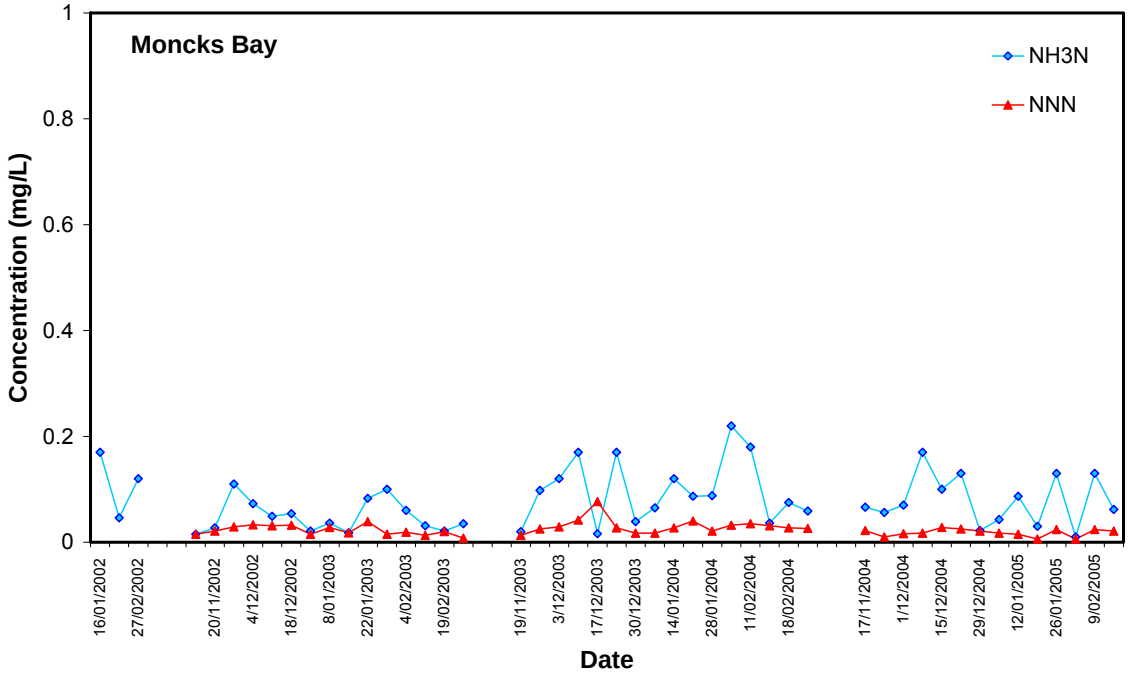
Appendix V: NH_3N and NNN concentrations in estuary water over time at sites sampled from 2002-2005

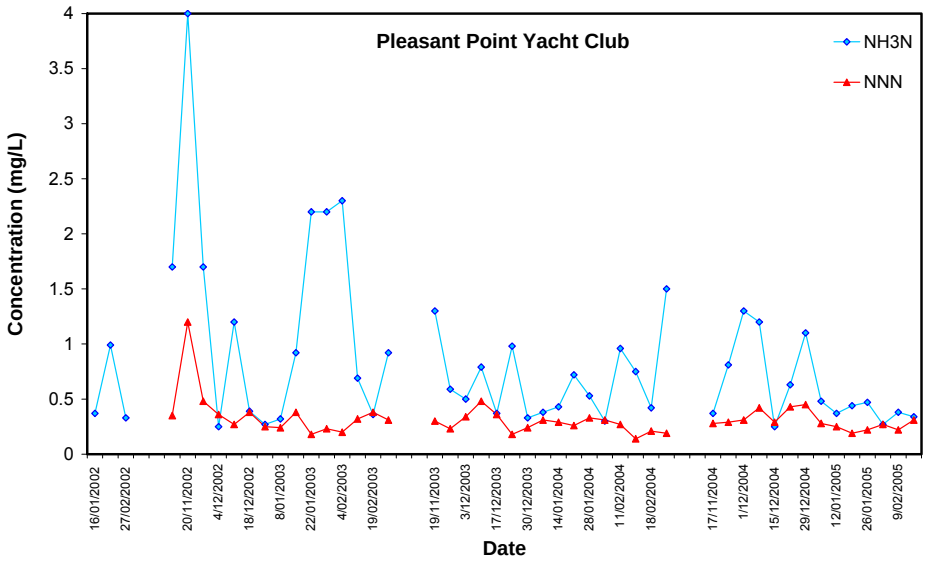
(Note the scale on the y axis differs between sites
The y axis scale is the same for South Spit, Penguin Street, Beachville Road and Moncks Bay.
The y axis scale is the same for the Pleasant Point Yacht Club, Humphries Drive and the Mt. Pleasant Yacht Club)

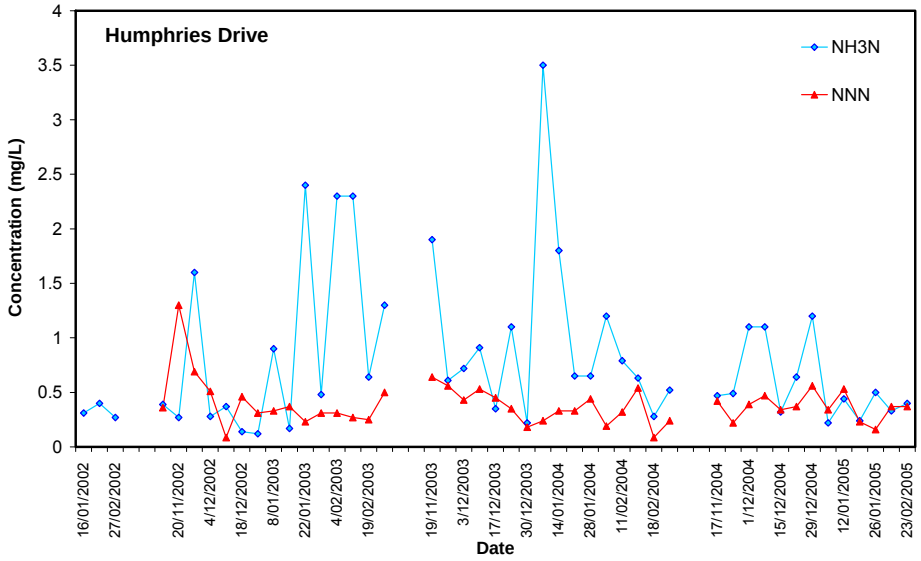

South Spit
NH3N
NNN
Concnetration (mg/L)
1
0.8
0.6
0.4
0.2
0
21/11/2001
5/12/2001
19/12/2001
9/01/2002
23/01/2002
13/02/2002
27/02/2002
20/11/2002
4/12/2002
18/12/2002
8/01/2003
22/01/2003
4/02/2003
19/02/2003
19/11/2003
3/12/2003
17/12/2003
30/12/2003
14/01/2004
28/01/2004
11/02/2004
18/02/2004
17/11/2004
1/12/2004
15/12/2004
29/12/2004
12/01/2005
26/01/2005
9/02/2005
Date

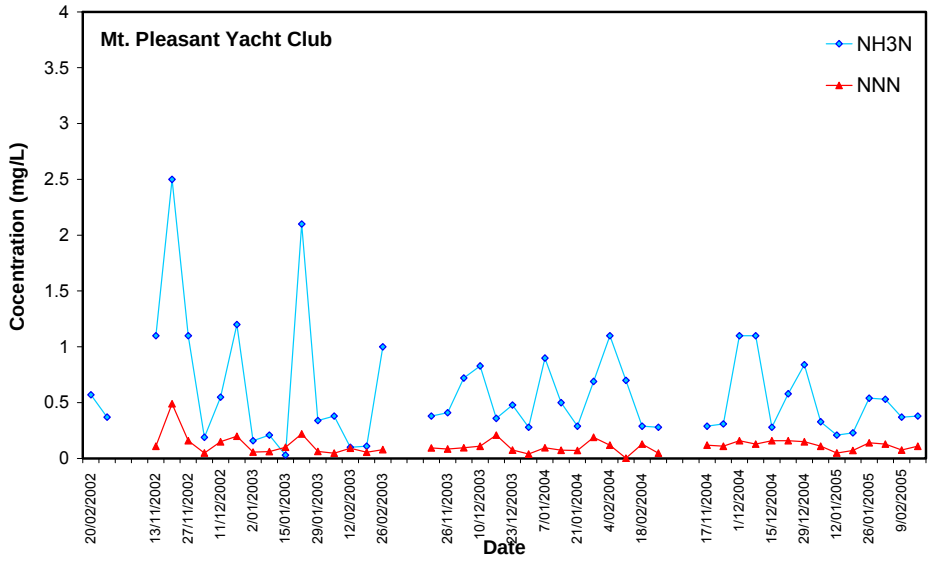

Penguin Street
NH3N
NNN
Concentration (mg/L)
1
0.8
0.6
0.4
0.2
0
21/11/2001
5/12/2001
19/12/2001
9/01/2002
23/01/2002
13/02/2002
27/02/2002
20/11/2002
4/12/2002
18/12/2002
8/01/2003
29/01/2003
12/02/2003
26/02/2003
26/11/2003
10/12/2003
23/12/2003
7/01/2004
21/01/2004
4/02/2004
16/02/2004
25/02/2004
24/11/2004
8/12/2004
22/12/2004
5/01/2005
19/01/2005
2/02/2005
23/02/2005
Date


Beachville Road
NH3N
NNN
Concentration (mg/L)
1
0.8
0.6
0.4
0.2
0
16/01/2002
27/02/2002
20/11/2002
4/12/2002
18/12/2002
8/01/2003
22/01/2003
4/02/2003
19/02/2003
19/11/2003
3/12/2003
17/12/2003
30/12/2003
14/01/2004
28/01/2004
11/02/2004
18/02/2004
17/11/2004
1/12/2004
15/12/2004
29/12/2004
12/01/2005
26/01/2005
9/02/2005
Date


Moncks Bay
NH3N
NNN
Concentration (mg/L)
1
0.8
0.6
0.4
0.2
0
16/01/2002
27/02/2002
20/11/2002
4/12/2002
18/12/2002
8/01/2003
22/01/2003
4/02/2003
19/02/2003
19/11/2003
3/12/2003
17/12/2003
30/12/2003
14/01/2004
28/01/2004
11/02/2004
18/02/2004
17/11/2004
1/12/2004
15/12/2004
29/12/2004
12/01/2005
26/01/2005
9/02/2005
Date


Pleasant Point Yacht Club
NH3N
NNN
Concentration (mg/L)
Date

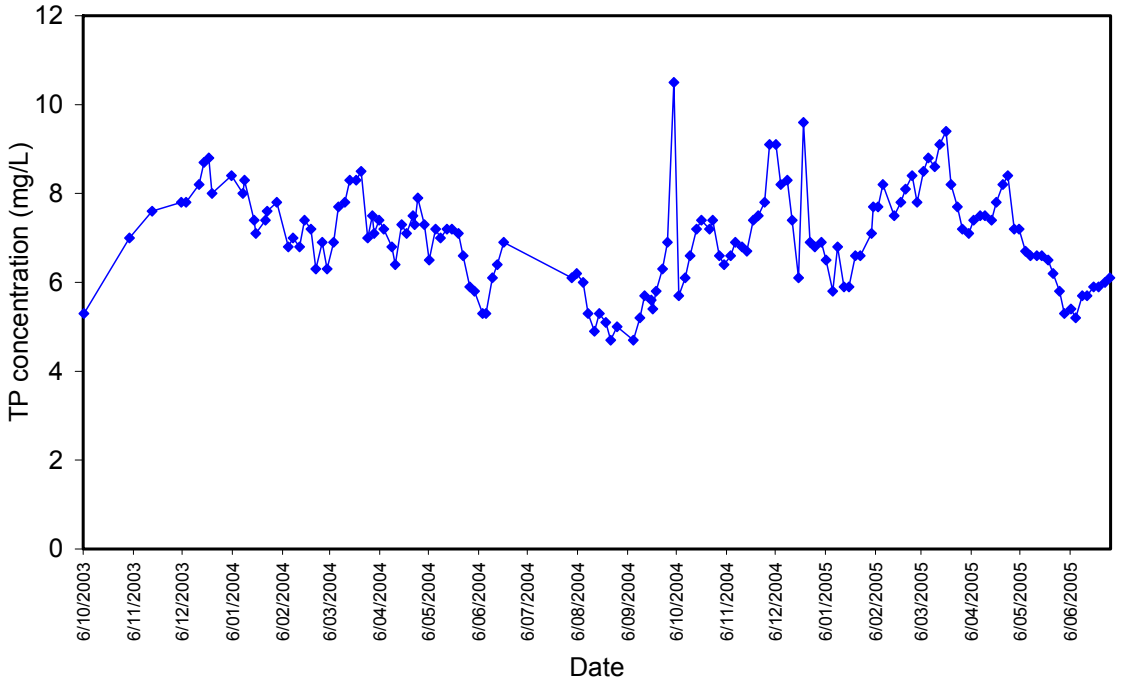

Humphries Drive
NH3N
NNN
Concentration (mg/L)
Date


Mt. Pleasant Yacht Club
NH3N
NNN
Cocentration (mg/L)
Date

Appendix VI: Mean nutrient concentrations (mg/L) recorded at sites within the estuary by various workers

	Bruce (1953)			Hogan & Wilkinson (1959)		Knox and Kilner 1973					NCCB		
	Collected 1950-51			collected 1955-56		Collected 1970-71					Collected 1984		
	NH_3N	Alb-N	NO_2^-	NH_3N	Alb-N	NH_3N	NO_3^-	NO_2^-	TP	DRP	NH_3	NO_3^-	NO_2^-
Bridge Street			0.01	0.05	0.15	0.53	0.314	0.019	0.255	0.146		0.87	0.022
Pleasant Point Jetty	0.17	0.39	0.015	0.1	0.2								
Opposite main ox. pond outlet	0.25	0.32	0.01										
Sandy Point	0.22	0.13	0.015			0.63	0.204	0.012	0.278	0.142			
Humphries Drive	0.54	0.16	0.009										
Ferrymead Bridge	0.28	0.64	0.009	1.0	0.7	0.729	0.432	0.036	0.149	0.059	0.36	0.95	0.04
Opposite McCormacks Bay	0.11	0.42	0.013			0.286	0.162	0.018	0.182	0.069			
Outflow, McCormacks Bay						0.068	0.074	0.004	0.086	0.043			
Beachville Road	0.1	0.25	0.005			0.214	0.1	0.013	0.268	0.125			
Shag Rock	0.013	0.21	0.007	<.05	0.5	0.099	0.314	0.016	0.153	0.079			

Appendix VII: TP concentrations in the oxidation ponds from October 2003 – June 2005



Appendix VIII: Description of the determinands

Phosphorus

Phosphorus occurs in natural waters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates and organically bound phosphates. They occur in solution, in particles or detritus, or in the bodies of aquatic organisms. Phosphorus is essential to the growth of organisms and, particularly in fresh water, can be the nutrient that limits the primary productivity of a body of water. In instances where phosphate is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of photosynthetic aquatic micro- and macro- organisms in nuisance quantities. Phosphates also occur in bottom sediments and in biological sludges, both as precipitated inorganic forms and incorporated into organic compounds (APHA, 1998).

Dissolved reactive phosphorus is a form of dissolved phosphate (orthophosphate) that is available immediately for plant and algal growth.

Total phosphorus is a measure of the concentration of orthophosphates, condensed phosphates and organically bound phosphates in the water. This includes both dissolved and suspended phosphates.

Nitrogen

In water, the forms of nitrogen of greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia, and organic nitrogen. All these forms of nitrogen, as well as nitrogen gas (N_2) and dinitrogen oxide (N_2O), are biologically interconvertible and are components of the nitrogen cycle (APHA, 1998).

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidised to nitrate (Chapman, 1992).

Nitrate and nitrite-nitrogen (NNN, also called total oxidised nitrogen) is the sum two oxidised forms of inorganic nitrogen. It is reported in terms of the sum of concentration of nitrogen that was in the forms of nitrate and nitrite.

Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with the atmosphere. It is also discharged into water bodies by some industrial processes and also as a component of municipal or community waste (Chapman, 1992). Compared to nitrate, ammonia is usually a very minor component of plant available nitrogen. The main concern with ammonia concentrations in water bodies is toxicity effects on aquatic ecosystems. In water ammonia occurs in two forms; the ammonium ion (NH_4^+) and un-ionised ammonia (NH_3). The proportion of these chemical forms is dependent on the pH, temperature and ionic composition of the water. The un-ionised form of ammonia (NH_3) is the most toxic, although toxicity effects also occur with the ammonium ion (ANZECC, 2000). Measurement of ammonia concentrations usually measures total ammonia (NH_3+ NH_4^+).

Dissolved inorganic nitrogen is a measure of the nitrogen available to plants, and is the sum of the concentrations of nitrate and nitrite-nitrogen and ammonia nitrogen. Nitrogen is essential to the growth of organisms and, particularly in sea water, can be the nutrient that limits the primary productivity of a body of water. In instances where nitrogen is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of photosynthetic aquatic micro- and macro-organisms in nuisance quantities.

Total nitrogen is a measure of all nitrogen in the water; both inorganic and organic nitrogen forms.

Albuminoid nitrogen is an old method of measuring organic nitrogen which has fallen out of favour.