Technical Report

Investigations and Monitoring Group

Timaru Harbour water quality

September 1998 – June 2005

Report No. U06/38

Environment Canterbury

Your regional council

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Report No. U06/28

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May 2006

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Executive Summary

The area designated as Timaru Harbour for the purpose of this report includes the Port of Timaru, Caroline Bay and the coastal waters out to the starboard buoy (Figure 1.1). Water quality monitoring was carried out at seven sites in Timaru Harbour. At all sites the surface water was sampled while at two of the sites samples were also collected from at least one other water depth. Sampling was carried out approximately monthly over two, year-long periods; September 1998 to June 1999 and July 2004 to June 2005.

Significant differences occurred in the surface water nutrient concentrations between sites. There was, in general, a pattern to the differences in nutrient concentrations between sites. This pattern consisted of:

- significantly lower nutrient concentrations at the starboard buoy, some 500 m offshore off the end of the southern mole, than at the other sites.
- significantly higher nutrient concentrations at inner port sites than at one or more of the outer port and beyond the port sites.
- significant differences in nutrient concentrations between sites in the inner port.

Over time i.e. between 1998-1999 and 2004-2005, there was:

- a significant difference in DRP and TP concentrations at one or other of the inner port sites with higher concentrations over 1998-1999 than over 2004-2005.
- no significant difference in the concentration of any of the nitrogen-based nutrients.

The data suggest that stormwater contributes TN, DRP and TP to the water within the inner port.

The stormwater that is discharged into the inner port could account for:

- the differences in nutrient concentrations between sites in the inner port over 1998-1999.
- the higher variability in nutrient concentrations at inner port sites than at the other sites.
- the higher variability in TN, DRP and TP concentrations at inner port sites over 1998-1999 than over 2004-2005.
- the significant differences in DRP and TP concentrations at inner port sites between sampling periods.

Discharged stormwater in combination with the flushing characteristics of the inner port likely accounts for:

- the significantly higher nutrient concentrations at inner port than at outer port and beyond the port sites.

The results suggest that the wharf structures, that extend into the port and divide it in two (inner and outer port), are a barrier to efficient water mixing throughout the whole port. There are no hydrodynamic data to corroborate this. The sea water from the open sea that enters and circulates around the outer port is of sufficient volume to dilute the outward flowing nutrient enriched inner port water to significantly lower concentrations within the time/distance it takes to reach the port entrance.

The chlorophyll-a concentrations were very variable between sites on each sampling and at each site over time. Analysis of the DIN concentrations at all sites indicates there is a greater potential for enhanced phytoplankton growth in the inner port than at other localities within and beyond the port.

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1 Introduction

1.1 Timaru Harbour

The area called Timaru Harbour for the purpose of this report is that enclosed within the red rectangle in the aerial photo of Figure 1.1. It includes the Port of Timaru, Caroline Bay and the coastal waters out to the starboard buoy (used by ships to line up the entrance to the Port).

The shoreline of Timaru Harbour is highly modified. In the late 1870s a breakwater was constructed at what is now the south-eastern side of the port. This structure was built to protect any port development from the high-energy southerly storms that frequently occur along this exposed eastern South Island coastline. The port facilities were then constructed in the shelter of the breakwater. Over time the port facilities have been enlarged, the south-eastern breakwater (southern mole) has been extended and a northern mole constructed. The present port is now enclosed in the area between the northern and southern mole.

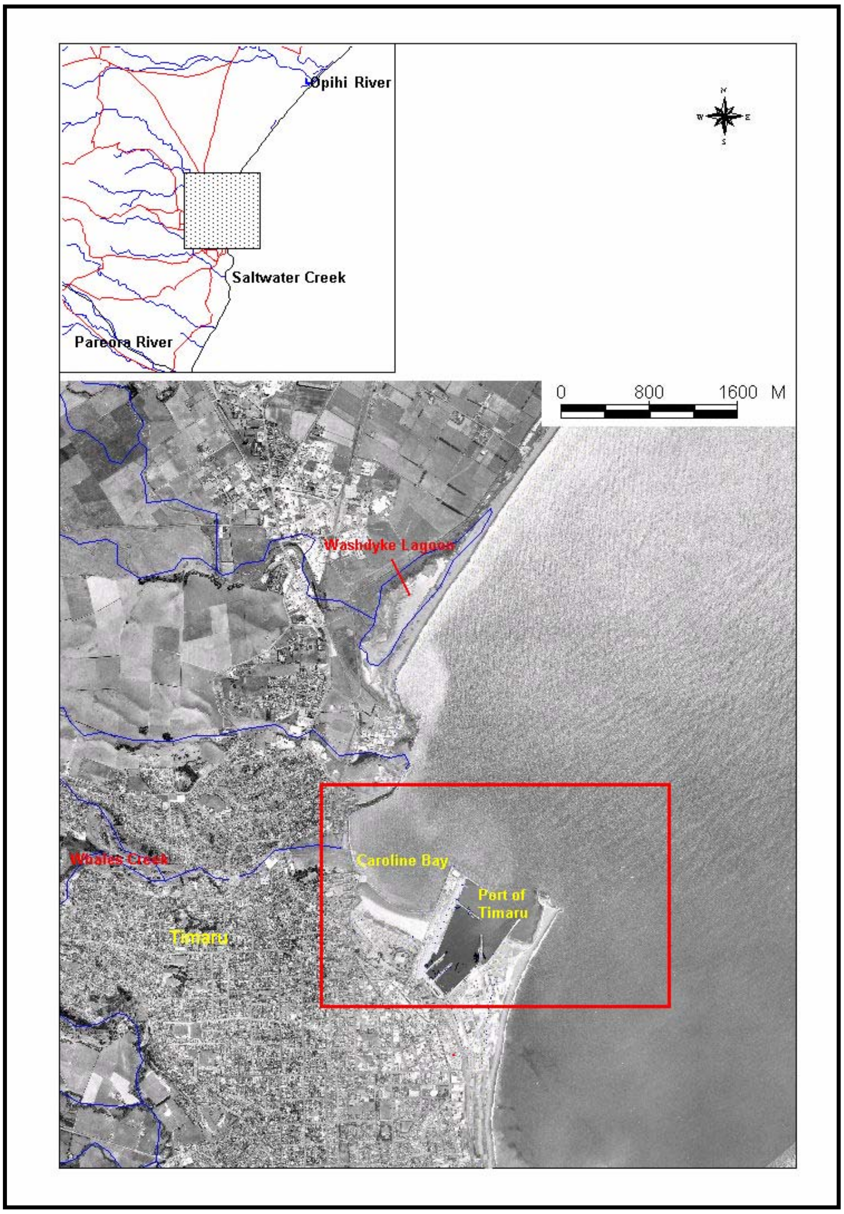

Figure 1.1 Timaru Harbour: location, proximity of streams, creeks and rivers and aerial view

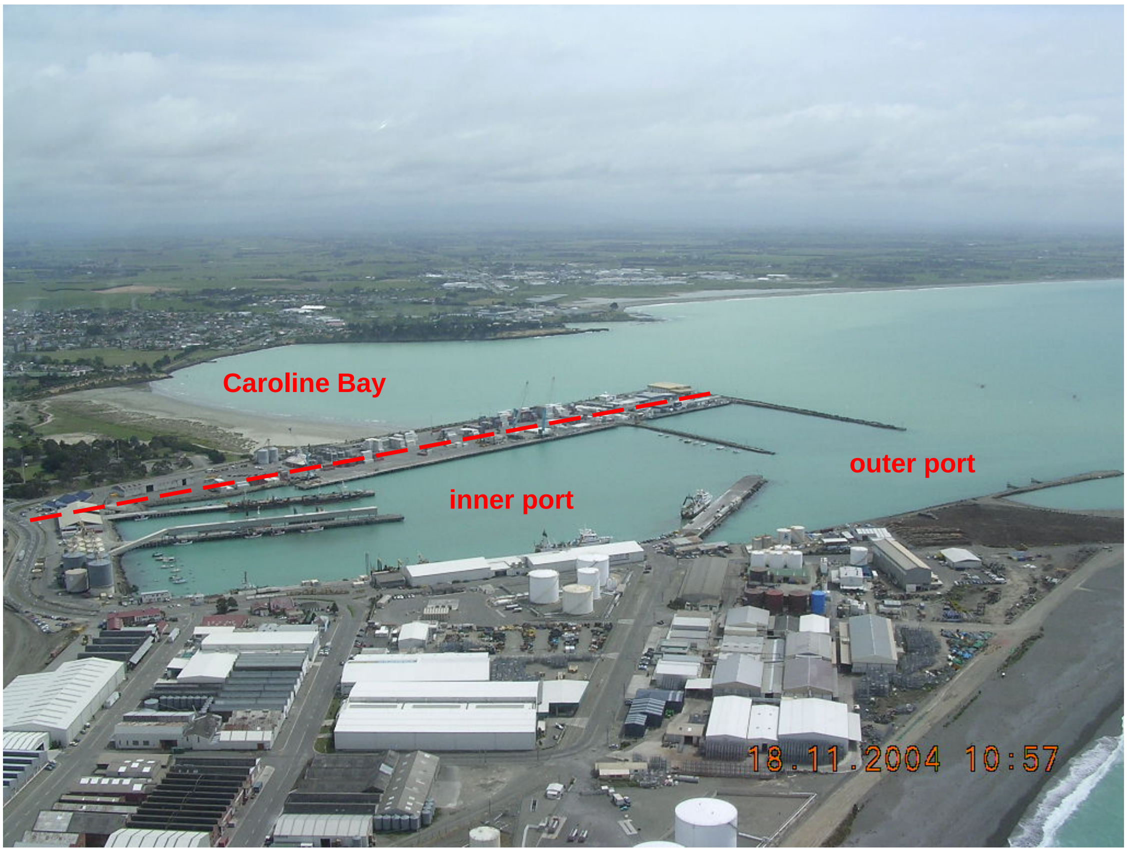

Figure 1.2 Aerial view of the Port of Timaru and Caroline Bay

NOTE: The length of the wharf (as designated by the red line) is 1000 m long

The presence of the southern mole has altered the nearshore hydrodynamics along this part of the coastline. The northward movement of gravels and coarse sands has been almost completely disrupted by the mole (Grindell and Scarf, 1980). However, large quantities of fine and very fine sand are carried northward and some of this sand is deposited into the protected water of Caroline Bay. This has resulted in the accretion of sand in Caroline Bay to form what is now a very popular bathing beach for the people of Timaru (Figures 1.1and 1.2).

The Port of Timaru facilities cater for vessels up to 228 m in length and up to 10.9 m draft. Since 2000-01, some 350-400 vessels per year have passed through the port. The cargoes handled include logs, fish, bulk liquids (fuels, bitumen, molasses, chemicals and vegetable oils), fertiliser, wood chips, milk products, grain, tallow, wool, meat, fresh produce, processed vegetables, livestock and general cargo. With container facilities at the port a considerable amount of this cargo is shipped via container. For example, in 2004 55,000 containers of cargo passed through the port; the remaining 646,000 tonnes of cargo was un-containerised (Primeport, 2005). With such volumes of shipping and quantities of cargo there is considerable potential for spillages of fuel and other materials into the water within the port.

The land and wharf structures surrounding the port support cargo storage facilities including grain silos and bulk liquid silos, industries, and fish processing plants, the latter located at the outer end of the northern mole. Stormwater from this land, wharves and adjacent roading, flows into the port via ten stormwater outlets. In addition, the stormwater from the central business district of Timaru is discharged into the port via two outlets. There is also a direct discharge of melted freeze water from one of the fish processing plants into the port.

Caroline Bay is a popular recreational area. The waters of the bay are used for swimming and sailing while the foreshore is a popular walking and picnic area with a wide range of facilities available to the public in the area behind the beach. At the western end of the sandy beach is Whales Creek. This creek, which receives stormwater from a residential catchment, discharges into Caroline Bay.

The water quality within the Port of Timaru is potentially impacted by stormwater discharges and cargo handling spillages. The water quality within Caroline Bay is potentially impacted by a stormwater discharge and by the water that comes out of the port. By measuring the concentrations of various water quality determinands within the Port of Timaru, Caroline Bay and beyond, the water quality and the impacts of the discharges etc. on overall water quality can be assessed. The concentration of various water quality determinands can also be used to assess whether there is the potential for ecological impacts.

In this coastal location the ecological impact of concern is excessive growth of phytoplankton (plant plankton). Such blooms can be obvious to the naked eye, have the potential to be toxic to humans and also have the potential to impact on other marine life. Such excessive growth of phytoplankton is a response to nutrient enrichment of the coastal water. Under optimal conditions marine phytoplankton will take up chemically available forms of nutrients in the molar 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 by either N or P independently. If the ratio of N:P is less than 16:1 then growth can, at times, be nitrogen-limited and if it is greater than 16:1 growth can be phosphorus limited (NRC, 2001).

1.2 Timaru Harbour water quality

In 1998 Environment Canterbury set up a programme to routinely sample the water at sites in Timaru Harbour. Year-long, routine water sampling was undertaken at these sites over two time periods. These water quality data are the focus of this report.

1.3 Objectives of this study

To investigate if:

1. there was a significant difference in water quality between sites in Timaru Harbour in each sampling period.
2. there was a significant difference in water quality with water depth at each site over 1998-1999.
3. there was a significant difference in water quality at each site over time.
4. the water quality in Timaru Harbour is of ecological concern.

2 Methods

2.1 Sites and depths

Samples were collected from 7 sites in Timaru Harbour (Figure 2.1). At each site the surface water was sampled and over 1998 - 1999 samples were also collected at 5 and 10 m below the surface at two sites. Details of the sites and depths sampled are given in Appendix I.

2.2 Sampling regime

These sites were sampled in the following time periods:

- 1998-1999 (on 11 occasions between 4 September 1998 and 25 June 1999)
- 2004-2005 (on 11 occasions between 14 July 2004 and 21 June 2005)

2.3 Sample collection

The samples were collected by staff from the Environmental Quality Section of the Canterbury Regional Council. Sampling was carried out from a boat with the surface water collected by leaning over the side of the boat and the water at depth collected using a modified 2L Van-Dorn sampler. 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 the field the water temperature and salinity were measured using a field meter and water clarity was determined using a secchi disc. General weather (cloud cover, wind direction, wind strength) observations were also recorded at the time of sampling.

2.4 Sample analyses

The water samples collected over 1998-1999 were analysed for turbidity and the nitrogen and phosphorus based chemical determinands (nutrients) listed in Table 2.1.

All samples collected over 2004-2005 were analysed for each of the determinands, except chlorophyll-a, listed in table 2.1. Chlorophyll-a concentration was measured in samples collected on 4 (~ 3 monthly) occasions over 2004-2005. All analyses were carried out in the Environment Canterbury laboratory. The details of the analytical methods are given in Appendix II.

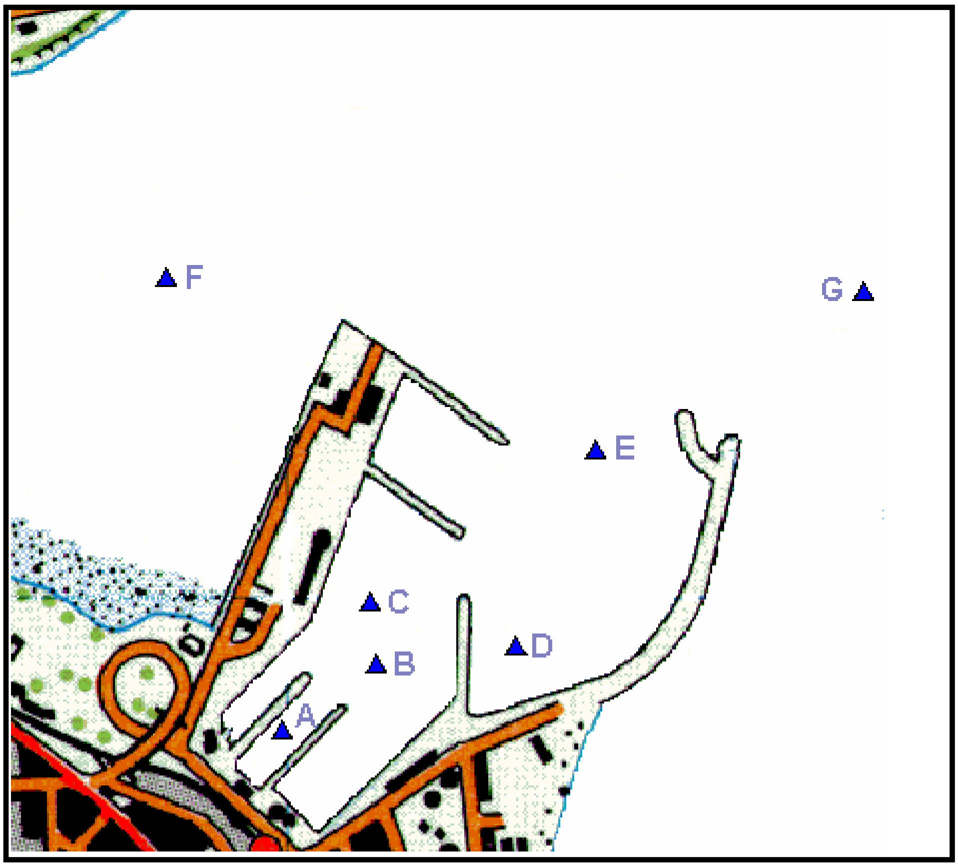

Figure 2.1 Water quality monitoring sites in Timaru Harbour

A = No. 2 wharf
B = inner port
C = north mole
D = No.1 extension wharf
E = port entrance
F = mid Caroline Bay
G= Starboard Buoy

Table 2.1 Physical and chemical determinands

Nitrate and nitrite nitrogen (NNN)
Total ammonia nitrogen (NH3N)
Dissolved inorganic nitrogen (DIN) (=NNN+ NH3N)
Total nitrogen (TN)
Dissolved reactive phosphorus (DRP)
Total phosphorus (TP)
Chlorophyll-a
Turbidity
Water clarity
Dissolved oxygen saturation
pH
Temperature

2.5 Data analyses

Microsoft Excel 2000 and Systat (version 9) (SPSS, 1999) were used for the production of summary statistics, charts, box plots and all statistical analyses.

To determine if there was a significant difference in the surface water concentration of each nutrient (NNN, NH3N, TN, DRP and TP) between sites the Wilcoxon signed rank test (Systat V9) was used. These analyses were carried out on the data from each year-long sampling period.

To determine if there was a significant difference in the concentration of each nutrient with water depth, the Wilcoxon signed rank test was also used. Statistical analyses were performed on data from those sites where more than one water depth was sampled.

To determine if there was a significant difference in the concentration of each nutrient at each site over time (between the two sampling periods) the Kruskal-Wallis ANOVA (Analysis of Variance) (Systat V9) was used.

To determine if the water quality in Timaru Harbour is of ecological concern the N:P ratio was calculated for all samples collected at all sites. This ratio was calculated using the DIN and DRP values.

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 Results

The data for the nitrogen- and phosphorus-based determinands, collected at each depth at each site in Timaru Harbour over the period September 1998 to June 2005, are summarised in Table 3.1. The data for the other measured determinands (including those measured in the field) are summarised in Table 3.2.

3.1 Variation between sites

3.1.1 Nitrogen- and phosphorus-based determinands (nutrients)

The data for each nutrient for each sampling period are presented in box and whisker plots (Figures 3.1-3.2). The results of the Wilcoxon two-tailed signed rank test, used to determine if, over each sampling period, there was a significant difference in the surface water concentration of each nutrient between sites, are presented in Appendix III.

<u>Nitrate and nitrite nitrogen (NNN)</u>

NNN concentrations over 1998-1999 were significantly higher at the innermost site within the port (No.2 wharf - site A) than at all other sites, except site B (inner port) (Appendix III). Significantly higher NNN concentrations also occurred at:

- sites B and C (north mole), within the inner port, than at the port entrance (site E).
- site D (No.1 extension wharf) than in mid Caroline Bay (site F).

Over 2004-2005, the NNN concentrations at site A were significantly higher than those at the port entrance (site E) and the starboard buoy (site G). Over this sampling period the NNN concentrations at the starboard buoy were significantly lower than those at the north mole (site C) and the port entrance (site E).

Ammonia nitrogen (NH_3N)

NH_3N concentrations over 1998-1999 were significantly higher at the innermost site within the port (site A) than at all other sites.

Over 2004-2005 NH_3N concentrations at the 3 sites within the inner port (sites A, B and C) were significantly higher than at the port entrance (site E). Over this sampling period the concentrations at the starboard buoy (site G) were significantly lower than those at all other sites.

Total nitrogen (TN)

TN concentrations over 1998-1999 were significantly higher at the innermost site within the port (site A) than at the No.1 extension wharf (site D) and at sites outside of the port (sites F and G). Over this period the TN concentrations at the starboard buoy (site G) were also significantly lower than those at two inner port sites (sites B and C) and at the port entrance (site E).

Over 2004-2005 TN concentrations at the starboard buoy (site G) were significantly lower than those at the innermost site within the port (site A) and those in mid Caroline Bay (site F).

Dissolved reactive phosphorus (DRP)

DRP concentrations over 1998-1999 were, in general, significantly higher at the sites within the inner port (sites A, B and C) than at the outer port (sites D and E) and beyond the port (sites F and G) sites. Over this sampling period the concentrations at the starboard buoy (site G) were also significantly lower than at the port entrance (site E) and in mid Caroline Bay (site F).

The DRP results for 2004-2005 were very similar to those for 1998-1999. However, there were no significant differences in concentrations between the inner port (sites A, B and C) and the No.1 extension wharf (site D) sites and between the starboard buoy (site G) and mid Caroline Bay (site F) sites.

Total phosphorus (TP)

TP concentrations over 1998-1999 were significantly higher at two of the inner port sites (sites A and C) than at outer port (sites D and E) and beyond the port (sites F and G) sites. Concentrations at the starboard buoy (site G) were also significantly lower than at the port entrance (site E).

Over 2004-2005 TP concentrations at all inner port sites (sites A, B and C) were significantly higher than those at the port entrance (site E) and the starboard buoy (site G). Concentrations at the starboard buoy (site G) were also significantly lower than those in mid Caroline Bay (site F).

Table 3.1 Summary of chemical determinand concentrations (mg/L) at each site, based on all the data (1998-1999 and 2004-2005) collected

n = number of samples
Sites : A – No.2 wharf, B – inner port, C – north mole, D – No1 extension wharf, E – port entrance, F – mid Caroline Bay, G – Starboard Buoy

	SITES										
	A	**B**	**B5**	**B10**	**C**	**C5**	**C10**	**D**	**E**	**F**	**G**
NH3N											
Minimum	0.006	0.005	0.02	0.029	<0.005	0.008	0.018	0.009	0.007	0.006	<0.005
Median	0.05	0.039	0.049	0.048	0.041	0.040	0.042	0.034	0.026	0.02	0.023
Mean	0.046	0.039	0.052	0.050	0.038	0.041	0.046	0.034	0.030	0.027	0.021
SD	0.028	0.024	0.020	0.014	0.024	0.021	0.020	0.019	0.019	0.016	0.014
Maximum	0.11	0.086	0.079	0.071	0.088	0.075	0.082	0.085	0.067	0.073	0.063
NNN											
Minimum	<0.005	<0.005	0.011	0.011	<0.005	0.013	0.009	<0.005	<0.005	<0.005	<0.005
Median	0.057	0.039	0.027	0.027	0.042	0.020	0.024	0.035	0.029	0.023	0.017
Mean	0.066	0.038	0.032	0.031	0.040	0.034	0.031	0.037	0.030	0.030	0.028
SD	0.055	0.023	0.021	0.021	0.028	0.021	0.022	0.027	0.022	0.023	0.038
Maximum	0.2	0.082	0.077	0.076	0.1	0.067	0.064	0.1	0.087	0.092	0.17
DIN											
Minimum	0.013	0.008	0.031	0.04	0.009	0.028	0.027	0.013	0.013	0.011	0.005
Median	0.105	0.087	0.093	0.082	0.088	0.086	0.065	0.062	0.060	0.051	0.045
Mean	0.112	0.078	0.084	0.081	0.078	0.075	0.077	0.070	0.060	0.057	0.049
SD	0.076	0.039	0.035	0.028	0.046	0.037	0.036	0.040	0.034	0.033	0.043
Maximum	0.29	0.143	0.147	0.124	0.15	0.124	0.132	0.151	0.119	0.113	0.197
TN											
Minimum	0.13	0.15	0.19	0.14	0.14	0.012	0.039	0.11	0.097	0.1	0.11
Median	0.28	0.24	0.250	0.250	0.25	0.240	0.260	0.255	0.205	0.215	0.2
Mean	0.341	0.273	0.341	0.309	0.279	0.254	0.317	0.245	0.257	0.255	0.213
SD	0.195	0.136	0.203	0.168	0.151	0.119	0.224	0.098	0.142	0.153	0.090
Maximum	0.89	0.75	0.83	0.74	0.84	0.47	0.89	0.43	0.67	0.85	0.48
DRP											
Minimum	0.003	0.001	0.011	0.012	0.001	0.01	0.008	0.003	0.003	0.002	0.002
Median	0.023	0.019	0.019	0.021	0.019	0.017	0.015	0.015	0.015	0.013	0.010
Mean	0.023	0.020	0.021	0.021	0.020	0.019	0.019	0.016	0.015	0.013	0.010
SD	0.011	0.008	0.007	0.007	0.010	0.007	0.009	0.007	0.006	0.006	0.004
Maximum	0.054	0.034	0.032	0.033	0.042	0.031	0.033	0.027	0.027	0.021	0.021
TP											
Minimum	0.009	0.02	0.031	0.035	0.009	0.031	0.029	<0.008	<0.008	0.018	<0.008
Median	0.039	0.039	0.042	0.047	0.044	0.042	0.037	0.036	0.038	0.04	0.031
Mean	0.048	0.045	0.065	0.072	0.048	0.072	0.070	0.036	0.043	0.044	0.036
SD	0.034	0.025	0.048	0.055	0.032	0.063	0.062	0.014	0.030	0.030	0.026
Maximum	0.16	0.14	0.17	0.2	0.16	0.24	0.21	0.066	0.15	0.17	0.14
n	**22**	**22**	**11**	**11**	**22**	**11**	**11**	**22**	**22**	**22**	**22**

Table 3.2 Summary of physical and biological determinands in the surface water at each site, based on all the data (1998-1999 and 2004-2005) collected

n = number of samples
Sites : A – No.2 wharf, B – inner port, C – north mole, D – No1 extension wharf, E – port entrance
F – mid Caroline Bay, G – Starboard Buoy

	Site						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Temperature (ºC)							
Minimum	5.9	6	5.6	6	5.1	5.1	5
Maximum	17.8	18	17.9	17.7	17.7	17.8	17.3
Turbidity (NTU)							
Minimum	0.9	0.8	1.2	1.2	1.3	1.2	0.8
Median	3.2	3.25	2.5	3.2	3.3	4.2	3.15
Mean	3.091	3.209	2.955	3.732	4.350	5.936	3.741
SD	1.391	1.550	1.353	1.852	3.027	4.637	3.074
Maximum	6.1	7	5.9	7.1	12	21	14
Water clarity (m)							
Minimum	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Median	1	0.9	0.9	0.9	0.725	0.725	0.8
Mean	1.027	0.957	0.952	0.910	0.875	0.741	1.031
SD	0.553	0.524	0.437	0.457	0.378	0.210	0.583
Maximum	3	2.8	2.1	2.7	2	1.1	3
n	**22**	**22**	**22**	**22**	**22**	**22**	**21**
DO saturation (%)							
Minimum	77.4	76.2	79.6	75.2	77.5	68.3	82.4
Median	80.8	80.2	82.1	82	82.6	82.7	85.7
Mean	81.182	80.373	82.409	81.045	83.955	82.555	87.827
SD	3.659	2.698	2.150	4.127	6.193	9.572	4.980
Maximum	91.4	84.4	87.3	90.3	100.1	100.6	95.2
pH							
Minimum	7.9	7.9	7.8	7.9	7.9	7.9	7.9
Median	7.9	8	8	8	8	8	8
Mean	8.04	8.05	8.01	8.05	8.01	8.00	8.05
SD	0.22	0.12	0.11	0.18	0.10	0.11	0.08
Maximum	8.6	8.2	8.2	8.5	8.2	8.2	8.2
n	**11**	**11**	**11**	**11**	**11**	**11**	**11**
Chlorophyll (ug/L)							
Minimum	1.1	0.3	1	0.3	1.8	0.8	0.9
Maximum	3.9	1.7	1.8	3.4	2.9	3.4	3.1
n	**4**	**4**	**4**	**4**	**4**	**4**	**4**

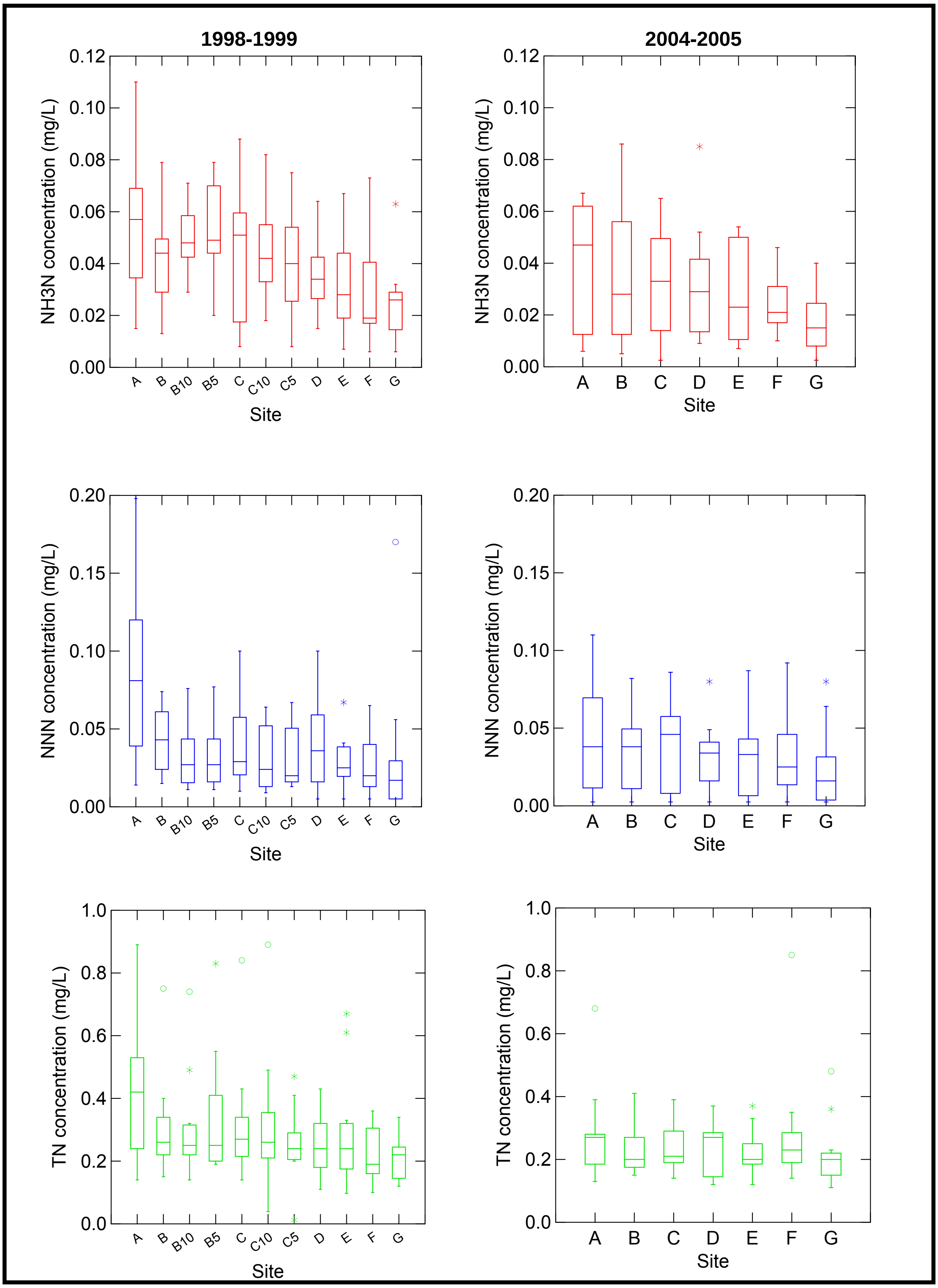

Figure 3.1 Ammonia nitrogen, nitrate-nitrite nitrogen and total nitrogen concentrations (mg/L) at seven sites in Timaru Harbour over 1998-1999 and 2004-2005

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

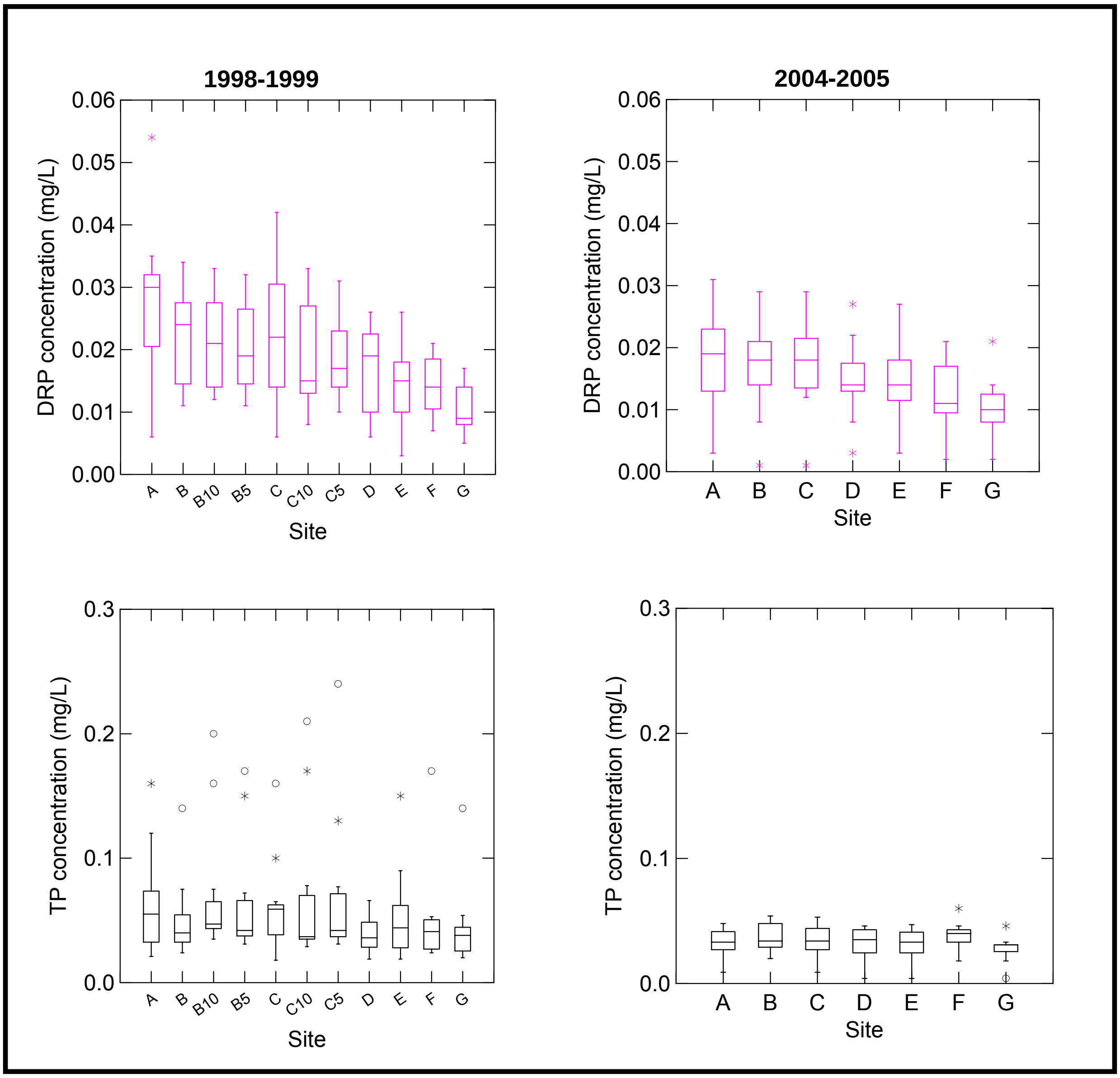

Figure 3.2 Dissolved reactive phosphorus and total phosphorus concentrations (mg/L) at seven sites in Timaru Harbour over 1998-1999 and 2004-2005

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

A = No. 2 wharf
B = inner port
C = north mole
D = No.1 extension wharf
E = port entrance
F = mid Caroline Bay
G= Starboard Buoy

3.1.2 Physical determinands

Turbidity
The water turbidity (NTU) at each site was variable over time (Figure 3.3). In general, the highest turbidity water occurred in mid Caroline Bay with water at the port entrance and at the starboard buoy also quite turbid at times. The water at sites within the port was typically less turbid than that at the port entrance and at sites beyond the port.

Water clarity
The water clarity (depth in metres) was mostly quite low. At each site water clarity was variable (Figure 3.3) with the clarity being more variable over 1998-99 than over 2004-2005. In general the lowest water clarity occurred in mid Caroline Bay with high water clarity occurring at the starboard buoy and at sites within the inner port. There was no statistically significant relationship between turbidity and water clarity at any of the sites.

pH
The pH of sea water is 8.0 – 8.1. The pH values at some sites were found to be outside of this range (Figure 3.4). There was no obvious pattern with respect to deviation of the pH value from that in pure sea water, to site location.

Dissolved oxygen saturation
The highest variability in dissolved oxygen saturation occurred in mid Caroline Bay water, while the lowest variability occurred in water at the starboard buoy (Figure 3.4). On some sampling occasions there was little difference in dissolved oxygen saturation between sites while on other occasions there was a difference of up to 20% saturation between sites.

Chlorophyll-a concentration
Chlorophyll-a concentrations were highly variable both between sites on any one sampling occasion and between sampling occasions (Figure 3.5). There was no obvious relationship between chlorophyll-a concentration and site location.

3.2 Variation within sites

3.1.3 Variation in chemical determinands with water depth

Three water depths were sampled at two sites within the port over 1998-1999. The data for each nutrient at each depth are presented in the box and whisker plots (Figures 3.1-3.2). The results of the Wilcoxon two-tailed sign test, used to determine if there was a significant difference in the concentration of each nutrient with water depth at each site are presented in Appendix IV.

At the inner port site (site B) the concentrations of NNN and DRP were significantly higher in surface water than in water at 5 and 10 metres depth. There was no significant difference in the concentrations of any nutrients with water depth at the north mole (site C).

3.2.2 Variation over time

The results of the Kruskal-Wallis ANOVA, used to determine if there was a significant difference in the concentration of each nutrient at each site between the two sampling periods, are presented in Table 3.4.

DRP concentrations at the innermost site in the port (site A) were significantly higher over 1998-1999 than over 2004-2005. TP concentrations at the north mole (site C) were significantly higher over 1998-1999 than over 2004-2005. There were no significant differences over time in the concentration of any of the nitrogen-based nutrients, at any of the sites.

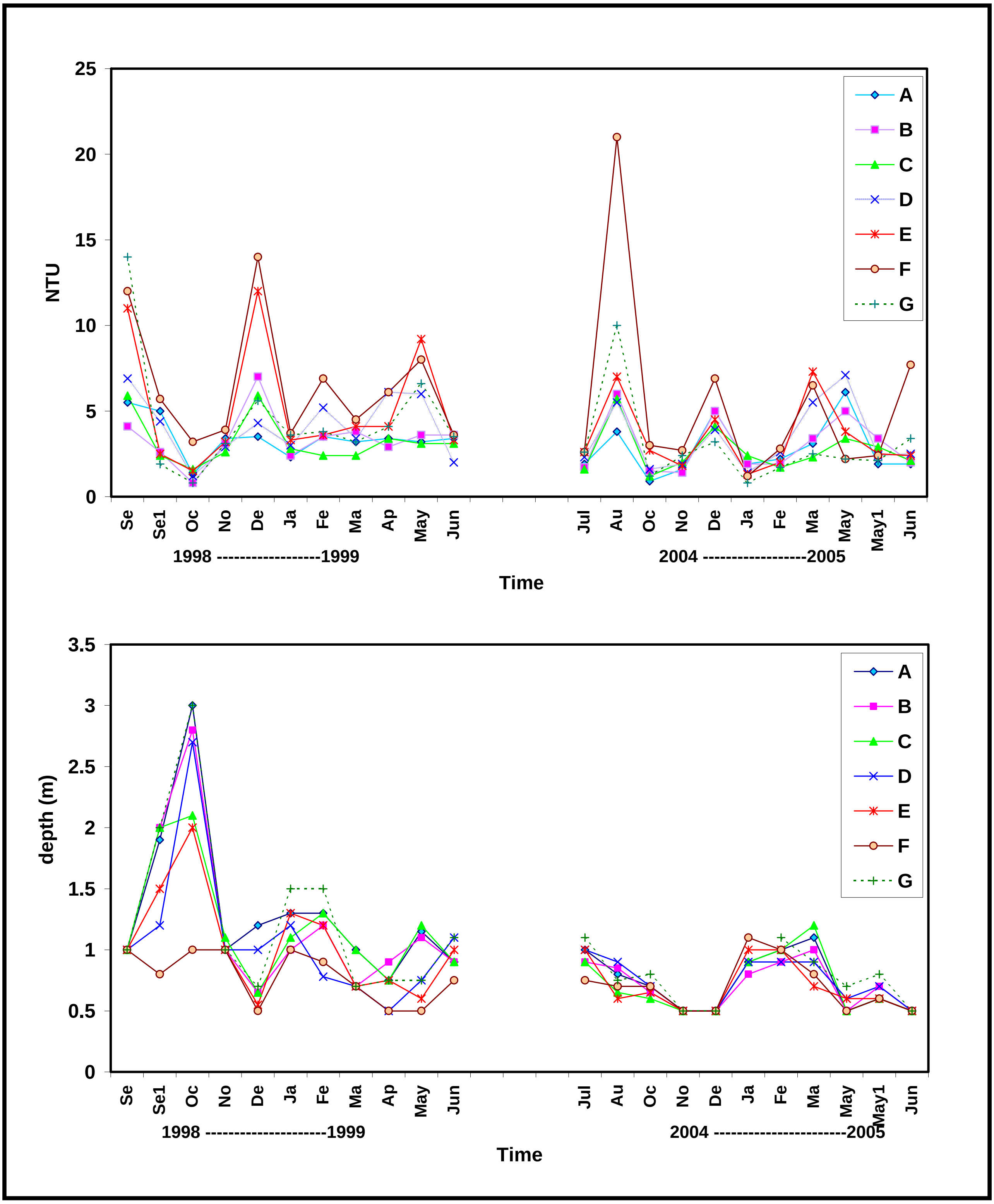

Figure 3.3 **Turbidity (NTU) and water clarity (depth (m)) at seven sites in Timaru Harbour over1998-1999 and 2004-2005**

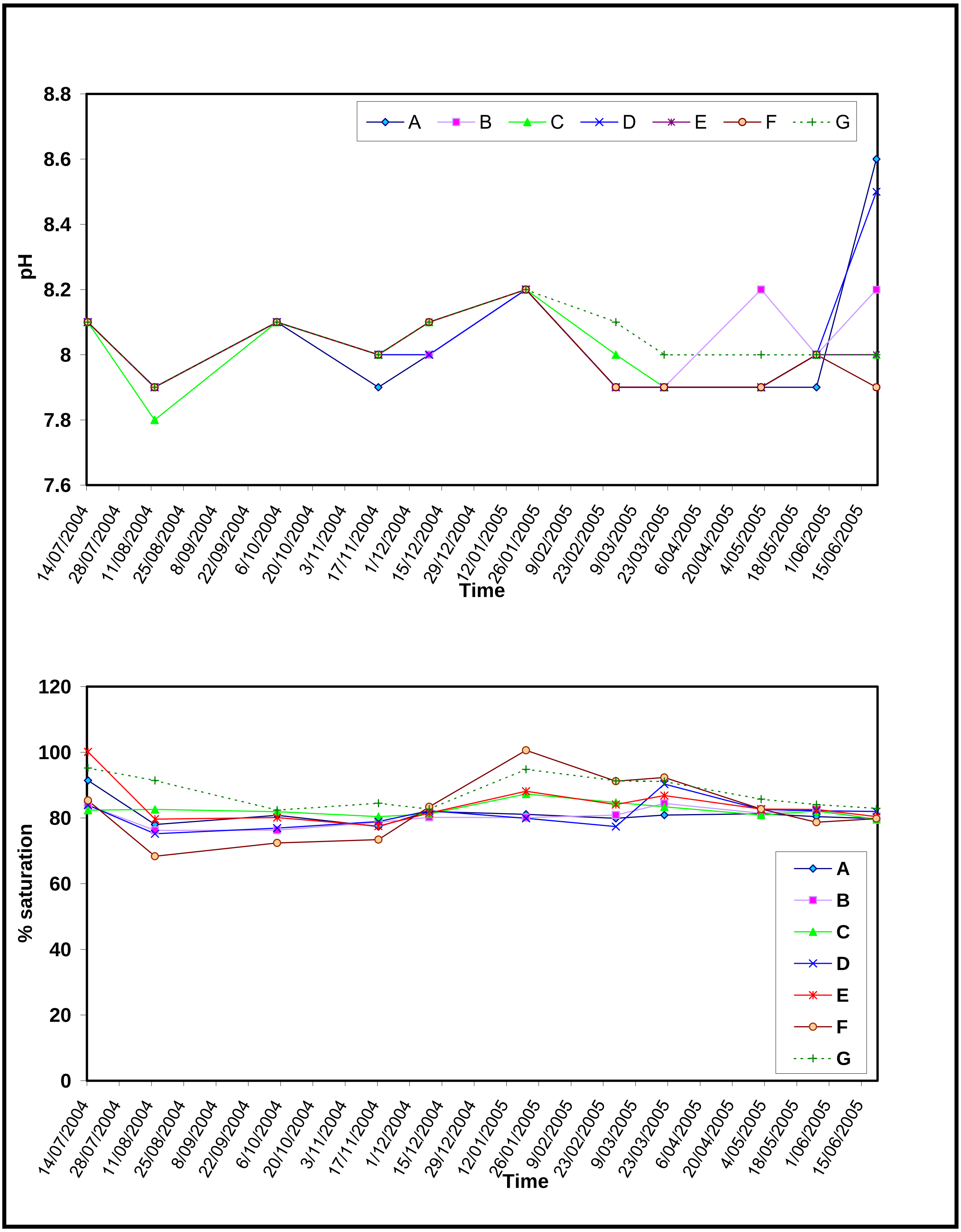

Figure 3.4 **pH and dissolved oxygen saturation (%) at seven sites in Timaru Harbour over 2004-2005**

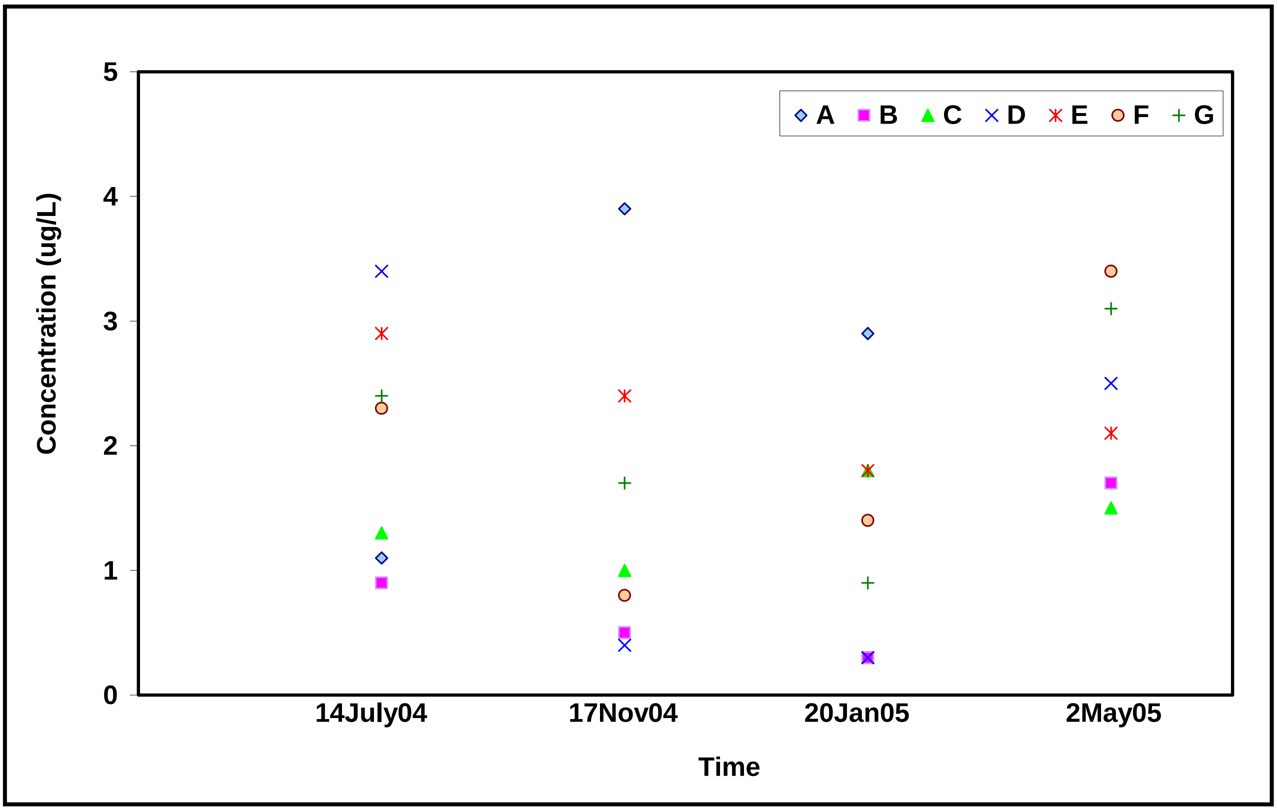

Figure 3.5 **Chlorophyll-a concentrations (µg/L) at seven sites in Timaru Harbour over 2004-2005**

Table 3.3 **Significant differences in the concentration of each nutrient at each site over time, T1 = 1998-1999 and T2 = 2004-2005**

ns - no significant difference in concentration over time
* - significant difference between sites at p< 0.05

		Determinand				
		NH3N	NNN	TN	DRP	TP
Site	A	ns	ns	ns	* T1 > T2	ns
	B	ns	ns	ns	ns	ns
	C	ns	ns	ns	ns	* T1 > T2
	D	ns	ns	ns	ns	ns
	E	ns	ns	ns	ns	ns
	F	ns	ns	ns	ns	ns
	G	ns	ns	ns	ns	ns

3.3 Potential nutrient limitations

3.3.1 N:P ratio

The DIN and DRP values were used to calculate the N:P ratio for all samples. The results are presented in Figure 3.6.

The N:P ratio in all samples on all sampling occasions at all sites and depths in Timaru Harbour was less that 16:1.

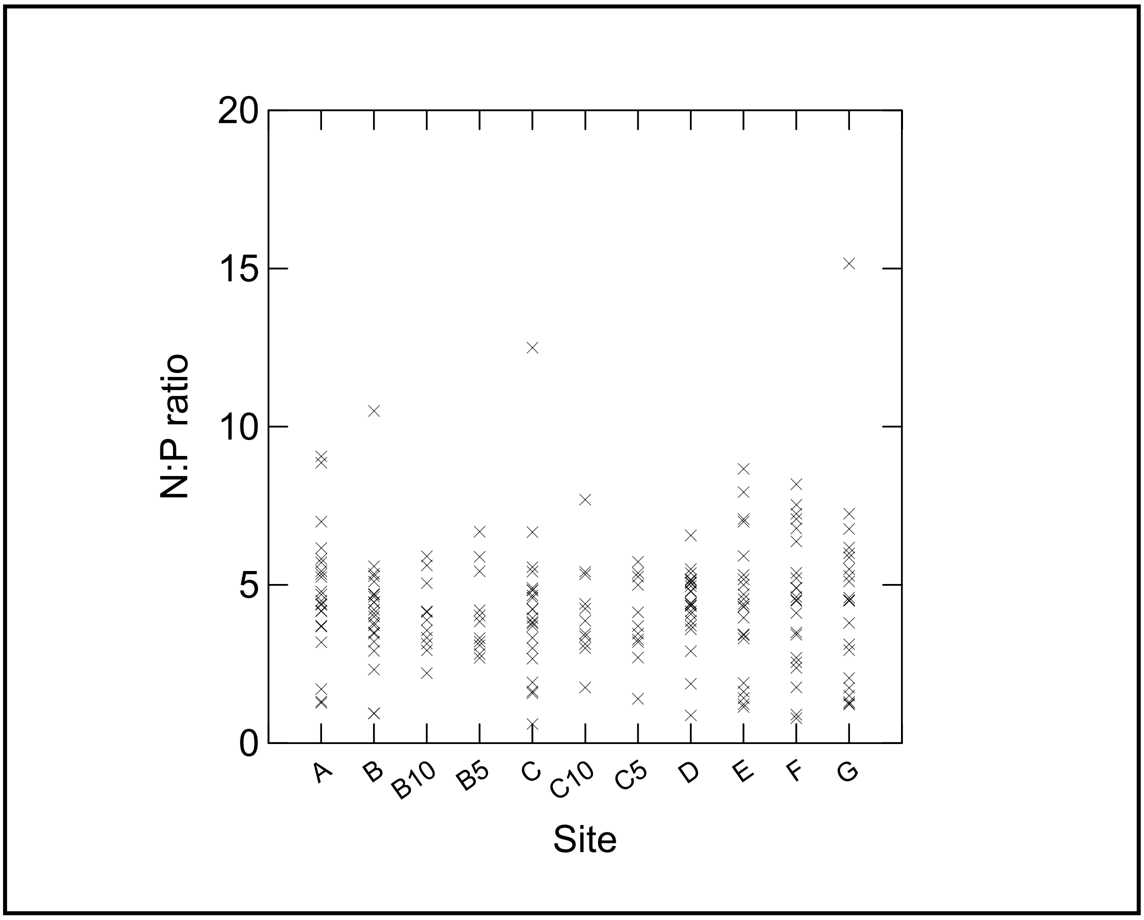

Figure 3.6 N:P ratio in water sampled at each depth at each site in Timaru Harbour, 1998-1999 and 2004-2005

4 Discussion

The near-shore coastal water in the vicinity of Timaru is a complex mix of southland current water and fresh water from the numerous rivers, streams and drains discharging into the sea south and north of Timaru. The closest rivers are the Pareora River some 13 km to the south and the Opihi River some 14 km to the north (Figure 1.1). There are also creeks that flow through Timaru and discharge into the sea (Figure 1.1). In addition, within a 12km radius of Timaru, there are two large point source wastewater discharges into the sea on or adjacent to the shore. This wastewater is from the meat processing plant at Pareora (south of Timaru) and the Timaru District wastewater outfall (north of Timaru). The near-shore water of this coastline has a predominantly longshore (northeast – southwest) flow (Barter *et al*, 2003). However, onshore and offshore flows do occur at times (CH2M Beca Ltd, 2002). Thus Timaru Harbour water will at times originate from the nearshore water south of Timaru and at other times originate from that north of Timaru.

At the starboard buoy site, some 500 m offshore of the southern mole (Figure 2.1), the water sampled is that most likely to reflect the near-shore coastal water that occurs in the vicinity of Timaru. The variability in the concentration of the nitrogen- and phosphorus-based compounds (nutrients) at this site over the periods of sampling could be because of:

- differences in the nutrient concentrations between north and south flowing coastal water (due to differences in the quantity and quality of the freshwater inputs and wastewater discharges).
- differences in the quantity of the freshwater input (affected by rainfall) over time.

It is not known if the water flowing from the nearby creeks and out of the port also influences the concentrations of the nutrients at the starboard buoy. At the sites closer to the shore, i.e. mid Caroline Bay and the port entrance, there is a likelihood that the near-shore coastal water becomes mixed with creek water, diluted stormwater and at the port entrance melted freeze water (from a fish processing plant). The further into the port the sites are, the greater the likelihood that stormwater, any other discharges and any accidental spills affect the concentrations of nutrients in the sea water. Stormwater is a recognised contributor of nutrients to coastal waters (Vincent and Thomas, 1997).

The NH_3N, NNN concentrations recorded at the starboard buoy were not significantly different to those recorded between the heads of Akaroa Harbour (Bolton-Ritchie, 2005) and at the entrance of Lyttelton Harbour (Bolton-Ritchie, 2004). However, the TN and TP concentrations were significantly higher and the DRP concentrations were significantly lower at the starboard buoy, than at one or other of these two sites. These differences in TN and TP concentrations likely result from inputs of nutrients from the numerous rivers, streams and drains and the wastewater discharges into the coastal waters within a radius of 30 or more km of Timaru. By the nature of location, the water at the Akaroa and Lyttelton sites is also more likely to consist of offshore oceanic water than that in the vicinity of Timaru. The lower DRP concentrations at the starboard buoy than at the entrance of Lyttelton Harbour is likely to be a reflection of the difference in the origin, number and type of non-oceanic inputs into coastal water in each area.

Significant differences occurred in NH_3N, NNN, TN, DRP and TP concentrations between some of the sites in Timaru Harbour in each sampling period. The most obvious difference was the lower concentrations of the nutrients at the starboard buoy than at the other sites that were sampled. At the starboard buoy the concentrations of each nutrient were lower than those at the inner-most port site (A) over both sampling periods. For example, the median and maximum concentrations of NNN (Table 3.1) were respectively 3.4 and 1.2 times higher, and the median and maximum concentrations of DRP were respectively 2.3 and 2.8 times higher, at site A than at the starboard buoy. The differences between the starboard buoy and the other five sites occurred in the concentrations of one to four of the nutrients. These differences generally consisted of lower concentrations of DRP, TP and TN over 1998-1999 and lower concentrations of NH_3N, NNN, DRP and TP over 2004-2005 at the starboard buoy than at some of the other sites.

This difference in nutrient concentrations, between those at the starboard buoy to those at the other sites, is suggestive of nutrient inputs in proximity to the sites within the port and in Caroline Bay. These inputs appear to be higher at the inner-most site within the port (site A) than at the other five sites. However, the semi-enclosed location of site A, i.e. within the innermost part of the inner port, could result in the sea water being retained in this part of the port for a period of time.

Thus the nutrient concentrations at site A likely results from localised nutrient inputs in combination with the water flushing characteristics in this part of the port.

Over 1998-1999 there were significant differences in the concentrations of NH_3N, NNN, TN, DRP and TP between the three sites within the inner port. These differences are indicative of location specific influences. For example, the concentrations of NH_3N, NNN and DRP were higher at innermost port site A, located close to shore, between two wharves and in proximity to two stormwater outlets, than at sites B and C located in the middle of the inner part of the port some distance from the wharves and land. These significant differences in nutrient concentrations between the inner port sites did not occur over 2004-2005. This temporal difference is suggestive of less rainfall and hence less stormwater discharged around the time of sampling over 2004-2005 than over 1998-1999. This is supported by the rainfall observations made at the time of sampling. It was or had been raining prior to sampling on five of the 11 sampling occasions over 1998-1999 but only on one of the 11 sampling occasions over 2004-2005. Between site differences in the concentration of NH_3N, NNN, TN, DRP and TP have also been found to occur within the Port of Lyttelton, with site-specific nutrient sources considered as the most likely reason for the differences (Bolton-Ritchie, 2004).

Over both sampling periods there were significantly higher concentrations of some of the nutrients at inner port sites A, B and C than at the port entrance site (E). These results suggest that:

- the inner port water can be nutrient-enriched and likely circulates around the inner port before being flushed out into the outer port.
- the water volumes in the outer port and exchanged between the outer port and the ocean are sufficient to dilute nutrient enriched inner port water to significantly lower concentrations before it reaches the port entrance.

The two wharf structures that extend into the port and divide it into two parts (inner port and outer port) (Figure 2.1) could be the barrier to efficient water mixing and water circulation throughout the whole port. The mixing and circulation of the water within the whole port is likely driven by the tides, wind and waves but there are no hydrodynamic data to corroborate this. However, as wind and wave energy is affected by solid structures, the barrier effect, of the two wharf structures, is considered a valid assumption. This physical barrier likely accounts for the higher concentrations of some of the nutrients at inner port sites A, B and C than at the port entrance site (E). While the lack of a barrier between the outer port sites (site D at No.2 wharf and site E at the port entrance) accounts for their being no significant difference in nutrient concentrations between these two sites over both time periods. This indicates that even if there are stormwater or other discharges into the outer port, the water becomes well mixed and diluted within a short distance of the discharge points.

It should be noted that nutrient-enriched water retained in the inner port area has the potential to result in nutrients adsorbing onto the suspended sediments and settling to the seabed. Over time this could result in nutrient enrichment of the sediment within the inner port. This nutrient enriched sediment could become re-suspended and the nutrients released when the seabed is stirred up by vessels or by natural forces such as waves. The nutrient enriched sediment could also have a follow-on impact on DIN concentrations in the water column in the inner port area as benthic re-mineralisation rates may be enhanced (P. Gillespie, *pers.comm.)*.

Site D, located in the outer port between the southern mole and the No.1 extension wharf, is unlikely to be in the direct path of the nutrient-enriched water flowing out from the inner port. However, some of this enriched water could, through tidal flows and wind-generated water movement, flow into this area of the port. This flow of water, in combination with the possible input of nitrogen-based compounds in particular to this area from stormwater discharges, is possibly why the only significant differences between site D and sites B and C were in the TP or DRP concentrations.

Over 1998-1999 water was collected from three water depths at sites B and C in the inner harbour. At site C there was no significant difference in nutrient concentrations between depths (to 10 metres). That is, water at this site was well mixed. At site B there was a significant difference in the concentration of NNN with depth, with concentrations being significantly higher in the surface water that in water at depths of 5 and 10 m. This could be as a result of either NNN-rich inputs to the surface water in the vicinity of this site or limited mixing through the water column or a combination of both i.e. a possible surface layer of low salinity water. Given that there were no significant differences in the concentrations of any of the other nutrients with depth at this site, it is more than likely that the depth differences results from NNN-rich inputs to the surface water. The DRP concentration in the surface water from site B was significantly higher than in water at depths of 5 and 10 m at site C. This result is somewhat of an anomaly.

Routine sampling over two year-long periods reveals that the nutrient concentrations are variable over time. The largest variability in concentrations occurred at the inner port sites (Figure 3.1 and 3.2; Figures in Appendix V) while the smallest variability occurred at the starboard buoy and at the No.1 extension wharf (site D). The concentrations of all nutrients except TN were more variable over 1998-1999 than over 2004-2005. For TN, concentrations at the mid Caroline Bay and the starboard buoy sites were more variable over 2004-2005 than over 1998-1999. At all other sites the TN concentrations were more variable over 1998-1999 than over 2004-2005.

These differences in variability between sites and over time are indicative of irregular nutrient inputs in the vicinity of some sites. For example:

- in September 1998 following heavy rain there was a notable peak in TN concentration (site labelled Se1 - Figures in Appendix V) at the innermost site in the port (A) and at the north mole site (C) in the inner port
- in December 1998 following and during rain there was a notable peak in TN concentration at the innermost site in the port (A).

These results suggest that the stormwater is the source of the TN (stormwater is discharged into the port in proximity to sites A and C). However, the impact of stormwater discharge on TN concentrations was localised as high concentrations did not occur at inner port site B some 140-270 m away from the other sites within the inner port. The peaks in the concentration of TN and other nutrients at the inner port sites on other sampling occasions did not correlate to periods of rainfall. There was also no correlation of peak nutrient concentrations to documented spill events (Environment Canterbury pollution hotline records) within the Port of Timaru. When the small peaks in the concentration of one or more of the nutrients occurred, they occurred at all sites. This is suggestive of a common source of the water at all sites and likely reflects the origin of the water in Timaru Harbour i.e. either north or south flowing coastal water, at the time of sampling.

At inner port sites A and C there were DRP and TP concentration peaks in September and December 1998. Given that there was rainfall at or prior to the sampling in both months (refer to previous paragraph), it is likely that stormwater is a contributor of DRP and TP to the water of the inner port. The effect of rainfall on DRP and TP concentrations in the inner port likely accounts for the concentrations of these nutrients being significantly higher over 1998-1999 than over 2004-2005. This is because there were fewer rainfall events at or prior to sampling over 2004-2005 than over 1998-1999.

Chlorophyll-a concentration, a measure of the biomass of phytoplankton present in the water, was quantified on four occasions at each of the sites over 2004-2005. The highest recorded concentration was 3.9 µg/L (0.0039 mg/L) and the lowest was 0.3 µg/L (0.0003 mg/L). The chlorophyll-a concentrations were very variable between sites on each sampling occasion and at each site over time. The largest variability over time occurred at site D in the outer port, with high variability also at the innermost site (A) in the port. The smallest variability in concentration occurred at inner port site C.

The between-site differences in chlorophyll-a concentration on each of the sampling occasions are suggestive of high natural variability. A more definitive evaluation of the between-site differences cannot be made because only one sample was collected at each site on each sampling occasion.

In the marine environment the growth of phytoplankton is generally limited and regulated by the dissolved inorganic nitrogen (DIN) concentration. Although high DIN concentrations can lead to excessive phytoplankton growth (which can result in an algal bloom), the relative availability of nitrogen and phosphorus i.e. the N:P ratio, the flushing, light regime, temperature and the availability of other chemicals such as silica and iron are also important (ANZECC, 2000; NRC, 2001).

To assess the potential for enhanced phytoplankton growth DIN concentrations can be evaluated. In a recent study of the potential for nutrient-rich wastewater to stimulate algal blooms it was found that a mean DIN concentration of 0.07-0.14 mg/L over 72 hours resulted in an increase in chlorophyll-a concentration to around 0.002 mg/L (Zeldis and Gall, 1999). A chlorophyll-a concentration of 0.005 mg/L has been found to cause physical discolouration of surface waters (Eppley *et al*., 1977) and a concentration of 0.015 mg/L is associated with eutrophication (Harris *et al*., 1996). In this study the maximum DIN concentration at all sites and water depths was higher than 0.07 mg/L and at some sites it was also higher than 0.14 mg/L. DIN concentrations higher than 0.07 mg/L occurred in 63-68% of the samples from the inner port sites (A, B and C), in 41-46% of samples in the outer port (D and E), in 36% of samples from Caroline Bay and 23% of samples from the starboard buoy. DIN concentrations of higher than 0.14 mg/L occurred in 23 % of samples from the inner most port site (A), in 14% of samples from site C in the inner port and in 0 – 4.5% of samples from all other sites. Given the percentage occurrence of these DIN concentrations, there is a greater potential for enhanced phytoplankton growth within the inner port than at any of the other sites sampled.

The N:P ratio in water from the surface and at depth at all sites on all sampling occasions in Timaru Harbour was less than 16:1, which indicates that N was the nutrient limiting phytoplankton growth. This is in agreement with the widely accepted view that nitrogen is generally the critical limiting nutrient for phytoplankton growth in the marine environment (NRC, 2001; Rosenberg, 1985; Valiela, 1995). Optimal nutrient conditions for phytoplankton growth, that is an N:P ratio of 16:1 did not occur during the period of sampling. Nonetheless, phytoplankton blooms have occurred in Timaru Harbour in the past; for example in February 2004 there was a bloom of the non-toxic diatom *Chaetoceros armatus* in Caroline Bay.

5 Future investigations and monitoring

The current monitoring programme, i.e. every 5 years at seven sites, represents the minimum desirable regime for the continued monitoring of the water quality of Timaru Harbour. In future the ideal would be to measure the chlorophyll-a concentration at each site on every sampling occasion and also measure salinity and suspended sediment concentrations at all sites in addition to the concentrations of the chemical and physical determinands measured to date. This will allow for an assessment of the relationships between nutrient concentrations and primary productivity, nutrient concentrations and sediment loads in the water column and nutrient concentrations and salinity.

6 Acknowledgements

The author wishes to thank staff of the Timaru Coastguard for running the boats used to access the sampling sites. The water samples, were collected by Zella Smith from Environment Canterbury, and analysed by the laboratory staff of Environment Canterbury. This report was reviewed by Dr. Paul Gillespie from the Cawthron Insititute and edited by Ken Taylor from Environment Canterbury.

7 References

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Appendix I: Details of the sampling sites and sampling depths at each site in Timaru Harbour

Site ID	Site label	Site description	Site depth (m)	Sampling depth (m)	Grid reference NZMS 260 map series
SCY000753	A	No. 2 wharf	7	0-0.5	K39:7099-4470
SCY001005	B	inner port	10.4 (dredged)	0-0.5	K39:7120-4485
	B5			5	
	B10			10	
SCY000265	C	north mole	10.4 (dredged)	0-0.5	K39:7119-4499
	C5			5	
	C10			10	
SCY001011	D	No.1 extension wharf	6.2	0-0.5	K39:7151-4489
SCY001008	E	Port entrance	10.7 (dredged)	0-0.5	K39:7169-4533
SCY001010	F	mid Caroline Bay	3.5	0-0.5	K39:7073-4571
SCY001009	G	Starboard Buoy	10	0-0.5	K39:7229-4568

Appendix II: Details of analyses included in the water quality monitoring programme

Determinand	Analysis provider	Method	Time Period	Detection Limit	Units
Nitrate/nitrite nitrogen (NNN)	CRC laboratory	Cadmium reduction by SFA	1998-1999	0.01	mg/L
	ECan laboratory	APHA 4500 NO_3 - F (20th ED)	2004-2005	0.005	mg/L
Total ammonia-nitrogen (NH3N)	CRC laboratory	Automated gas diffusion. APHA 4500-NH3F – modified	1998-1999	0.005	mg/L
	ECan laboratory	APHA 4500 NH3-F - modified (20th ED)	2004-2005	0.005	mg/L
Total nitrogen (TN)	CRC laboratory	APHA 4500-ND.SFA. Persulphate digestion (19th ED)	1998-1999	0.05	mg/L
	ECan laboratory	APHA 4500-N C modified (20th ED)	2004-2005	0.08	mg/L
Dissolved reactive phosphorus (DRP)	CRC laboratory	Ascorbic Acid Mo-Sb reagent, Water and Soil No 3	1998-1999	0.003	mg/L
	ECan laboratory	APHA 4500-P B, F (20th ED)	2004-2005	0.001	mg/L
Total phosphorus (TP)	CRC laboratory	H2SO4/K2S2O8 digestion Ascorbicacid Mo-Sb reagent	1998-1999		mg/L
	ECan laboratory	APHA 4500-P B (20th ED)	2004-2005	0.008	mg/L
Chlorophyll-a	ECan laboratory	APHA 10200 (20th ED) Fluorimetry	2004-2005		µg/L
Turbidity	CRC laboratory	Hach 2100A meter	1998-1999		NTU
	ECan laboratory	APHA 2130 B (20th ED) - meter	2004-2005		NTU
pH	ECan laboratory	APHA 4500-H B (20th ED) - meter	2004-2005		
Salinity	Field	NI-YSI 63 meter	2004-2005		ppt
Dissolved oxygen saturation	Field	NI-YSI/55 DO meter	2004-2005		%
Water clarity	Field	Secchi disc	2004-2005		m
Water temperature	Field	Thermometer	1998-1999		ºC
	Field	NI-YSI/55 DO meter	2004-2005		ºC

Appendix III: Comparison of nutrient concentrations in surface water between all sites in Timaru Harbour: results from the two-tailed Wilcoxon Signed Rank Test

* - significant difference between sites at p< 0.05
** - significant difference between sites at p < 0.01
*** - significant difference between sites at p < 0.001
blank cells indicate there was no significant difference between sites

1998-1999		Higher value						
		A	B	C	D	E	F	G
Lower value	A							
	B	NH3N *						
	C	NH3N * NNN * DRP *						
	D	NH3N * NNN ** TN * DRP ** TP *	DRP *	TP **				
	E	NH3N * NNN ** DRP ** TP *	NNN * DRP **	NNN * DRP * DRP ** TP *				
	F	NH3N * NNN ** TN * DRP ** TP *	DRP **	DRP ** TP *	NNN *			
	G	NH3N * NNN * TN ** DRP ** TP *	DRP ** TN *	DRP * TN * DRP ** TP **	DRP *	TN * TP *	DRP *	

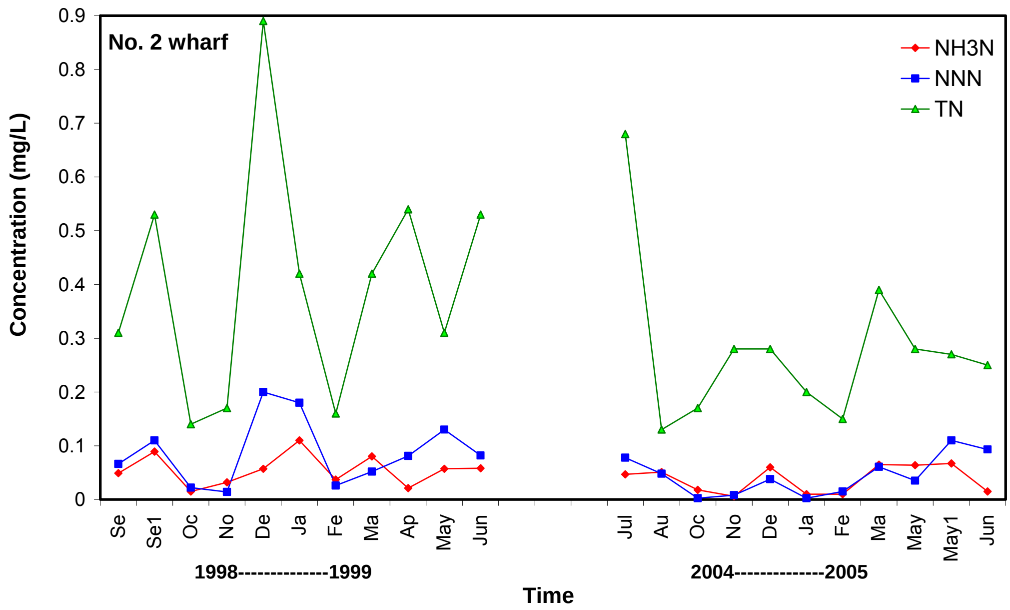
2004-2005		Higher value						
		A	B	C	D	E	F	G
Lower value	A							
	B							
	C							
	D		TP *					
	E	NH_3N * NNN * DRP * TP *	NH_3N * DRP * TP *	NH_3N * DRP * TP *				
	F	DRP **	DRP *	DRP *	DRP *			
	G	NH_3N ** NNN ** TN ** DRP ** TP ***	NH_3N * DRP ** TP ***	NH_3N * NNN * DRP ** TP *	NH_3N * DRP **	NH_3N * NNN * DRP **	NH_3N * TN* TP *	

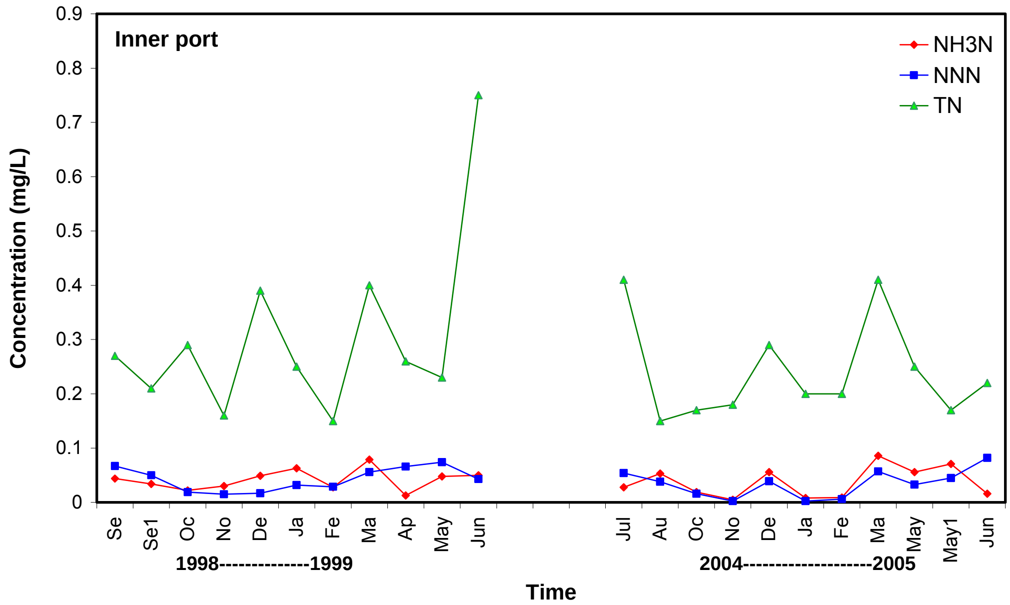
Appendix IV: Comparison of nutrient concentrations between water depths at two sites in Timaru Harbour: results from the two-tailed Wilcoxon Signed Rank Test

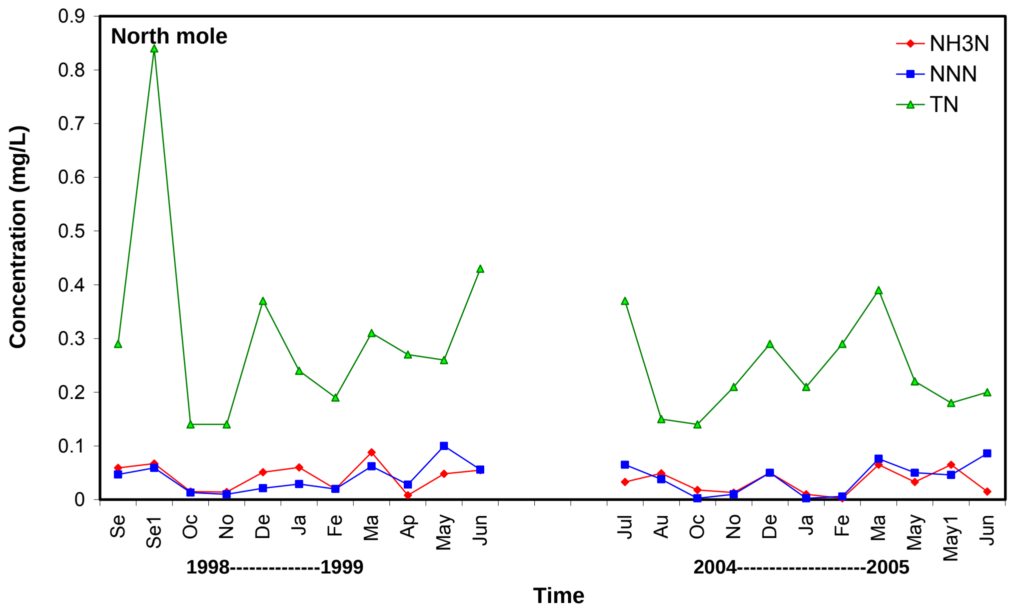
* - significant difference between sites at p< 0.05
** - significant difference between sites at p < 0.01
*** - significant difference between sites at p < 0.001
blank cells indicate there was no significant difference between sites

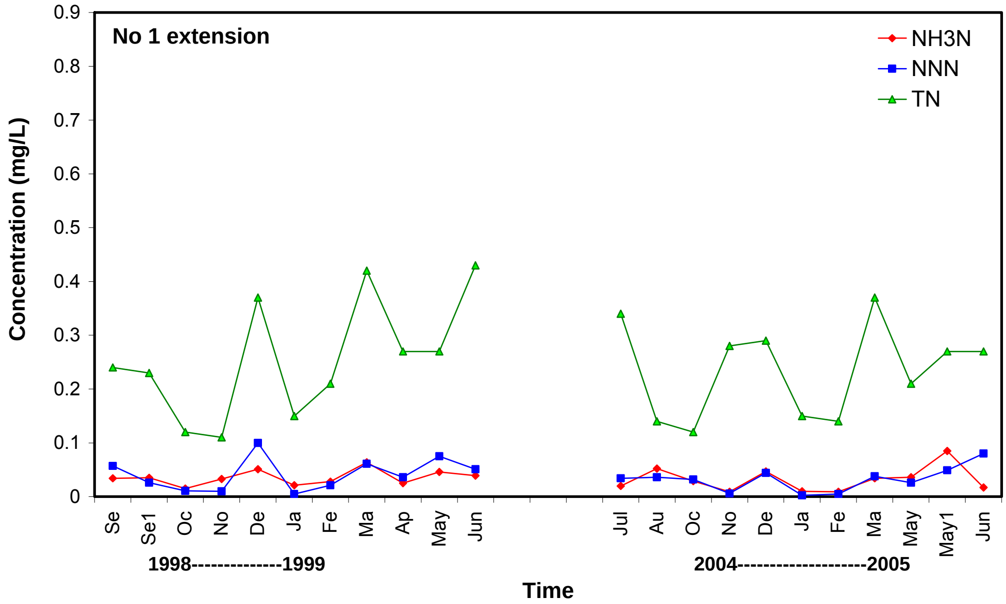
		Higher value					
		B (0 m)	B (5 m)	B (10 m)	C (0 m)	C (5 m)	C (10 m)
Lower value	B (0 m)						
	B (5 m)	NNN *					
	B (10 m)	NNN *					
	C (0 m)						
	C (5 m)	DRP *					
	C (10 m)	DRP *					

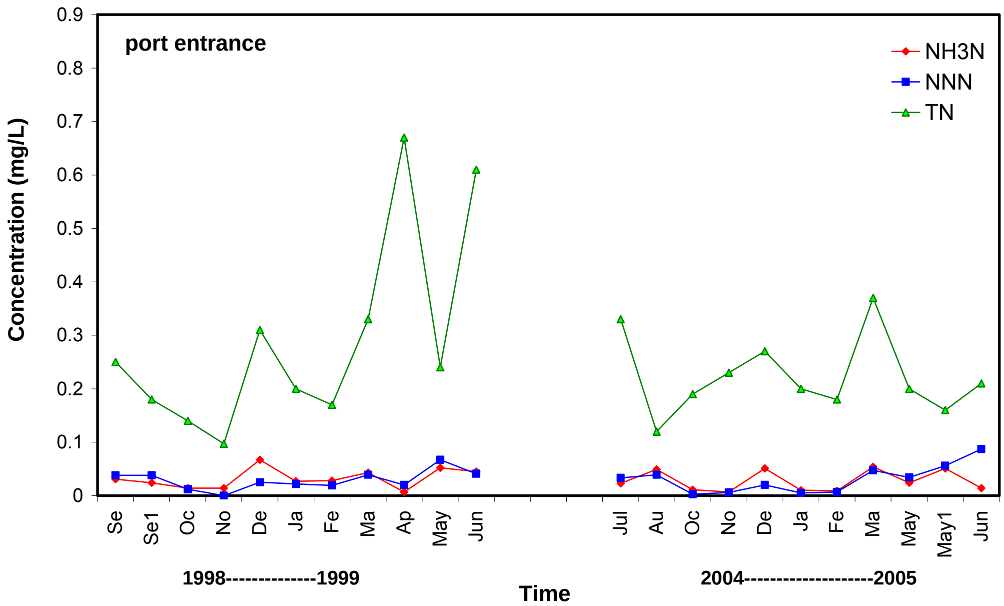
Appendix V: Nutrient concentrations in water at each depth at each Timaru Harbour site over time

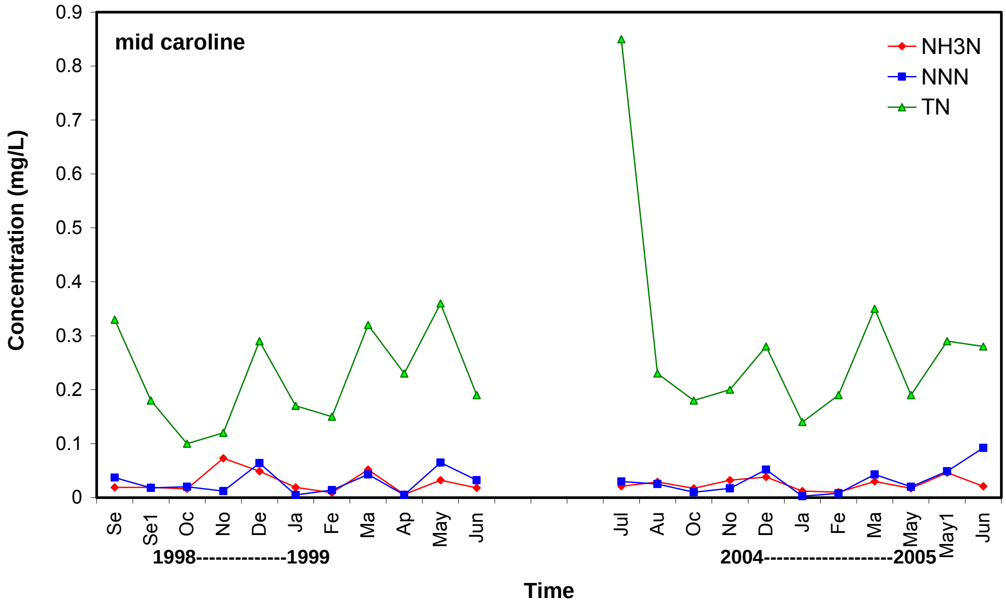

No. 2 wharf
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------2005
Time

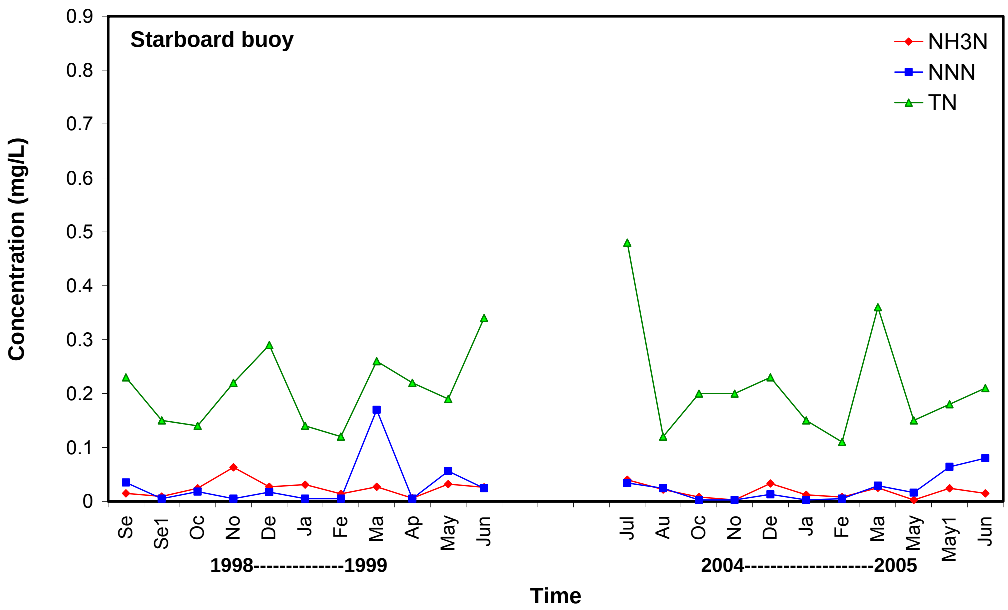

Inner port
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------------2005
Time

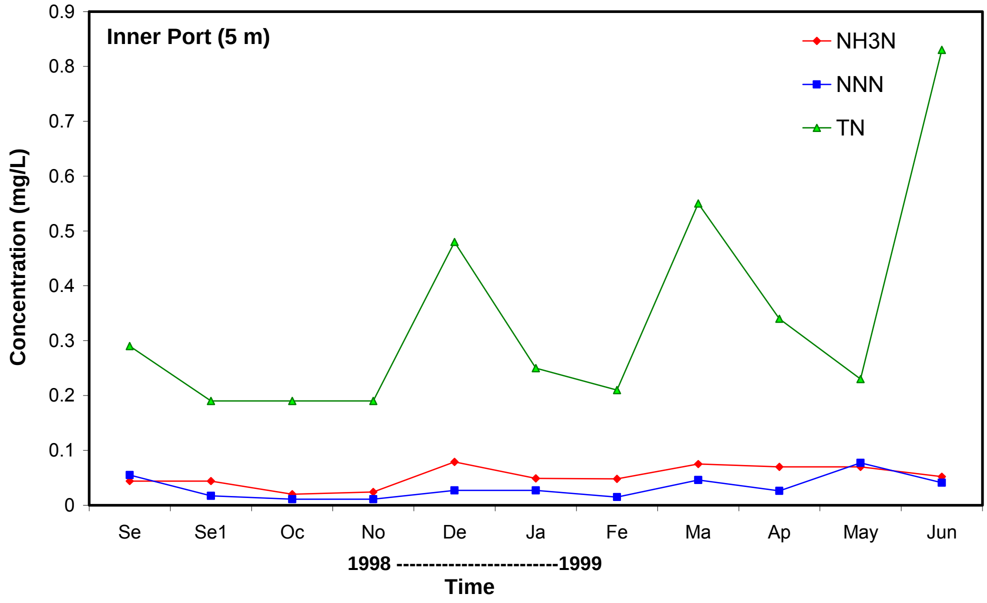

North mole
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------------2005
Time

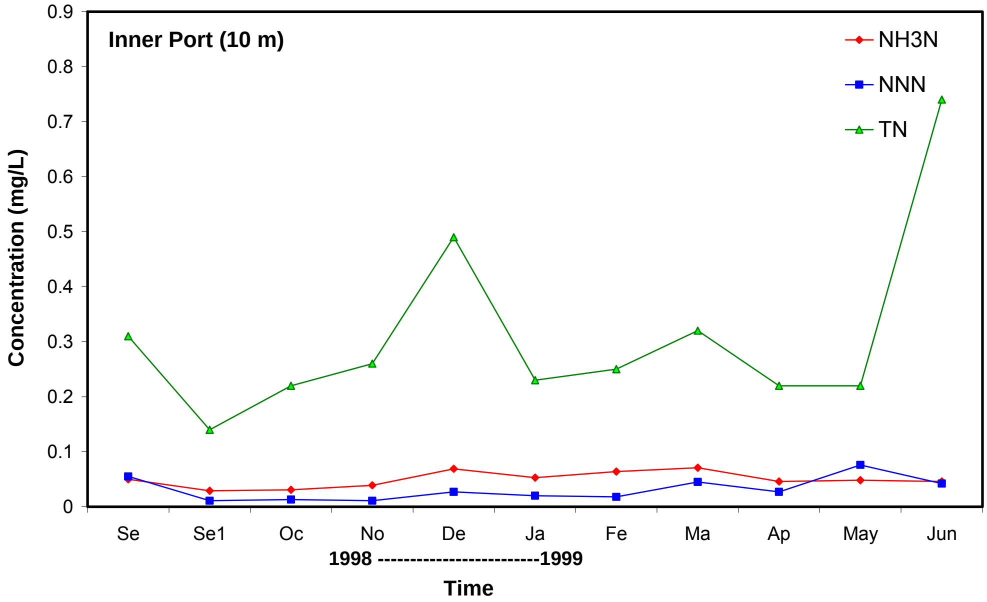

No 1 extension
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------------2005
Time

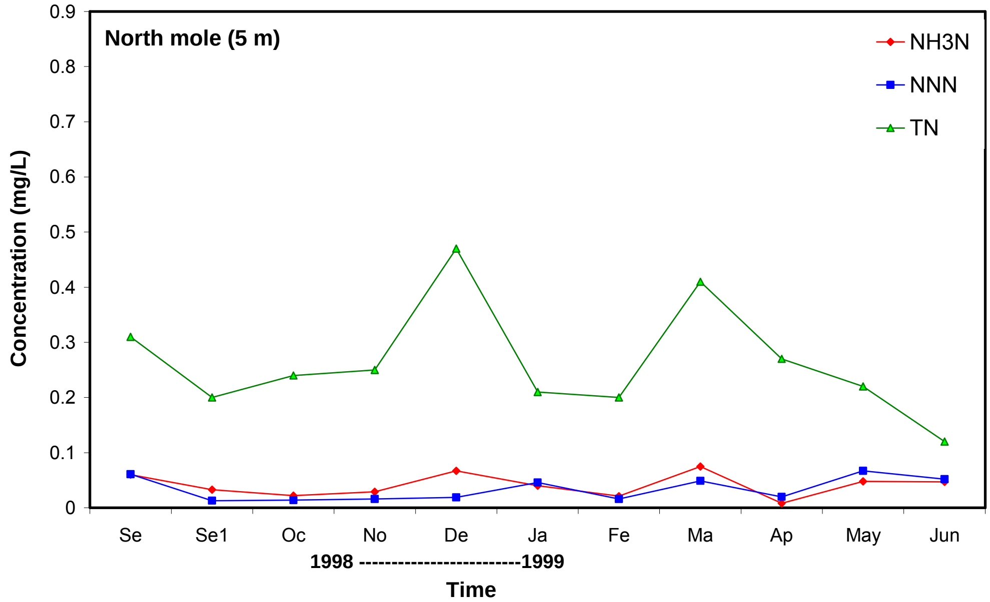

port entrance
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------------2005
Time

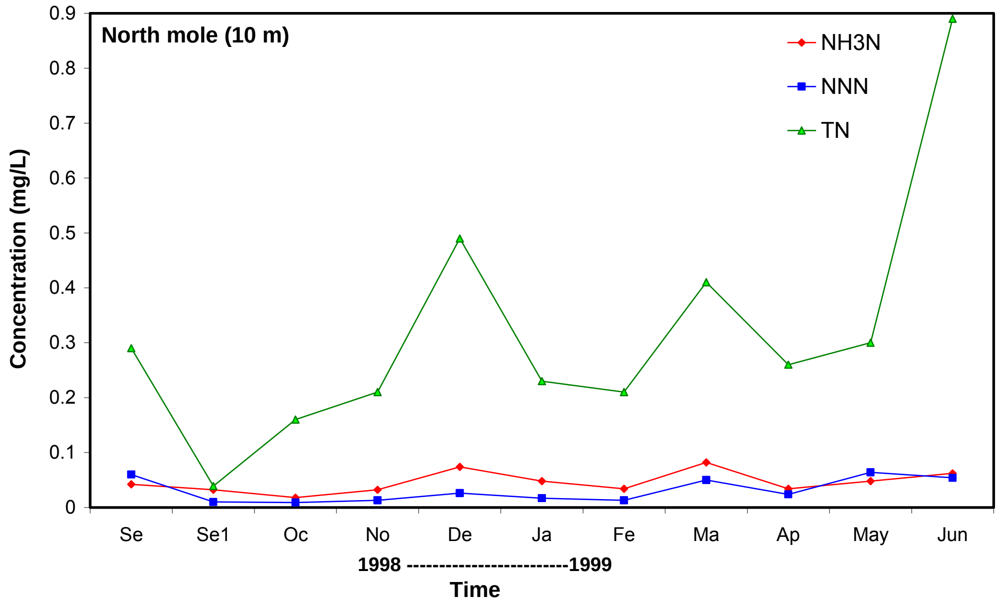

mid caroline
NH3N
NNN
TN
Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------------2005
Time

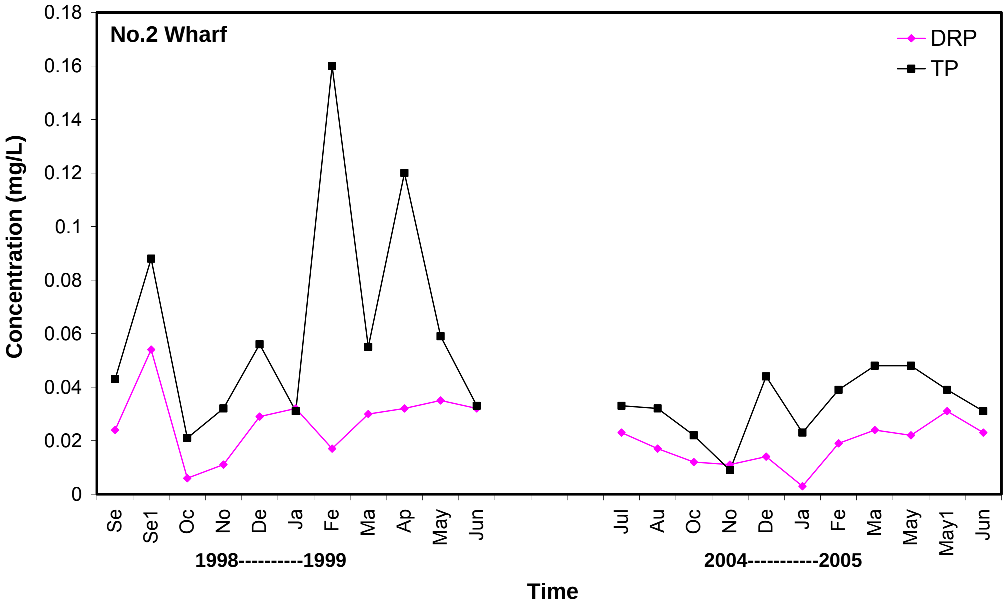

Starboard buoy
NH3N
NNN
TN
Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998--------------1999
2004--------------------2005
Time

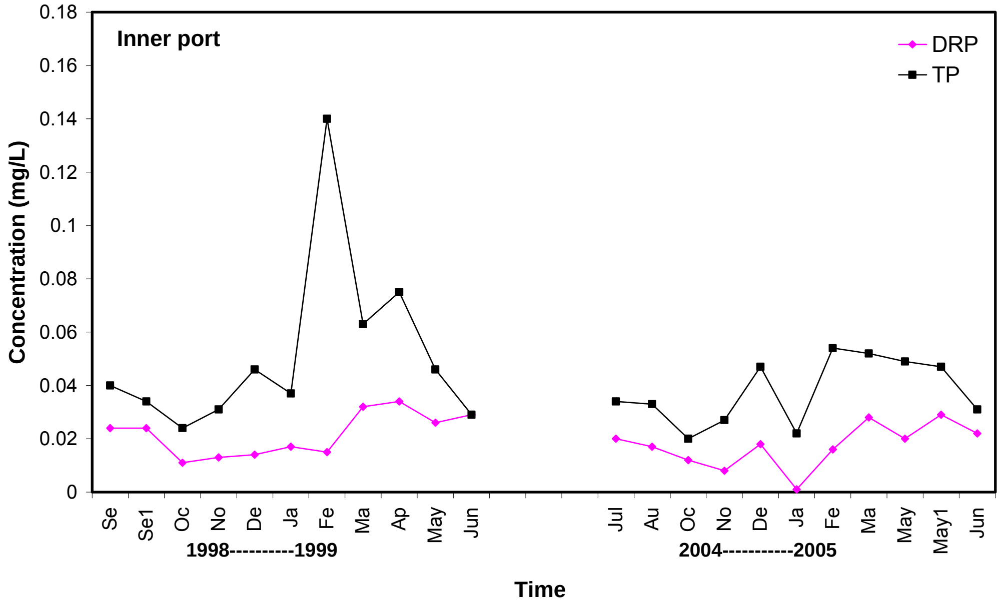

Inner Port (5 m)
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 -------------------------1999
Time

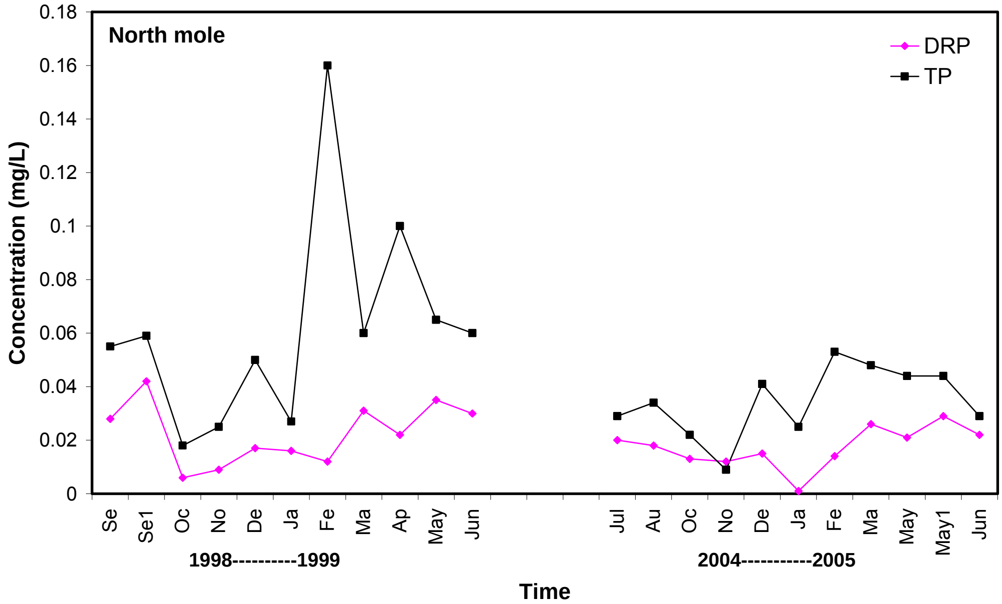

Inner Port (10 m)
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 -------------------------1999
Time

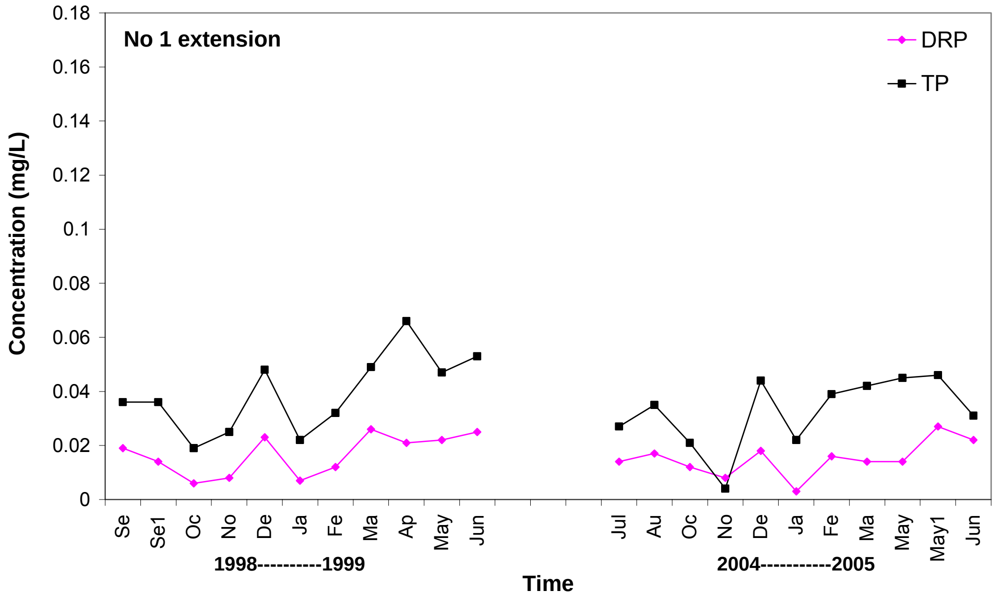

North mole (5 m)
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 ------------------------1999
Time

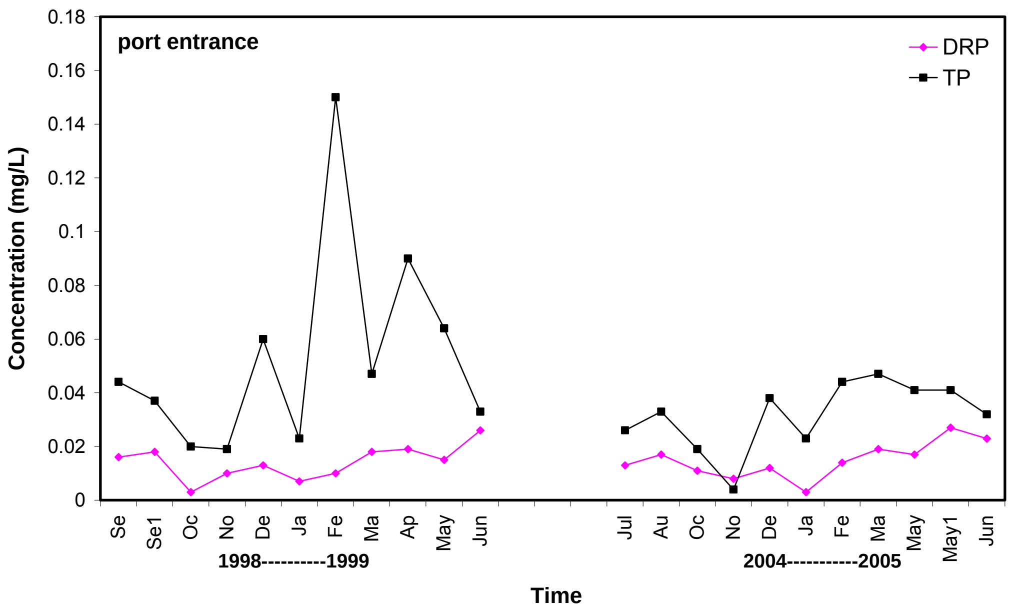

North mole (10 m)
NH3N
NNN
TN
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 ------------------------1999
Time

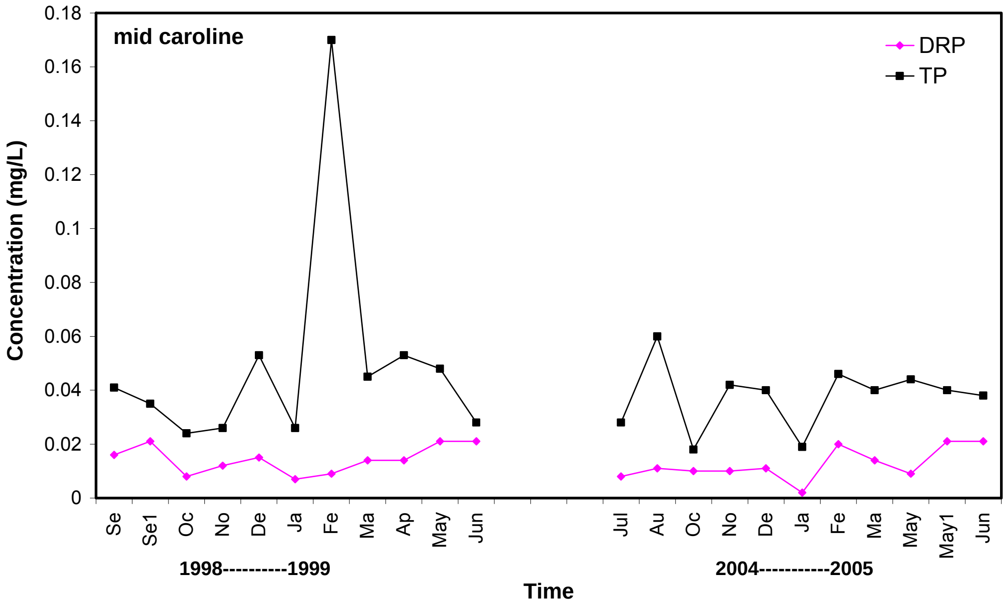

No.2 Wharf
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998----------1999
2004-----------2005
Time

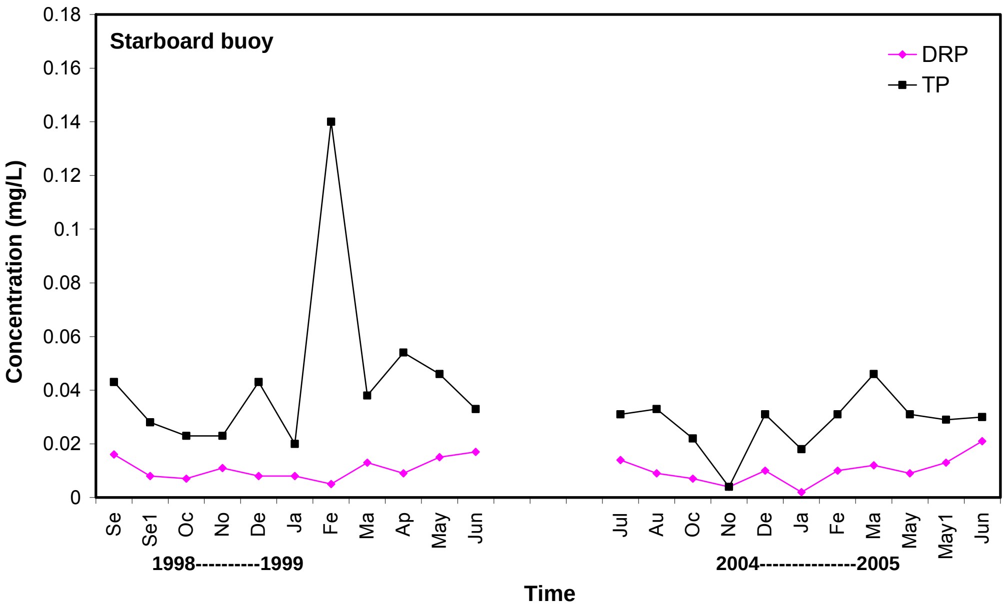

Inner port
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998----------1999
2004-----------2005
Time

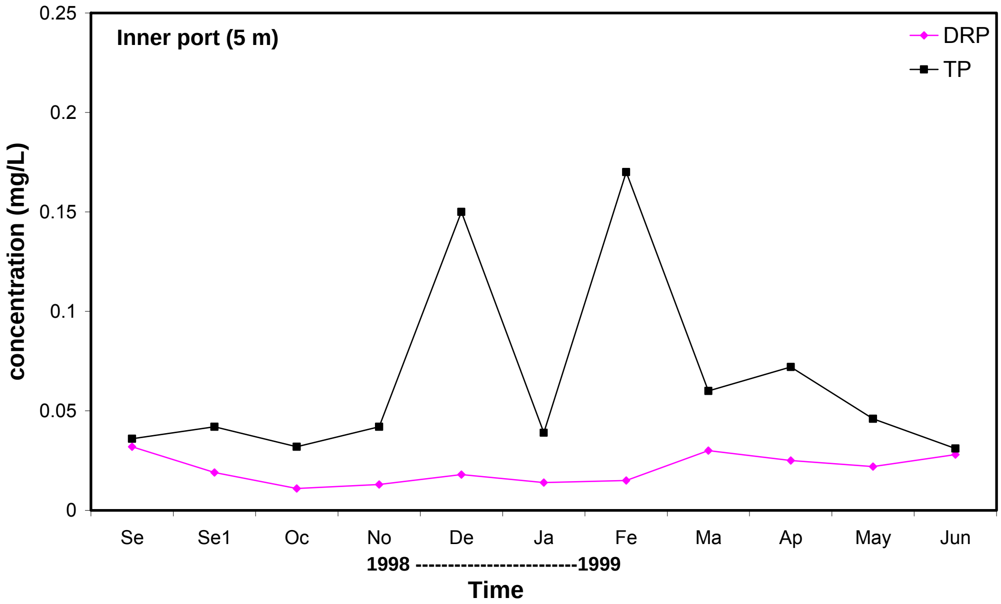

North mole
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998----------1999
2004-----------2005
Time

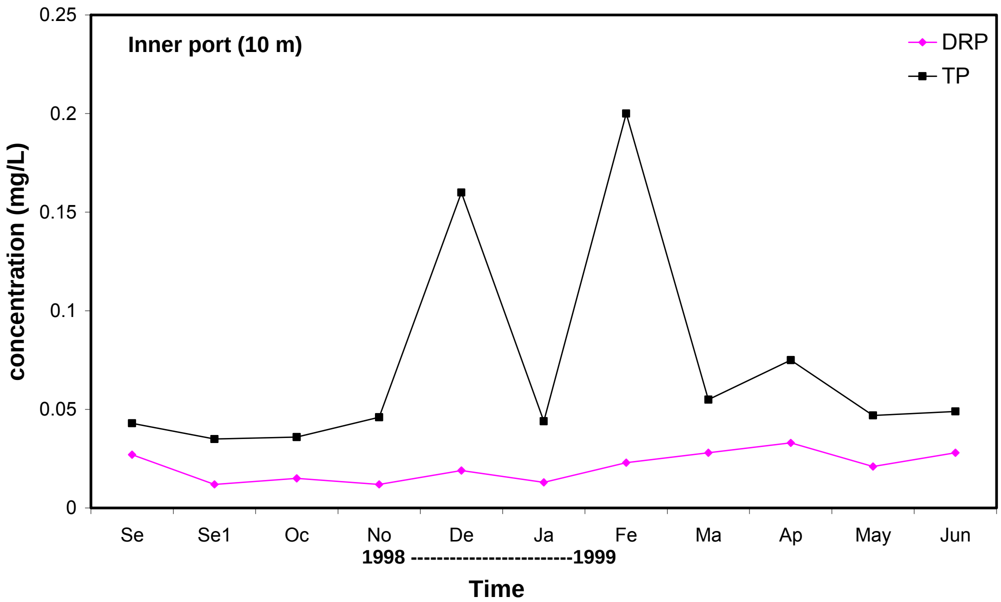

No 1 extension
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998----------1999
2004-----------2005
Time

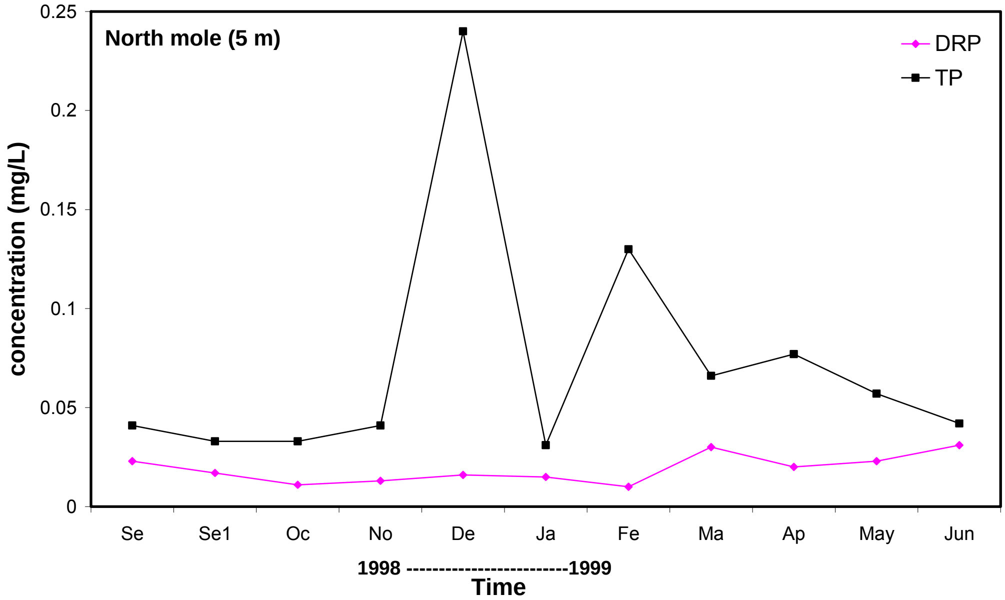

port entrance
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
Jul
Au
Oc
No
De
Ja
Fe
Ma
May
May1
Jun
1998----------1999
2004-----------2005
Time


mid caroline
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se Se1 Oc No De Ja Fe Ma Ap May Jun
Jul Au Oc No De Ja Fe Ma May May1 Jun
1998----------1999
2004-----------2005
Time

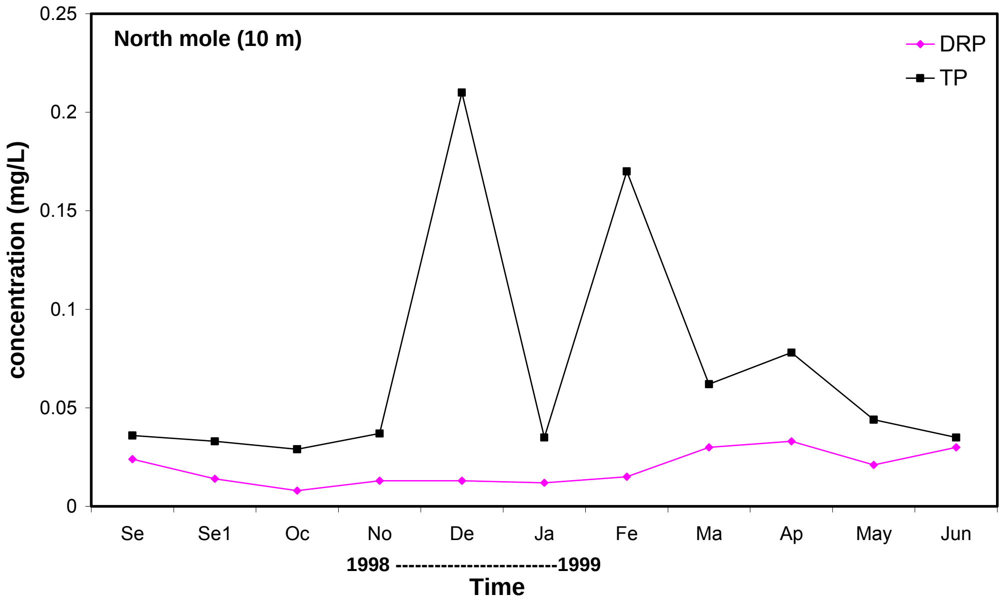

Starboard buoy
DRP
TP
Concentration (mg/L)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Se Se1 Oc No De Ja Fe Ma Ap May Jun
Jul Au Oc No De Ja Fe Ma May May1 Jun
1998----------1999
2004---------------2005
Time


Inner port (5 m)
DRP
TP
concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 -------------------------1999
Time


Inner port (10 m)
DRP
TP
concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 -------------------------1999
Time



North mole (5 m)
DRP
TP
concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 ------------------------1999
Time



North mole (10 m)
DRP
TP
concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Se
Se1
Oc
No
De
Ja
Fe
Ma
Ap
May
Jun
1998 ------------------------1999
Time

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