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# NUTRIENT LOAD AND WATER QUALITY IN COCKBURN SOUND 1986-1987

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Field work was carried out by G Bastyan, P Lavery, R Masini and F Salleo from the Centre for Water Research, The University of Western Australia, and M Donnelly, M Butler, C Scrimshaw and G Fulford from the Environmental Protection Authority. Nutrient analyses were carried out in the nutrient analysis laboratory, Centre for Water Research, The University of Western Australia.

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# 1. INTRODUCTION

The 1976-79 Cockburn Sound study showed that massive dieback of seagrass in the Sound since the mid 1950's, and the subsequent appearance of phytoplankton blooms, occurred during a period of increased nitrogen loading associated with industrial development (Cambridge, 1979; Cambridge and McComb, 1984). The Cockburn Sound Study Report (Anonymous, 1979) recommended that nitrogen loads to Cockburn Sound be substantially reduced to improve water quality, and arrest this seagrass dieback. The two principal nutrient sources to the Sound were identified as the Kwinana Nitrogen Company (KNC)/ CSBP and Farmers Ltd (CSBP) outfall, and the Water Authority of Western Australia's wastewater treatment plant at Woodman Point (WPTP). In accordance with the Cockburn Sound Study Report recommendation. KNC commissioned, in late December 1982, a steam scrubber designed to remove a large proportion of the nitrogen from the plant's effluent, and on 12 July 1984, secondary treated effluent originally discharged from the WPTP outfall was diverted into a new pipeline which discharges into 20 m deep water 4 km west of Cape Peron.

In order to assess the effects of reduced nitrogen loading to the Sound, the Environmental Protection Authority in conjunction with the Centre for Water Research, University of Western Australia carried out 14-week monitoring studies during the summer of 1982/83 (Chiffings and McComb, 1983) and 1984/85 (Hillman, 1986), in which weekly changes in nutrient and chlorophyll 'a' levels and light attenuation in the Sound were documented. During the 1982/83 study (Chiffings and McComb, 1983) significant reductions were found in phytoplankton levels and light attenuation compared with previous years, and this was attributed to the reduction in nitrogen loading from KNC. During the 1984/85 study, phytoplankton levels and light attenuation were not significantly different from those during the 1982/83 study, suggesting that the Sound had reached a new trophic equilibrium in response to several years of similar nitrogen loading (Hillman, 1986). Both studies noted, however, that effluent output from KNC was extremely variable, and the 1984/85 study recommended that a similar exercise be carried out over the 1986/87 summer to re-assess water quality. In accordance with the recommendation, this study was carried out from 18 December 1986 to 2 April 1987, consisting of 14 trips carried out at approximately weekly intervals. It was also decided to obtain records of daily nitrogen loads from both CSBP and KNC to determine their relative contributions to the nitrogen load coming from the KNC/CSBP outfall, since the original estimate by Murphy (1979) that KNC and CSBP contributed 98% and 2% respectively was based on only one week of intensive sampling.

# 2. NUTRIENT LOADS TO THE SOUND

## 2.1 CHANGES SINCE THE 1976-79 COCKBURN SOUND STUDY

Mean daily loads (kg) of nitrogen from the KNC/CSBP outfall (WPTP no longer discharges effluent into the Sound) for summer 1986/87 are compared with data from the KNC/CSBP and WPTP outfalls for corresponding periods in previous years in Table 1. The combined nitrogen load of the two outfalls has fallen from about 4,500 kg/d in 1977/78 to 1128 kg/d in 1986/87. It should be emphasised that the data in Table 1 give no indication of the diurnal or hourly variability associated with these loads.

## 2.2 VARIABILITY OVER THE STUDY PERIOD

It is important to know the variability of nitrogen loads to Cockburn Sound, since extremes may be more critical than average conditions in affecting biological processes such as phytoplankton response. Daily loads of total nitrogen from the KNC/CSBP outfall are shown for the study period (Figure 1). Daily variation from the outfall was considerable, ranging from 49-3058 kg/d; the latter figure reaches levels measured in 1977. This is due to variations in effluent concentration which, in turn, are due to both alterations in the production process and discontinuities in pumping of waste (Chiffings and McComb, 1983). There are 14 days for which no results are depicted (Figure 1) because the KNC plant was not discharging.

Table 1. Changes in nitrogen loads to Cockburn Sound from WPTP and KNC/CSBP outfalls (loads in kg/day). Total nitrogen (TN) includes inorganic and organic nitrogen. Total inorganic nitrogen (TIN) includes ammonia-nitrogen ($NH_4$-N) and nitrate-nitrogen ($NO_3$-N). Data for the last three studies are presented two ways : the mean load for the entire study period (all days), and the mean load on days when the plants were discharging (operational).

| | Woodman Point Treatment Plant | | KNC/CSBP Outfall | | Data Source |
|---|---|---|---|---|---|
| | TIN | TN | TIN (all days) | TIN (operational) | |
| October 1977 | - | - | 3015 | - | 1 |
| Jan - Feb 1978 | 1124 | 1422 | - | - | 1 |
| March 1981 | 1560 | - | 1593 | - | 2 |
| March 1982 | - | - | 257 | - | 3 |
| Nov 1982 - Feb 1983 | - | 2004 | 563 (KNC only) | 1061 (KNC only) | 4 |
| Dec 1984 - Mar 1985 | 0 | 0 | 974 | 1018 | 5 |
| Dec 1986 - April 1987 | 0 | 0 | 1128 | 1215 | 5 |

1 Murphy (1979) Data for KNC are mean values from one week's intensive sampling at three-hourly intervals. Data for WPTP are mean-values from a four week continuous sampling programme.

2. Mean value from one week's intensive sampling by DCE at three-hourly intervals.

3. Talbot (1983) Sampling carried out from 12/11 - 22/11/82.

4. Chiffings and McComb (1983) - The total for KNC was calculated from daily figures over the period of the study.

5. Present study - The total for the KNC/CSBP outfall was calculated from daily figures for the period of the study.

## 2.3 LOADS SINCE THE COMMISSIONING OF KNC'S AMMONIUM STRIPPER

During the 1982/83 summer, when KNC's steam scrubber first became operational, the mean daily nitrogen load from KNC on operating days was 1061 kg (Chiffings and McComb, 1983). During the 1984/85 study the corresponding figure was 804 kg, and during this study, 589 kg. Thus the nitrogen concentration of KNC effluent has continued to decrease, even though variability is still high.

The mean daily nitrogen load from CSBP on operating days during this study was 634 kg. On days when both plants were operating the mean total load was 1215 kg/day, of which KNC contributed 48.5% and CSBP 51.5%. CSBP have, however, expressed less confidence in the accuracy of measured "peak" loads (> 1000 kg/day) than "normal" loads due to uncertainties in the accuracy of flow measurements and difficulties in sampling slug loads.

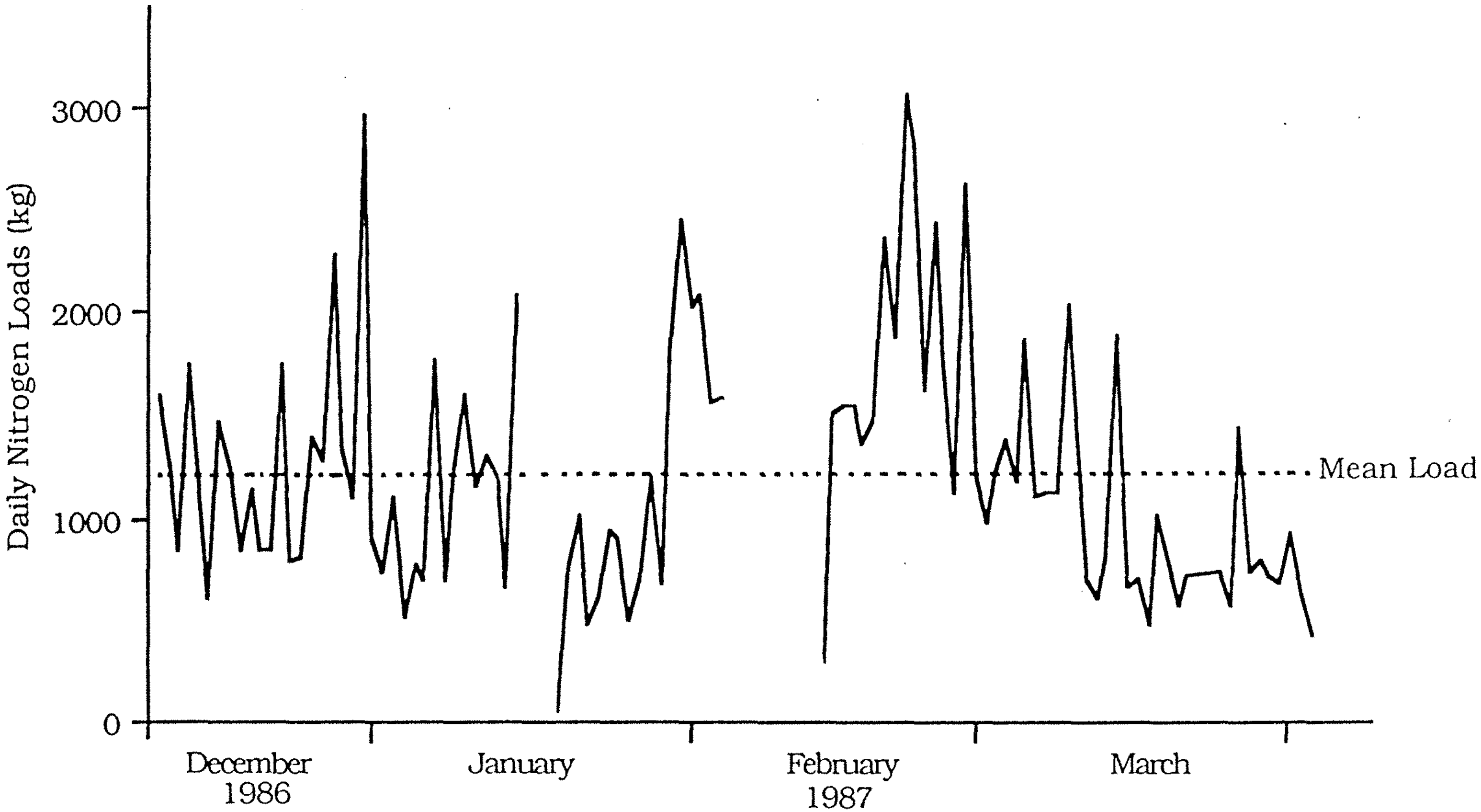


Figure 1 Daily nitrogen loads (kg) from the KNC/CSBP outfall over the 1986/87 summer period. The dashed line is the mean value of the daily loads.

The mean daily load from CSBP on 'normal' days was 402 kg. Assuming discharge on peak days would be at least this figure, the mean total load from the outfall would be at least 991 kg/day, of which CSBP would contribute 43.7%. The real situation presumably lies somewhere between these two estimates.

The mean daily nitrogen load during the entire study period (that is, including the days when KNC was not discharging) was 1128 kg, of which KNC contributed 45.9% and CSBP 54.1%. If the above adjustment for peak loads from CSBP is carried out, the mean daily nitrogen load decreases to 920 kg, and KNC and CSBP's contributions change to 56.3% and 43.7% respectively. Once more, the true situation presumably lies between these two extremes. Comparisons with the 1982/83 study cannot be made because CSBP's contribution is not reported, however data supplied by CSBP for the 1984/85 study puts the mean daily nitrogen load from the outfall at 974 kg. Since KNC's mean daily nitrogen load for the 1984/85 study period was 661 kg (Hillman, 1986), the relative contributions of KNC and CSBP become 67.9% and 32.1% respectively. Thus the contribution of CSBP to the daily nitrogen load of the outfall has risen slightly from 32% in 1984/85, to 44 - 54% in 1986/87. This increase is a function of both a decrease in KNC's contribution (from 3015 kg/day in October 1977 to 518 kg/day in this study), and an increase in CSBP's contribution from 313 kg/day in the 1984/85 study and 402-634 kg/day in this study. However although confidence can be placed in the total nitrogen load from the KNC/CSBP outfall, the relative contributions of KNC and CSBP are less certain due to differences between the sampling methods used by each company.

## 3. PHYTOPLANKTON CONCENTRATIONS

### 3.1 INTRODUCTION

The 1982/83 study sampling programme was designed to obtain maximum information from available time and resources, and involved weekly sampling at 11 sites; eight sites within Cockburn Sound, two in Owen Anchorage, and one between Carnac Island and Garden Island (Figure 2). For the same reasons, and also to enable direct comparisons, the same sampling programme was adopted for this study. Similarly, in view of the lack of vertical stratification in the Sound (Chiffings, 1979), the integrated sampling technique adopted in the 1982/83 exercise was also used.

### 3.2 METHODS

Integrated samples were collected at each station using a plastic ten litre Niskin bottle, and sampling at three depths. The first sample was taken just below the water surface, the second sample was taken just above the sediment/water interface, and the third was taken midway between the first two. The three samples were then mixed in a large plastic container and subsampled. Water samples were stored in 150 ml polyethylene bags ("Whirlpak", Nasco, Kansas, USA.) on wet ice, and upon return to the laboratory were deep frozen until analysed.

Samples of particulate matter were collected onto pre-combusted (1 hour at 450°C) GFC glass fibre filters by filtering a known volume of water (usually 1L) using positive pressure not exceeding 10 mm Hg.

Salinity, temperature and light attenuation profiles were recorded at each station at 1 m intervals through the water column. Secchi depths were also measured.

Orthophosphate was analysed by the single solution method (Major et al., 1972); nitrate and nitrite after copper-cadmium reduction with a Technicon Autoanalyser II; and ammonia by the phenol-prusside method (Dal Pont et al., 1974). Total nitrogen and phosphorus were from sulphuric and perchloric acid digests respectively; followed by analysis for ammonia and phosphate by the methods given below. Chlorophyll 'a' was read after 24 hours in 90% acetone at 750, 664, 647 and 630 nm (Jeffrey and Humphrey, 1975).

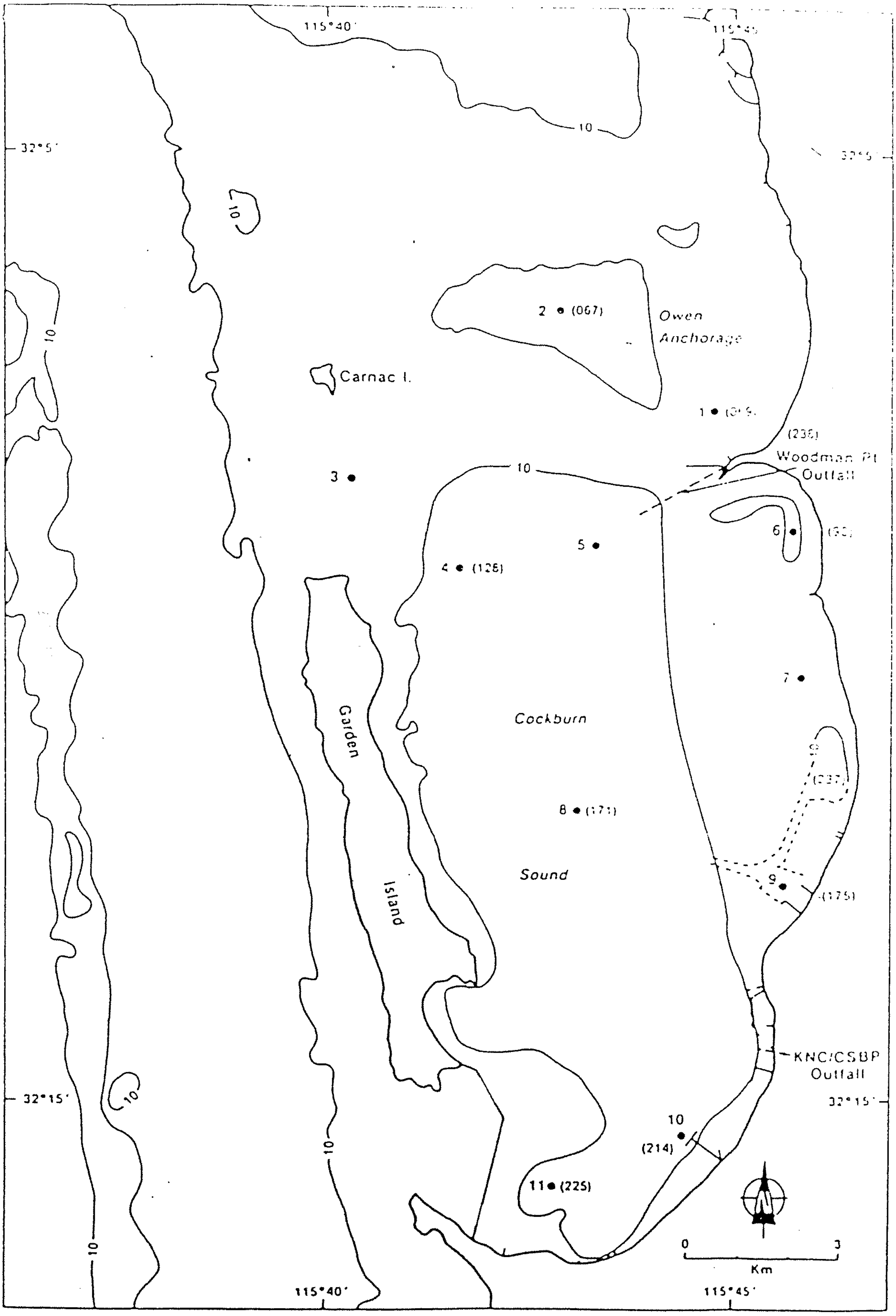


Figure 2. Location of sampling stations for the 1986|87 investigation in Cockburn Sound. The numbers in brackets are the original Cockburn Sound station numbers.

## 3.3 RESULTS

Mean phytoplankton concentrations (as chlorophyll 'a') for the study period are compared with those for earlier studies (Figure 3). Results for the 1977/78, 1979/80 and 1980/81 studies were calculated for a set of eight stations similar to those used during the 1982/83, 1984/85 and 1986/87 studies, over similar summer periods (Anonymous, 1979).

Mean chlorophyll 'a' for the 1986/87 summer was slightly higher than the 1984/85 value, which in turn was slightly higher than the 1982/83 value, but all three values were significantly less than mean values for the three earlier periods ($p < 0.05$; t test). This indicated that phytoplankton levels in the Sound have altered little since the improvement first noted in the 1982/83 study (Chiffings and McComb, 1983).

A corresponding comparison of light attenuation data for the six summer periods is presented (Figure 4). The data indicate that water clarity has also not altered significantly since the marked improvement observed in the 1982/83 summer.

Average nutrient concentrations, chlorophyll 'a' concentrations and attenuation coefficients are shown for three sites (Table 2) during similar summer periods in 1977/78, 1982/83, 1984/85 and 1986/87. The 1977/78 data are for Cockburn Sound sites 238, 237 and 214 (see Figure 2); these are sites of the 1976-79 study for which suitable data were collected at weekly intervals, and which closely correspond to sites 1, 7 and 10 of the 1982/83, 1984/85 and 1986/87 studies (Chiffings and McComb, 1983).

Chlorophyll 'a' levels and attenuation coefficients have changed little since the 1982/83 study, and chlorophyll 'a' values still represent a considerable improvement over conditions of 1976-79 (Table 2). This was also apparent for inorganic nitrogen concentrations at all sites, which presumably reflects the sustained period of lower nitrogen loading to the Sound. In contrast, orthophosphate ($PO_4$-P) concentrations have continued to decline since 1977/78. The observed declines at all sites can be attributed to a combination of factors; CSBP ceased discharging gypsum slurry into the Sound in 1980, the CSBP phosphoric acid plant has been shut down for the 18 months prior to the study, and the diversion of phosphate-rich WPTP effluent from the Sound. The inorganic N:P ratios were 17.2, 11.1 and 8.4 for sites, 1, 7 and 10 respectively, and were 11-16 times greater than those measured in 1977/78. Weekly fluctuations in N:P ratios were considerable as indicated by the large standard deviations in Table 2; at sites 1 and 7 the standard deviation exceeded the mean value.

An increase in organic phosphorus was recorded at site 10 while the other sites remain constant (bearing in mind an error in detection of $\pm$ 10 $\mu g\ l^{-1}$ at these levels). The 50% decrease at site 1 between 1982-83 and 1984-85 was presumably due to the diversion of the WPTP outfall. In contrast, decreases in organic nitrogen levels at all three sites were recorded during this study. The increased organic nitrogen up to 1984-85 followed by a decrease over this study cannot be accounted for by phytoplankton. The organic nitrogen is presumably not in a form readily available for phytoplankton growth, since it would otherwise be quickly taken up in this nitrogen-limited system. Mean particulate nitrogen for Cockburn Sound was 49 $\pm$ 5 $\mu g\ l^{-1}$, while particulate phosphorus was 5 $\pm$ 1 $\mu g\ l^{-1}$, thus the majority of the organic nitrogen would appear to be dissolved. It should be emphasised that interpretations of trends in organic nitrogen concentrations be made with caution since data become unreliable at these low levels.

Similar trends in physico-chemical parameters to those described above for sites 1, 7 and 10 were found for the remaining eight sites of the study, the results of which are presented in Appendix 1. These data do not, however, include results for 1977/78, since weekly sampling for the appropriate summer period was only carried out at sites 1, 7 and 10 (Chiffings, 1979).

No correlation was found between average weekly total chlorophyll 'a' in the Sound and average weekly nitrogen load. As noted in the 82/83 and 84/85 studies, it is possible that this was due to the lack of sustained periods of uniform discharge. Alternatively, phytoplankton populations may well respond to short-term (less than one day) pulses of high nitrogen concentrations, but this could not be investigated with the available data.

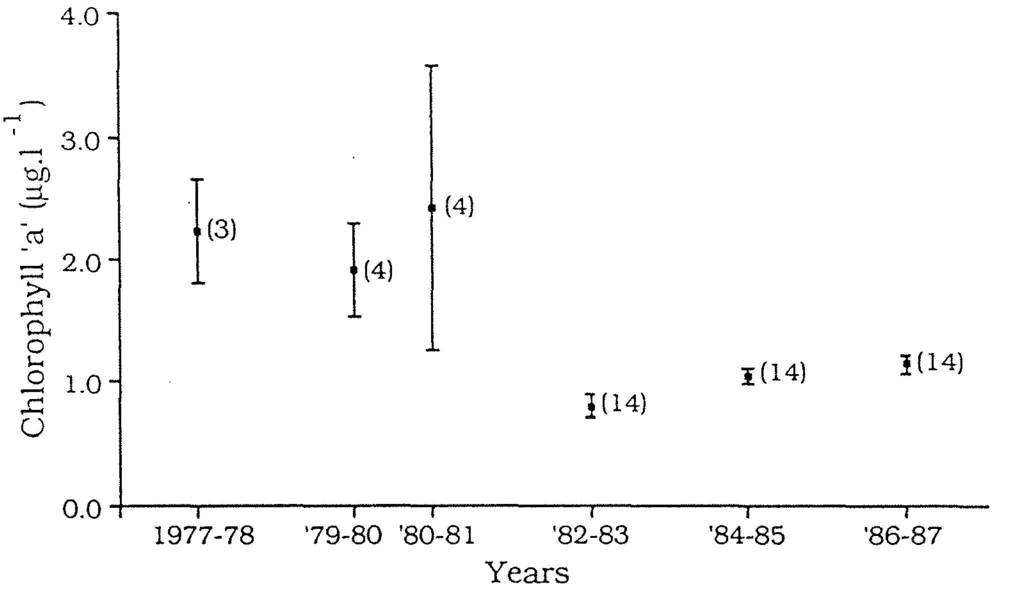


Figure 3 Mean chlorophyll 'a' concentrations for cruises made over summer periods in Cockburn Sound. Standard error bars are shown, and the numbers in brackets represent the number of cruises in the 'sample'. The 1977-78 sample is for 2 cruises in the 1977-78 summer and 1 cruise in November 1978. All other samples are for cruises during a single summer period.

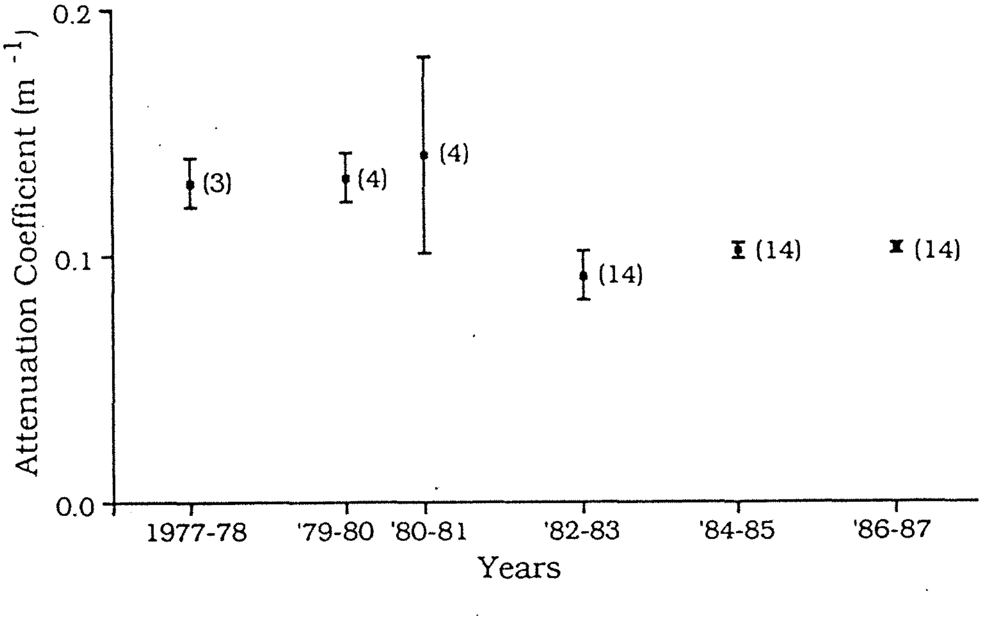


Figure 4 Mean light attenuation coefficients for cruises made over summer periods in Cockburn Sound. Details as for Figure 3.

Table 2. Comparison of three individual stations during Cockburn Sound studies 1976-79, 1982-83, 1984-85 and 1986-87.

X values are for 14 week summer periods. 1977-78 data from Chiffings (1979), 1982-83 data from Chiffings and McComb (1983), 1984-85 data from Hillman (1986) and 1986-87 data from present study.

| Water quality parameter | Site 10 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1977-78 | | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 105 | (45) | 56 | (14) | 15 | (9) | 9 | (4) |
| Organic phosphorus | 22 | (20) | 29 | (18) | 25 | (11) | 38 | (50) |
| Total phosphorus | 119 | (57) | 86 | (15) | 40 | (16) | 47 | (52) |
| Ammonia-nitrogen | 31 | (30) | 16 | (16) | 16 | (7) | 21 | (10) |
| Nitrate-nitrogen | 7 | (5) | 7 | (3) | 6 | (4) | 4 | (2) |
| Organic nitrogen | 142 | (47) | 320 | (103) | 476 | (116) | 321 | (164) |
| Total nitrogen | 173 | (61) | 339 | (96) | 497 | (119) | 346 | (162) |
| Chlorophyll 'a' | 5.2 | (3.5) | 1.2 | (0.8) | 1.9 | (0.8) | 1.4 | (0.8) |
| Inorganic N:P atomic ratio | 0.8 | (0.5) | 0.7 | (9.4) | 3.5* | (1.3) | 8.4 | (6.0) |
| Attenuation coefficient | 0.14 | (0.03) | 0.09 | (0.01) | 0.11 | (0.02) | 0.10 | (0.02) |

| Water quality parameter | Site 7 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1977-78 | | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 72 | (19) | 66 | (22) | 12 | (6) | 6 | (5) |
| Organic phosphorus | 25 | (18) | 33 | (18) | 26 | (10) | 32 | (36) |
| Total phosphorus | 96 | (26) | 99 | (31) | 37 | (11) | 38 | (38) |
| Ammonia-nitrogen | 12 | (11) | 14 | (12) | 9 | (8) | 9 | (6) |
| Nitrate-nitrogen | 4 | (3) | 7 | (5) | 4 | (3) | 3 | (3) |
| Organic nitrogen | 210 | (79) | 409 | (213) | 504 | (178) | 297 | (144) |
| Total nitrogen | 208 | (80) | 429 | (217) | 517 | (175) | 310 | (142) |
| Chlorophyll 'a' | 4.4 | (2.6) | 0.9 | (0.6) | 1.3 | (0.5) | 1.3 | (0.8) |
| Inorganic N:P atomic ratio | 0.7 | (0.9) | 1.3 | (1.0) | 2.7* | (2.0) | 11.1 | (11.4) |
| Attenuation coefficient | 0.16 | (0.02) | 0.11 | (0.02) | 0.11 | (0.02) | 0.12 | (0.02) |

| Water quality parameter | Site 1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1977-78 | | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 36 | (7) | 39 | (15) | 8 | (5) | 5 | (4) |
| Organic phosphorus | 22 | (12) | 45 | (20) | 22 | (8) | 29 | (41) |
| Total phosphorus | 74 | (57) | 73 | (31) | 30 | (9) | 34 | (42) |
| Ammonia-nitrogen | 13 | (6) | 14 | (10) | 13 | (10) | 13 | (10) |
| Nitrate-nitrogen | 3 | (2) | 5 | (3) | 4 | (2) | 3 | (1) |
| Organic nitrogen | 150 | (67) | 414 | (159) | 478 | (143) | 259 | (104) |
| Total nitrogen | 172 | (56) | 432 | (164) | 495 | (144) | 275 | (103) |
| Chlorophyll 'a' | 3.2 | (2.2) | 0.6 | (0.2) | 0.6 | (0.4) | 0.4 | (0.3) |
| Inorganic N:P atomic ratio | 1.1 | (0.6) | 1.0 | (0.7) | 6.9* | (6.7) | 17.2 | (17.4) |
| Attenuation coefficient | 0.16 | (0.03) | 0.13 | (0.06) | 0.11 | (0.02) | 0.08 | (0.02) |

* N:P ratios for the 1984/85 study were reported as weight ratios in Hillman (1986), rather than atomic ratios as in 1977-78, 1982-83 and 1986-87 studies. Weight ratios may be converted to atomic ratios by multiplying by a factor of 2.214.

## 3.4 DISCUSSION

Comparisons of the 1982/83, 1984/85 and 1986/87 results with those of the 1976-79 study suggest that chlorophyll 'a' levels and turbidity levels in Cockburn Sound are responding to decreased nitrogen loading. Since the marked improvement noted in the 1982/83 study chlorophyll 'a' levels have increased slightly. This apparent slight increase might be attributed in part to increased nitrogen loading from the KNC/CSBP outfall, as suggested by the data for site 9 (see Appendix 1) - the site most influenced by the outfall. There are, however, insufficient data about other nitrogen sources to quantify any relationship, and the unusually calm conditions in the 1986/87 summer (and therefore poorer nutrient dispersal) may also have been partly responsible.

It might be noted in passing that the surveys dealt with in this report concentrated on 14-week periods in summer. However, seasonal changes may exceed those measured during these periods; for example, mean chlorophyll data collected on a monthly basis between May 1985 and November 1986 show that chlorophyll 'a' levels were higher during the winter and spring months than in summer (K. Hillman, unpublished data). It would be informative to obtain a more complete seasonal data set for comparison with the information in the original Cockburn Sound Study.

The total nitrogen load from KNC over the study period increased by 17% from 1982/83 to 1984/85, and then decreased by 22% to date. Fluctuations in the daily load, however, remain unchanged. In retrospect the original expectation of a stabilized output of around 100 kg/d (Chiffings and McComb, 1983) was unrealistically low, with 250 kg/d now viewed as the achievable target. This has still to be attained. The data indicates that the decrease in nitrogen load from KNC has been offset to some extent by a corresponding increase in nitrogen loading from CSBP: the total nitrogen load from CSBP increased by 28-103% from 1984/85 to 1986/87. On the basis of the data, the total nitrogen load from the KNC/CSBP outfall has increased by 73% from 1982/83 to 1984/85, and by 16% from 1984/85 to 1986/87. The accuracy of these figures is in some doubt, however, because of CSBP's lesser confidence in the accuracy of measured "peak" loads than "normal" loads and in the true apportioning of CSBP and KNC's contribution to the outfall, and because the 1982/83 data do not include CSBP's contribution. Comparisons with the 1977 data are also of limited use since Murphy's (1979) data may not be representative because the survey was brief: discussions with CSBP personnel indicate that CSBP has nearly always contributed about half of the total nitrogen load in the KNC/CSBP outfall.

Inorganic N:P ratios were considerably higher in this study than in 1984/85, which was due to lower recorded orthophosphate levels, since inorganic nitrogen levels have remained similar. The decrease in orthophosphate levels can be attributed to CSBP's cessation of gypsum slurry discharge into the Sound, the shut-down of CSBP's phosphoric acid plant (in favour of using imported phosphoric acid), and the diversion of phosphate-rich WPTP effluent from the Sound. Since N:P ratios less than 5:1 indicate possible nitrogen limitation, and greater than 10:1 possible phosphorus limitation, it could be inferred that phosphorus rather than nitrogen is the limiting nutrient in the Sound. However, the considerable weekly fluctuations in N:P ratios make the true situation more complex. At present the Sound appears to be at a point where phytoplankton growth may be nitrogen-limited one week and phosphorus limited the next. Thus industrial inputs of nitrogen or phosphorus may be controlling phytoplankton levels at different times.

Overall, the water quality in Cockburn Sound has declined slightly since the significant improvement documented in 1982/83 study, but remains a considerable improvement over conditions documented in the 1976-79 study. Nitrogen loading into the Sound has also increased since the 1982/83 study, but the phosphorus loading has significantly decreased. Nevertheless, it is useful to note that despite the significant fall on phosphate concentrations, chlorophyll concentrations have remained essentially the same (or even increased slightly), so that phosphate concentrations are still not so low that phytoplankton growth is limited on average by this element. It will be particularly important to monitor N:P ratios in the future, since management practices will depend on whether the ecosystem becomes phosphorus- or nitrogen-limited. At present, the ecosystem appears to have reached a point where weekly variations in inorganic nitrogen and phosphorus concentrations determine which element is limiting.

## 4. CONCLUSIONS AND RECOMMENDATIONS

1. The inorganic nitrogen load entering the Sound from the KNC/CSBP and WPTP outfalls during this study was almost a quarter of that measured during the 1976-79 study, but was twice that measured in the 1982/83 study. However the data from 1982/83 lack CSBP's contribution, therefore the actual load in 1982/83 was probably higher.

2. Water quality (in terms of phytoplankton levels and light penetration) has declined slightly since the improvement first noted in the 1982/83 study, but remains a marked improvement over conditions during the 1976-79 study.

3. The nitrogen output from KNC has continued to decline but has yet to achieve a stable output of 250 kg/day. CSBP's nitrogen output has risen slightly since 1984/85. A reduction in CSBP's nitrogen output and further reductions in KNC's nitrogen output and CSBP's phosphorus output should be encouraged.

4. Ratios of N:P in the water, as inorganic forms readily available for phytoplankton growth, indicate that nitrogen and phosphorus are alternating as the limiting nutrient for phytoplankton growth.

5. N:P ratios have increased markedly since the 1984/85 study, which appears to be due to decreased phosphorus loading into the Sound. If the present rate of change is maintained, phosphorus may become the limiting nutrient for phytoplankton growth within two years.

6. It would be beneficial if KNC and CSBP could coordinate their sampling procedures and overcome any sampling difficulties.

7. A further investigation into nutrient loads, nutrient concentrations and phytoplankton growth should be carried out during the 1988/89 summer. It will be particularly important to check on N:P ratios. It will also be useful to carry out independent checks on the nutrient concentrations in KNC and CSBP effluents at the same time, for increased confidence in nutrient load data.

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APPENDIX 1

Reference Section 3.3

**Supplementary Water Quality Data**

Mean nutrient levels, chlorophyll levels and attenuation coefficients during Cockburn Sound Studies 1982-83, 1984-85 and 1986-87 for sites 2-6 inclusive, 8, 9 and 11 (see Table 2 for sites 1, 7 and 10).

| Water Quality Parameter | Site 2 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 16 | (6) | 5 | (2) | 4 | (3) |
| Organic phosphorus | 22 | (8) | 20 | (7) | 30 | (44) |
| Total phosphorus | 38 | (12) | 24 | (6) | 33 | (46) |
| Ammonia-nitrogen | 8 | (6) | 7 | (5) | 11 | (6) |
| Nitrate-nitrogen | 5 | (5) | 3 | (1) | 2 | (1) |
| Organic nitrogen | 296 | (101) | 446 | (118) | 225 | (98) |
| Total nitrogen | 309 | (98) | 455 | (119) | 238 | (99) |
| Chlorophyll 'a' | 0.3 | (0.5) | 0.5 | (0.2) | 0.3 | (0.2) |
| Inorganic N:P atomic ratio | 2.1 | (1.6) | 5.7 | (6.0) | 15.0 | (15.1) |
| Attenuation coefficient | 0.06 | (0.01) | 0.09 | (0.02) | 0.09 | (0.01) |

| Water Quality Parameter | Site 3 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 12 | (7) | 5 | (1) | 4 | (3) |
| Organic phosphorus | 25 | (9) | 18 | (8) | 27 | (42) |
| Total phosphorus | 36 | (14) | 23 | (8) | 31 | (43) |
| Ammonia-nitrogen | 10 | (16) | 11 | (8) | 9 | (5) |
| Nitrate-nitrogen | 6 | (5) | 4 | (2) | 4 | (2) |
| Organic nitrogen | 291 | (94) | 469 | (122) | 274 | (167) |
| Total nitrogen | 308 | (94) | 484 | (122) | 282 | (161) |
| Chlorophyll 'a' | 0.2 | (0.3) | 0.4 | (0.2) | 0.3 | (0.2) |
| Inorganic N:P atomic ratio | 3.6 | (2.6) | 7.1 | (3.3) | 16.8 | (14.7) |
| Attenuation coefficient | .06 | (.01) | 0.09 | (0.02) | 0.09 | (0.01) |

| Water Quality Parameter | Site 4 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 23 | (7) | 7 | (3) | 5 | (3) |
| Organic phosphorus | 28 | (10) | 21 | (10) | 32 | (43) |
| Total phosphorus | 52 | (13) | 28 | (11) | 36 | (45) |
| Ammonia-nitrogen | 9 | (6) | 10 | (7) | 12 | (9) |
| Nitrate-nitrogen | 7 | (7) | 3 | (2) | 3 | (2) |
| Organic nitrogen | 314 | (101) | 443 | (112) | 277 | (174) |
| Total nitrogen | 330 | (103) | 455 | (115) | 292 | (172) |
| Chlorophyll 'a' | 0.4 | (0.3) | 0.6 | (0.2) | 0.6 | (0.2) |
| Inorganic N:P atomic ratio | 1.6 | (0.7) | 4.6 | (4.0) | 14.7 | (12.7) |
| Attenuation coefficient | 0.06 | (0.01) | 0.09 | (0.02) | 0.09 | (0.01) |

| Water Quality Parameter | Site 5 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 32 | (12) | 7 | (3) | 5 | (4) |
| Organic phosphorus | 29 | (10) | 23 | (10) | 36 | (49) |
| Total phosphorus | 61 | (17) | 29 | (9) | 39 | (50) |
| Ammonia-nitrogen | 15 | (10) | 11 | (6) | 12 | (7) |
| Nitrate-nitrogen | 5 | (4) | 3 | (1) | 3 | (2) |
| Organic nitrogen | 360 | (142) | 485 | (89) | 289 | (114) |
| Total nitrogen | 380 | (145) | 499 | (90) | 304 | (113) |
| Chlorophyll 'a' | 0.6 | (0.5) | 0.8 | (0.3) | 0.7 | (0.3) |
| Inorganic N:P atomic ratio | 1.6 | (1.4) | 5.7 | (4.6) | 12.9 | (11.9) |
| Attenuation coefficient | 0.08 | (0.02) | 0.09 | (0.02) | 0.10 | (0.01) |

| Water Quality Parameter | Site 6 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 52 | (18) | 9 | (5) | 5 | (4) |
| Organic phosphorus | 37 | (19) | 31 | (15) | 34 | (38) |
| Total phosphorus | 89 | (30) | 39 | (15) | 39 | (40) |
| Ammonia-nitrogen | 19 | (25) | 7 | (3) | 12 | (7) |
| Nitrate-nitrogen | 8 | (7) | 5 | (3) | 6 | (6) |
| Organic nitrogen | 396 | (180) | 524 | (137) | 284 | (149) |
| Total nitrogen | 424 | (173) | 536 | (139) | 302 | (149) |
| Chlorophyll 'a' | 1.1 | (0.9) | 1.6 | (0.8) | 1.4 | (0.6) |
| Inorganic N:P atomic ratio | 1.4 | (1.9) | 4.2 | (2.7) | 15.2 | (12.9) |
| Attenuation coefficient | 0.08 | (0.02) | 0.13 | (0.04) | 0.11 | (0.01) |

| Water Quality Parameter | Site 8 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 34 | (7) | 9 | (4) | 4 | (3) |
| Organic phosphorus | 27 | (8) | 24 | (10) | 36 | (52) |
| Total phosphorus | 60 | (10) | 34 | (11) | 40 | (52) |
| Ammonia-nitrogen | 9 | (5) | 15 | (13) | 13 | (12) |
| Nitrate-nitrogen | 5 | (6) | 4 | (4) | 2 | (1) |
| Organic nitrogen | 286 | (126) | 499 | (153) | 331 | (173) |
| Total nitrogen | 300 | (122) | 518 | (161) | 346 | (171) |
| Chlorophyll 'a' | 0.4 | (0.3) | 1.0 | (0.4) | 0.8 | (0.4) |
| Inorganic N:P atomic ratio | 1.0 | (0.6) | 4.6 | (4.0) | 12.7 | (11.7) |
| Attenuation coefficient | 0.07 | (0.01) | 0.09 | (0.01) | 0.10 | (0.02) |

| Water Quality Parameter | Site 9 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 75 | (18) | 17 | (11) | 9 | (8) |
| Organic phosphorus | 32 | (7) | 26 | (10) | 41 | (51) |
| Total phosphorus | 106 | (21) | 43 | (13) | 50 | (52) |
| Ammonia-nitrogen | 26 | (15) | 27 | (27) | 31 | (18) |
| Nitrate-nitrogen | 13 | (9) | 12 | (15) | 13 | (12) |
| Organic nitrogen | 453 | (213) | 473 | (108) | 323 | (143) |
| Total nitrogen | 492 | (213) | 512 | (120) | 367 | (148) |
| Chlorophyll 'a' | 1.0 | (0.8) | 1.5 | (0.7) | 1.7 | (1.1) |
| Inorganic N:P atomic ratio | 1.2 | (0.7) | 6.0 | (6.4) | 31.7 | (45.2) |
| Attenuation coefficient | 0.10 | (0.03) | 0.11 | (0.02) | 0.12 | (0.01) |

| Water Quality Parameter | Site 11 | | | | | |
|---|---|---|---|---|---|---|
| | 1982-83 | | 1984-85 | | 1986-87 | |
| | X | (SD) | X | (SD) | X | (SD) |
| Orthophosphate phosphorus | 54 | (14) | 13 | (8) | 6 | (4) |
| Organic phosphorus | 22 | (10) | 23 | (12) | 46 | (83) |
| Total phosphorus | 76 | (13) | 36 | (13) | 52 | (86) |
| Ammonia-nitrogen | 13 | (11) | 10 | (6) | 15 | (10) |
| Nitrate-nitrogen | 6 | (4) | 5 | (3) | 4 | (3) |
| Organic nitrogen | 261 | (86) | 487 | (103) | 327 | (101) |
| Total nitrogen | 279 | (86) | 502 | (107) | 345 | (98) |
| Chlorophyll 'a' | 1.1 | (0.6) | 1.5 | (0.8) | 1.3 | (0.7) |
| Inorganic N:P atomic ratio | 0.7 | (0.4) | 2.9 | (1.5) | 12.3 | (13.2) |
| Attenuation coefficient | 0.09 | (0.02) | 0.10 | (0.02) | 0.10 | (0.01) |