SALINE BASELINE WATER QUALITY SURVEY OF THE KAIPARA HARBOUR

REVIEW REPORT

SEPTEMBER 1991 - APRIL 1993

Auckland Regional Council

A.R.C. Environment Division
Technical Publication No. 42, July 1994.

ISSN 1172 - 6415

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1. INTRODUCTION

The Kaipara Harbour is the largest harbour in New Zealand and is therefore of regional and national significance. The boundary between the Auckland and Northland Regional Councils approximately bisects the harbour. Influences on water quality in the southern part of the Harbour are predominantly rural in nature although there are small pockets of urban/industrial development particularly in the Kaipara/Kumeu River Catchment. These influences include the townships of Kumeu, Huapai, Waimauku and Helensville.

This report presents the first twenty months of saline water quality data collected for the Kaipara Harbour from one site at Shelly Beach. The reporting format follows that established for the Manukau Harbour water quality surveys reported in various ARC technical publications.

The ARC undertakes monitoring programs into the resources of the Auckland Region as part of it's statutory responsibilities under Sections 30 and 35 of the Resource Management Act (1991).

The principal aims of Long Term Baseline saline water quality surveys are as follows:

1) Determine the temporal and spatial variability of selected water quality parameters at sites with different land-use influences through out the Region;

2) Provide a baseline of saline water quality information from which the presence, direction and magnitude of trends can be determined.

Subsidiary to these aims are:

1) Identification of the present and potential impacts of catchment development activities;

2) Collection of baseline data for calibration of short term surveys of similar areas;

3) Evaluation of improvement in water quality in response to pollution abatement activities;

4) Assessment of the effectiveness of landuse planning policies intended to protect water quality;

5) Ensure that existing environmental controls are adequate to avoid unacceptable adverse environmental impacts.

The twenty month sampling series reported herein began in September 1991 and concludes in April 1993 bringing the study in line with similar water quality studies of the Manukau Harbour and Waitemata Harbour and Hauraki Gulf.

Samples were taken at approximately monthly intervals.

2. SAMPLING SITES AND SURVEY DETAILS

The Shelly Beach site (figure 1) was seleced for a number of reasons, namely:

1) The site was likely to represent the "bulk" water quality of the Harbour due to it's separation from the influences of major freshwater inputs;

2) Convenient and accessible for sampling;

3) High level of public utilisation of the area.

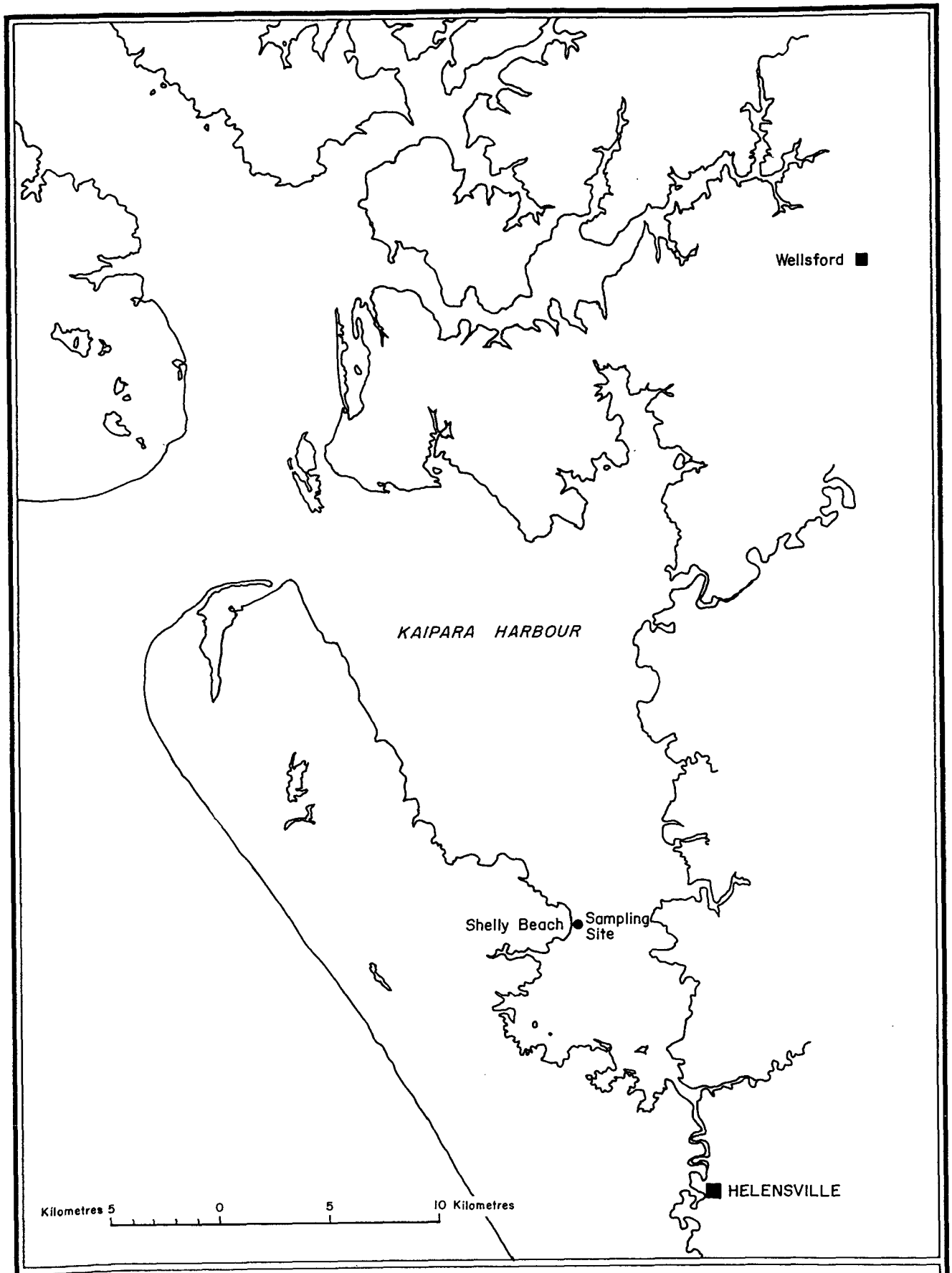


Figure I.

KAIPARA HARBOUR
SALINE BASELINE WATER QUALITY

Samples were taken on the outgoing tide approximately one hour after high water. This ensured that seawater mixed with freshwater from catchment inputs is sampled rather than open coastal water entering the Harbour on an incoming tide.

Specific times of sampling relative to high tide on each sampling occasion are presented in table 1 in Appendix 1.

Sampling is organised to coincide with sampling of saline baseline sites in the Manukau Harbour. Sampling at the Shelly Beach site was approximately 58 minutes after high tide on average however times ranged from 3 to 101 minutes. The wide range was predominantly due to errors resulting from daylight saving.

3. METHODS AND DATA QUALITY ASSURANCE

The sampling protocol is the same as that reported in various ARC Environment Technical Publications detailing saline baseline water quality monitoring for the Waitemata Harbour and Hauraki Gulf and Manukau Harbour.

Fifteen physical and chemical water quality parameters were measured on each sampling occasion. Of these three were measured in situ, namely:

1) Temperature;
2) Dissolved Oxygen;
3) Secchi Disc Depth;

The remaining eleven parameters were determined by laboratory analysis, namely:

1) Turbidity;
2) Non-filtrable Residue;
3) Presumptive Coliforms;
4) Faecal Coliforms;
5) Enterococci;
6) Ammonia;
7) Nitrate;
8) Nitrite;
9) Total Phosphorus;
10) Soluble Reactive Phosphorus
11) pH
12) Chloride

The techniques employed in laboratory analyses are detailed in the "Manual of methods for Water Analysis" ARA Corporate Services Laboratory (1989), which generally follow the "Standard Methods for the Examination of Water and Wastewater 16th Edition (1985) APHA AWWA WPCF".

Sampling was carried out at a number of depths on most occasions to check for stratification of the Harbour waters. Initially samples were taken at surface, one, two and five metres depth. After five months of sample collection a clear pattern of water quality emerged suggesting that a reduction to surface and five metres was approprate.

Subsurface samples were collected using a battery operated bilge pump and a weighted five metre long plastic hose. On several occasions during the sampling period subsurface samples could not be collected due to malfunction of this equipment.

Due to constraints on the availability of equipment chloride levels were measured so that salinity could be calculated. The number of records for secchi disc depth were also limited by the lack of equipment on several occasions.

4. STATISTICAL ANALYSES

Insufficient data is available to allow rigorous analysis for seasonal components or trends in water quality. Therefore analysis has been restricted to descriptions of water quality at the Shelly Beach site and comparisons with saline baseline data from other surveys.

Detailed water quality results for each parameter from surface and five metre samples are presented in tables 2-4 in Appendix 1. Plots of the raw data for selected parameters are contained in figures 2-7 in Appendix 2.

Water quality results are characteristically highly variable due to the wide variety of external factors influencing them therefore results were inspected for normality. Most of the parameters were found to be significantly non-normal, therefore the median has been used predominantly in this report as the measure of central tendency (typical value) as 50% of the data are above and below this value.

The variability of the data has been evaluated using the interquartile range divided by the median. This is considered to be the nonparametric equivalent of the coefficient of variance (Vant 1993).

5. RESULTS AND DISCUSSION

Vertical mixing tests confirmed that occasionally there was a measureable salinity difference between top and bottom waters. However on no occasion was the difference in salinity greater than two parts per thosand therefore the waters are described as fully mixed on all occasions.

The continued use of chloride determinations and subsequent calculation of salinty have allowed confidence in this data which has been absent from some of the other saline baseline surveys due to field and laboratory equipment problems.

Comparisons between the Kaipara site and those surveyed in the Manukau and Waitemata Harbours have been made. The raw data for these sites can be sourced from various ARC Environment Technical Publications.

5.1 Water Temperature

Water temperatures showed the expected pattern of seasonal fluctuation with the highest levels occurring in January- February and the lowest levels in June- July. Temperatures ranged from 12 to 24.8 degrees Celsius.

Comparisons between surface and bottom samples show that the maximum temperature differential was 0.6 degrees.

The median surface water temperature for the last twelve months of the survey period was 16.5 degrees Celsius. This value is very similar to those recorded for the Manukau Harbour sites and about one degree higher than found in the Waitemata Harbour.

5.2 Salinity

Salinity determinations were made by analysis of chloride levels in the laboratory and subsequent calculation.

As stated above, salinity differences between top and bottom waters were never greater than two parts per thousand (ppt) consequently the Harbour waters were considered fully mixed on all sampling occasions. However some clear differences between top and bottom were found and generally salinity was lower in the surface sample.

Salinities ranged from 25.6 to 35.7 ppt and as might be expected were generally lower during the winter months than in summer.

The median surface salinity for the last twelve months was 30 ppt. This is similar to all the Waitemata Harbour sites except Chelsea but noticably lower than the Manukau Harbour sites except Mangere Bridge and Weymouth.

5.3 Dissolved Oxygen Saturation

Where dissolved oxygen levels were recorded both top and bottom levels were generally the same. The largest difference (20%) was recorded in January 1993 when surface waters were considerably warmer than at the bottom.

Compared to Manukau Harbour saline baseline sites Shelly Beach was the most similar to Mangere Inlet and was about 10% lower than the other sites. More information is required before conclusions can be made about the causes or significance of these differences.

Dissolved oxygen levels showed a small degree of variability as shown by the inter-quartile range divided by the median (IQR/Median) of 6%.

5.4 Biochemical Oxygen Demand

In March 1993 the analytical laboratory advised the ARC Environment that they had reevaluated their limits of detection for biochemical oxygen demand (BOD) determinations. Their opinion was that the standard analytical method used was only only accurate to two parts per million (ppm) which subsequently became their limit of detection for BOD. The results of the surveys in February, March and April have been affected by this decision.

It is beyond the scope of this report to discuss the validity or otherwise of this assumption. However there are major implications in terms of current and future data analysis. Firstly comparisons between sites from other surveys based on historical data are questionable except where BOD values exceed two. Secondly future data analysis for temporal differences will be invalidated due to the appearance of a stepwise change in the data. One point in mitigation is that in saline waters BOD values less than two have little environmental significance.

All of the results recorded in this survey are two or less, therefore no further evaluation has been made.

5.5 Secchi Disc Depth

Of all the parameters measured in this survey Secchi Disc Depth was the one most affected by lack of equipment. On thirteen occasions during the sampling period no value was recorded. Therefore no further evaluation of this information can be made.

5.6 Turbidity

Turbidity levels were highly variable with an IQR/M of 70% for surface waters. The maximum value was 87 NTU and the minimum was 2.2 NTU. Bottom samples were at similar levels to those found at the surface.

The median surface turbidity value for the last twelve samples of the survey was 17 NTU. This is considerably higher than any of the sites surveyed in the Waitemata or Manukau Harbours during the same period.

The main influences on turbidity levels in the Kaipara are resuspension of sediments deposited on mudflats by the action of wind and tides and suspended materials in freshwater inputs.

5.7 Non-filtrable Residue

Non-filtrable Residue (NFR) levels, like turbidity, were highly variable with an IQR/M of 86%. Values ranged from 14 to 237 ppm with a median of 63.5 ppm. Bottom waters had generally higher levels of NFR where both top and bottom samples were available for comparison, however this did not occur on all sampling occasions.

The median NFR level at the Shelly Beach site over the last twelve months of the survey was approximately three times higher than any of the sites surveyed in the Waitemata Harbour saline baseline survey during the same period.

5.8 Presumptive Coliforms

As expected presumptive coliforms were one of the most variable parameters measured during the survey with an IQR/M value of 138%. Values were universially low and ranged from less than 2 to 79 MPN/100ml (MPN=Most Probable Number) and the median was 13. There were no obvious differences between top and bottom waters.

Comparisons between median values from other saline baseline sites for the last twelve months of the survey showed that the Kaipara site was considerably lower than all the Waitemata Harbour sites.

The ubiquitous nature of organisms detected by the presumptive coliform test within the terrestrial and aquatic environment makes linking high levels with sources extremely difficult. High levels do not necessarily indicate contamination by material of faecal origin, just that some source of organic matter has entered the waterway. Therefore elevated levels found occasionally may have come from general catchment runoff or resuspension of settled material by wind, wave or tidal action.

5.9 Faecal Coliforms

Faecal coliforms are the parameter most frequently considered by members of the public to represent compromised water quality in terms of use, particularly contact recreation and shellfish gathering. Studies have shown that faecal coliforms are found in faeces other than of mammalian origin and that the often assumed relationship between faecal coliform levels and the risk of contracting disease may not be valid. In light of these results recent ARC Environment surveys have utilised enterococci as a more reliable indicator of the presence of pathogens. A more detailed discussion can be found in ARC Environment and Planning Division Technical Publication 13 (1992). However for the purposes of comparisons between sites and determination of gross sources of contamination faecal coliforms are still seen as a usefull water quality tool.

Faecal coliform levels like pesumptive coliforms were highly variable with an IQR/M of 114%. Values ranged from the limits of detection (ie. less than two) to 79 MPN/100ml. The last four surface samples all had levels of less than two. Bottom samples generally had lower faecal coliform levels than found at the surface.

Comparison of median levels for the last twelve months of surveys show similar faecal coliform levels to most of the Waitemata and Manukau Harbour saline baseline sites. Exceptions were Mangere Inlet and Puketutu Island sites in the Manukau, which are influenced by the discharge from the Mangere Sewage Purification Works, and Henderson Creek in the Waitemata.

5.10 Enterococci

As stated in section 5.9 Enterococci have now been adopted by the ARC Environment as a more reliable bacterial indicator of the potential risk of contracting disease.

Enterococci levels were much lower than the other bacteriological parameters with so many results around the limits of detection that it forms the median value. The highest value recorded was found in bottom waters in October 1992, surface waters were not similarly elevated at the time.

The median for the last twelve months of samples from Shell Beach was considerably lower than all the Waitemata sites and all but three (Shag Point, Papakura Channel and Waiuku Channel) in the Manukau.

5.11 Ammonia

The value presented in this report as ammonia is a combination of unionised ammonia (NH_3) and the ammonium ion (NH_4^+). At normal saline water pH values the latter form predominates although it is the unionised ammonia which is the most toxic form to aquatic life. Several physico-chemical factors have been shown to influence the toxicity of ammonia, most notably temperature, salinity and pH (USEPA, 1989). There is little information currently available on the toxicity of ammonia to New Zealand marine organisms. Therefore regulatory agencies, such as the ARC Environment, rely on overseas criteria such as that promulgated by the USEPA.

At the typical values of salinity, pH and temperature found in this survey all ammonia concentrations were several orders of magnitude lower than toxic levels.

Ammonia levels generally were highly variable as shown by the IQR/M of 119%. Comparisons between top and bottom samples showed little difference. One extremely high value was recorded in March 1993 approximately ten times greater than the next highest value. The sample taken from the bottom was not similarly elevated therefore this value has been eliminated from subsequent evaluations.

Median ammonia levels, for the last twelve months of sampling, were similar to all Waitemata Harbour sites and Manukau Harbour sites except those influenced by the discharge from MSPW.

5.12 Nitrate

Nitrate levels were highly variable as shown by the IQR/M value of 110%. Values ranged from around the analytical limits of detection (<0.001 ppm) to 0.11 ppm.

Other saline baseline surveys have identified seasonal peaks in nitrate levels centred around mid-winter each year. Figure 5 shows that peaks also appear in the Shelly Beach data at around these times. Elevated nitrate levels at this time of the year can be explained by increased nitrogen in catchment runoff. ARC Environment Technical Publication 28 details the levels of nitrate present in runoff from a number of catchments in the Auckland Region, including the Kumeu River. The Kumeu site showed a clear seasonal pattern in nitrate in June, July and August each year.

Comparison between median values for the last twelve months of data from other saline baseline surveys shows lower levels at Shelly Beach than most Waitemata Harbour sites and all Manukau Harbour sites.

5.13 Nitrite

Nitrite is the intermediate step in the conversion of ammonia to nitrate. It is usually short lived in the aquatic environment and is therfore used as an indication of a source of nitrogenous waste near the sampling site.

As might be expected for well oxygenated saline waters nitrite levels were extremely low on all sampling occasions, seldom exceeding the analytical limits of detection (<0.001 ppm). Where bottom samples were taken they also appeared to be consistently low.

5.14 Total Phosphorus

Total phosphorus is a measure of all the phosphorus present in the sample and includes the soluble (bioavailable) fraction, that adsorbed onto sediment particles and present in the form of algae and other organic matter.

Total phosphorus levels were highly variable (IQR/M=70%) ranging from 0.03 to 0.16 ppm. Surface and bottom waters contained similar levels.

Comparisons with median values from other saline baseline sampling sites showed that Shelly Beach was approximately twice as high as any of the Waitemata Harbour sites and similar to the Manukau Harbour sites other than those affected by the discharge from MSPW (ie Shag Point, Puketutu and Mangere Inlet).

5.15 Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) is used by water managers as an important indicator of water quality as it is considered to be the bioavailable fraction of phosphorus present. It is frequently cited as the nutrient limiting algal d other aquatic plants in New Zealand. In saline waters monitoring for SRP is important in establishing the causes of phytoplankton blooms and other nuisance algal growths.

SRP results were highly variable (IQR/M=100%) ranging from the limits of detection (0.001ppm) to 0.03 ppm. Top and bottom waters generally contained similar levels of SRP.

Median SRP levels for the last twelve months of the survey period show that all the Waitemata and Manukau Harbour sites, with the exception of the Whau Creek, are approximately twice as high or more than Shelly Beach. Sites in the Manukau affected by the discharge from MSPW are more than an order of magnitude higher.

5.16 pH

As expected pH showed the least variability of an parameter monitored in the survey (IQR/M=1%). Top and bottom waters showed similar levels throughout the survey. The median value was identical to those recorded for the Waitemata Harbour during the same period.

6. SUMMARY AND CONCLUSIONS

The water quality from one site in the southern half of the Kaipara Harbour have been monitored monthly from September 1991 for a range of parameters. This report details results for a twenty month period up to April 1993 which corresponds to the period used for the Waitemata Harbour and Hauraki Gulf survey.

The aims of the program detailed in the introduction have been achieved as follows:

1) Data collected has been used to describe the saline water quality at the Shelly Beach site;

2) Comparison of median values from Manukau and Waitemata Harbour sites over the same period showed that Shelly Beach had:
   a) Similar levels for temperature, salinity, biochemical oxygen demand, faecal coliforms ammonia and pH;
   b) Lower levels for dissolved oxygen saturation, presumptive coliforms, enterococci, nitrate and soluble reactive phosphorus;
   c) Higher levels of turbidity, non-filtrable residue and total phosphorus.

3) Plots of raw data show clear indications of seasonal patterns for some parameters.

4) No attempts at trend analysis have been made due to the limited amount of data avaliable.

Overall the saline water quality of the Shelly Beach site would be described as extremely good. The only parameters showing some degree of compromise were suspended materials and total phosphorus.

The Kaipara Harbour is shallow with extensive areas of exposed mudflats at low tide leading to elevated levels of suspended materials due to wind, wave and tidal action. Catchment land use is predominantly rural which may explain phosphorus levels.

APPENDIX 1

Tables not appearing in the text

TABLE 1 Dates and Times of Sampling September 1991 - April 1992

Date	High Water Time NZST (hrs)	Sampling Time (hrs)	Time Differential (minutes)
9-Sep-91	1059	*	*
9-Oct-91	1215	1310	53
5-Nov-91	1034	1215	101
5-Dec-91	1055	1110	65
20-Jan-92	1146	1215	29
17-Feb-92	1041	1130	49
17-Mar-92	921	1010	52
16-Apr-92	948	1040	72
18-May-92	1133	1245	64
16-Jun-92	1116	1220	52
15-Jul-92	1059	1200	3
13-Aug-92	1038	1130	71
11-Sep-92	1012	1015	62
12-Oct-92	1149	1300	81
10-Nov-92	1123	1225	61
10-Dec-92	1149	1310	81
21-Jan-93	1044	1145	61
8-Feb-93	1229	*	*
24-Mar-93	1114	1220	66
20-Apr-93	938	1015	37
Median			61.5
Mean			58.9
IQR/Median			28.9

*** NOT RECORDED**

TABLE 2 Water Quality Results

Parameter	Temperature (deg C)		Salinity (ppt)		Dissolved Oxygen Saturation (%)		Biochemical Oxygen Demand (gO/m3)		pH	
	Surface	5 metres	Surface	5 metres	Surface	5 metres	Surface	5 metres	Surface	Five Metres
Date										
9-Sep-91	15.4	*	26	*	85	*	*	*	7.9	*
9-Oct-91	16	15.8	28.8	29.2	81	80	1	0.8	7.9	8.1
5-Nov-91	17.1	16.9	31.3	31.1	86	80	1.6	1.2	8.0	8.1
5-Dec-91	16.8	16.4	31.3	31.3	77	77	1.3	1	8.1	8.3
20-Jan-92	24.8	24.8	33.7	32.5	85	85	1.6	1.7	8.1	8.2
17-Feb-92	22.5	22.5	34.2	*	85	85	1.1	*	8.1	*
17-Mar-92	19	19	34.9	*	69	69	1	*	*	*
16-Apr-92	16.3	16.3	34.4	*	81	81	1	*	7.9	*
18-May-92	14.2	14.2	33.9	34	78	78	1.1	1	8.0	8.0
16-Jun-92	12.6	12.5	32	32.3	79	77	1.1	1	8.1	8.1
15-Jul-92	12.6	12.3	29.7	30.9	82	80	1.6	1.2	8.2	8.2
13-Aug-92	13.2	12.3	25.6	27.8	82	83	1.3	1	8.2	8.2
11-Sep-92	12	13.8	26.4	*	76	*	1.8	*	8.2	*
12-Oct-92	16.6	16.6	26.3	26.5	81	81	0.3	0.8	8.1	8.1
10-Nov-92	17.1	16	30	29.7	79	87	1.7	1.6	8.0	8.1
10-Dec-92	21	17.2	31.3	*	80	83	1.4	*	8.1	*
21-Jan-93	22.2	20.8	25	26.1	76	96	0.9	1	8.1	8.2
8-Feb-93	*	*	30	*	*	*	<2	*	8.1	*
24-Mar-93	22.2	22.2	35.7	34.7	77	84	2	<2	8.1	8.1
20-Apr-93	18	18	34.9	34.9	76	76	<2	*	8.1	8.1
Median	16.8	16.5	31.3	31.1	80.0	81.0	1.3	1.0	8.1	8.1
Mean	17.3	17.1	30.8	30.8	79.7	81.3	1.3	1.1	8.1	8.1
IQR/Median	31	25	18	11	6	7	46	20	1	1

*** NOT RECORDED**

TABLE 3 Water Quality Results

Parameter	Secchi Disc Depth (m)	Turbidity (NTU)		Non-filtrable Residue (g/m3)		Faecal Coliforms (MPN/100ml)		Presumptive Coliforms (MPN/100ml)		Enterococci (No./100ml)	
	Surface	Surface	Five Metres	Surface	Five Metres	Surface	Five Meters	Surface	Five Metres	Surface	Five Metres
Date											
9-Sep-91	0.6	20	*	17.6	*	11	*	22	*	2	*
9-Oct-91	*	28	45	79.2	93.6	8	5	13	13	0	0
5-Nov-91	*	38	26	142	144	13	<2	13	<2	0	0
5-Dec-91	*	17	18	41.2	42.4	2	<2	5	<2	0	0
20-Jan-92	*	44	41	21.3	22.4	79	8	79	11	15	5
17-Feb-92	*	20	*	91	*	5	*	5	*	0	*
17-Mar-92	0.4	18	*	65	*	9	*	14	*	0	*
16-Apr-92	0.4	22	*	66	*	2	*	6	*	2	*
18-May-92	0.3	33	42	91	110	8	5	17	23	<2	3
16-Jun-92	0.3	25	13	50	29	5	<2	49	46	0	3
15-Jul-92	0.8	6.5	5.2	14.5	14.2	49	33	79	33	17	17
13-Aug-92	*	17	24	65	92	49	13	49	23	5	3
11-Sep-92	*	2.2	*	62	*	13	*	23	*	5	*
12-Oct-92	*	37	23	106	74	2	2	2	2	2	86
10-Nov-92	*	87	81	237	226	5	9	5	9	3	3
10-Dec-92	*	*	*	118	*	13	*	13	*	8	*
21-Jan-93	*	17	21	48	120	<2	2	<2	2	0	3
8-Feb-93	*	6.8	*	16	*	<2	*	<2	*	2	*
24-Mar-93	*	16	*	50	*	<2	<2	2	<2	<2	2
20-Apr-93	0.1	5.9	7.3	17	30	<2	<2	<2	<2	<2	<2
Median	0.4	20	23.5	63.5	83	7	2	13	9	<2	3
Mean	0.4	24.2	28.9	69.9	83.1						
IQR/Median	50	70	104	86	100	114	288	138	156	250	67

*** NOT RECORDED**

TABLE 4 Water Quality Results

Parameter	Ammonia (gN/m3)		Nitrate (gN/m3)		Nitrite (gN/m3)		Total Phosphorus (gP/m3)		Soluble Reactive Phosphorus (gP/m3)	
	Surface	Five Metres	Surface	Five Metres	Surface	Five Metres	Surface	Five Metres	Surface	Five Metres
Date										
9-Sep-91	0.01	*	0.029	*	<.001	*	0.030	*	0.010	*
9-Oct-91	0.008	<.002	0.005	0.004	<.001	<.001	0.100	0.100	0.010	0.006
5-Nov-91	0.03	0.06	0.073	0.050	<.001	<.001	0.090	0.070	0.010	0.006
5-Dec-91	0.008	0.01	0.087	0.064	<.001	<.001	0.060	0.060	0.010	0.010
20-Jan-92	0.026	0.015	0.010	0.004	<.001	<.001	0.160	0.150	0.010	0.032
17-Feb-92	0.035	*	0.006	*	<.001	*	0.070	*	0.020	*
17-Mar-92	0.004	*	0.006	*	<.001	*	0.080	*	0.030	*
16-Apr-92	0.004	*	0.007	*	0.001	*	0.030	*	0.030	*
18-May-92	0.04	0.055	0.004	0.004	0.004	0.001	0.110	0.160	0.020	0.015
16-Jun-92	0.006	0.007	0.013	0.006	<.001	<.001	0.070	0.040	<.001	0.005
15-Jul-92	0.016	0.008	0.023	0.007	0.001	<.001	0.050	0.030	0.000	0.010
13-Aug-92	0.022	0.049	0.109	0.087	0.003	0.003	0.060	0.070	0.010	0.007
11-Sep-92	0.011	*	0.009	*	0.001	*	0.050	*	0.000	*
12-Oct-92	0.003	0.003	0.002	0.007	0.001	<.001	0.100	0.080	0.000	0.003
10-Nov-92	0.005	0.009	0.005	0.011	0.001	0.001	0.160	0.160	0.010	0.011
10-Dec-92	0.026	*	0.015	*	<.001	*	0.130	*	0.010	*
21-Jan-93	0.022	0.031	0.013	0.012	0.001	0.001	0.090	0.150	0.020	0.015
8-Feb-93	0.044	*	0.013	*	<.001	*	0.050	*	0.020	*
24-Mar-93	0.375**	<.005	0.006	0.003	0.002	0.002	0.120	0.150	0.020	0.011
20-Apr-93	0.021	0.015	0.010	0.010	<.001	<.001	0.040	0.040	0.010	0.011
Median	0.016	0.015	0.010	0.007	0.001	0.001	0.075	0.080	0.010	0.010
Mean	0.018	0.024	0.022	0.021	0.002	0.002	0.083	0.097	0.013	0.011
IQR/Median	119	210	110	114	100	100	70	113	100	50

*** NOT RECORDED**
**** VALUE REMOVED FROM DATA SET**

APPENDIX 2

Figures not appearing in the text

Figure 2.

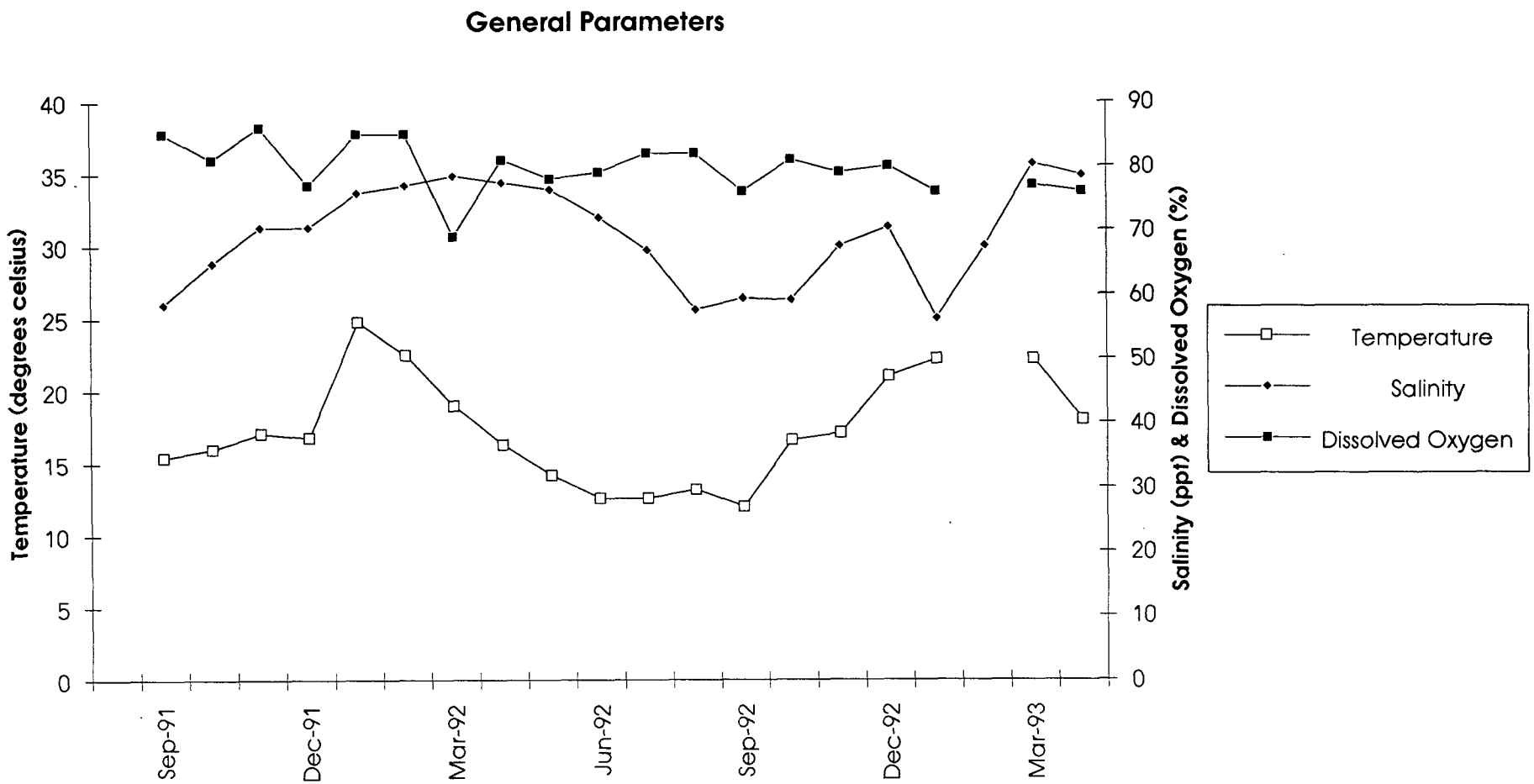

General Parameters
Temperature (degrees celsius)
Salinity (ppt) & Dissolved Oxygen (%)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
Sep-91
Dec-91
Mar-92
Jun-92
Sep-92
Dec-92
Mar-93
Temperature
Salinity
Dissolved Oxygen

Figure 3.

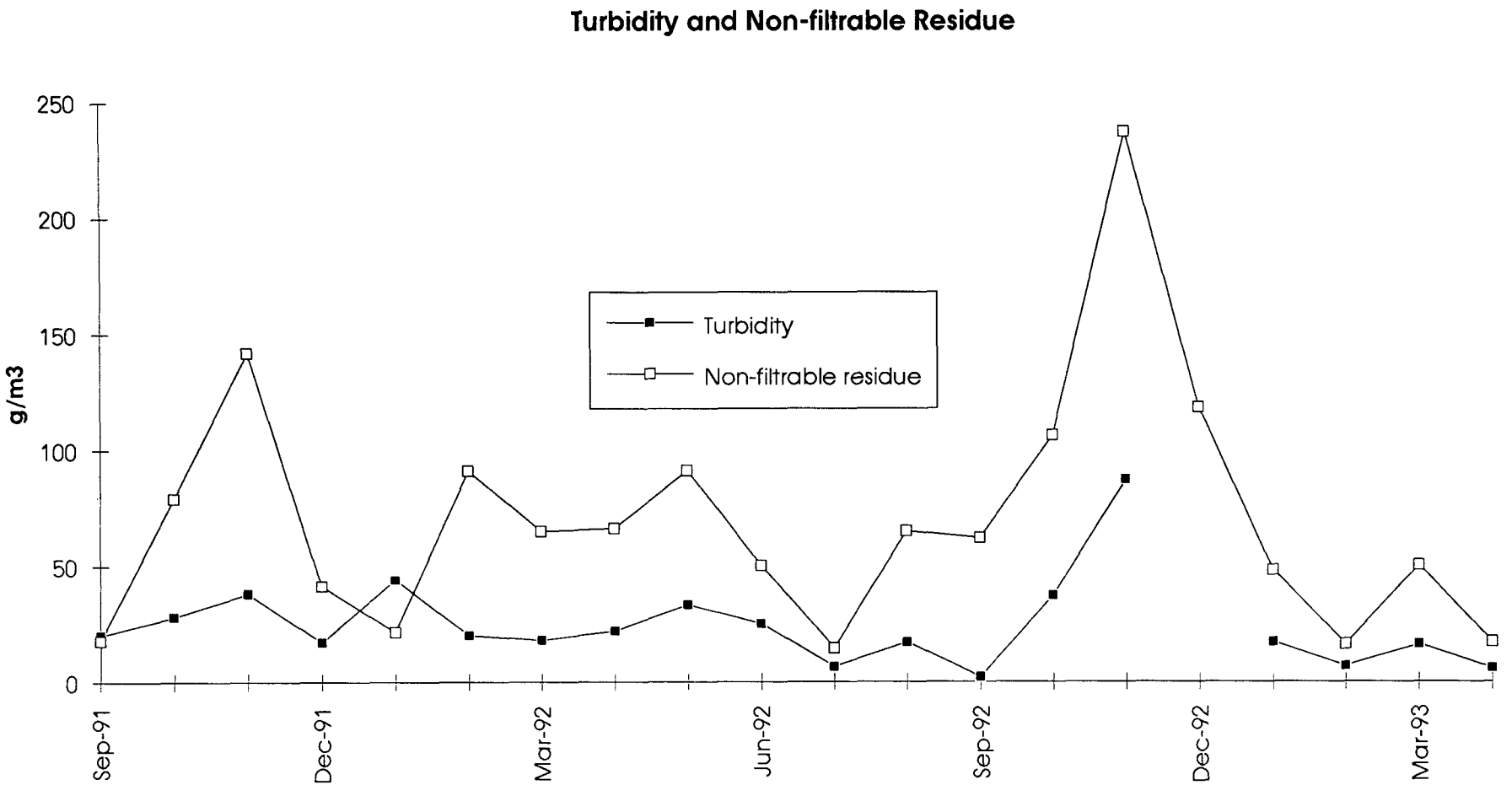

Turbidity and Non-filtrable Residue
250
200
150
100
50
0
g/m3
Turbidity
Non-filtrable residue
Sep-91
Dec-91
Mar-92
Jun-92
Sep-92
Dec-92
Mar-93

Figure 4.

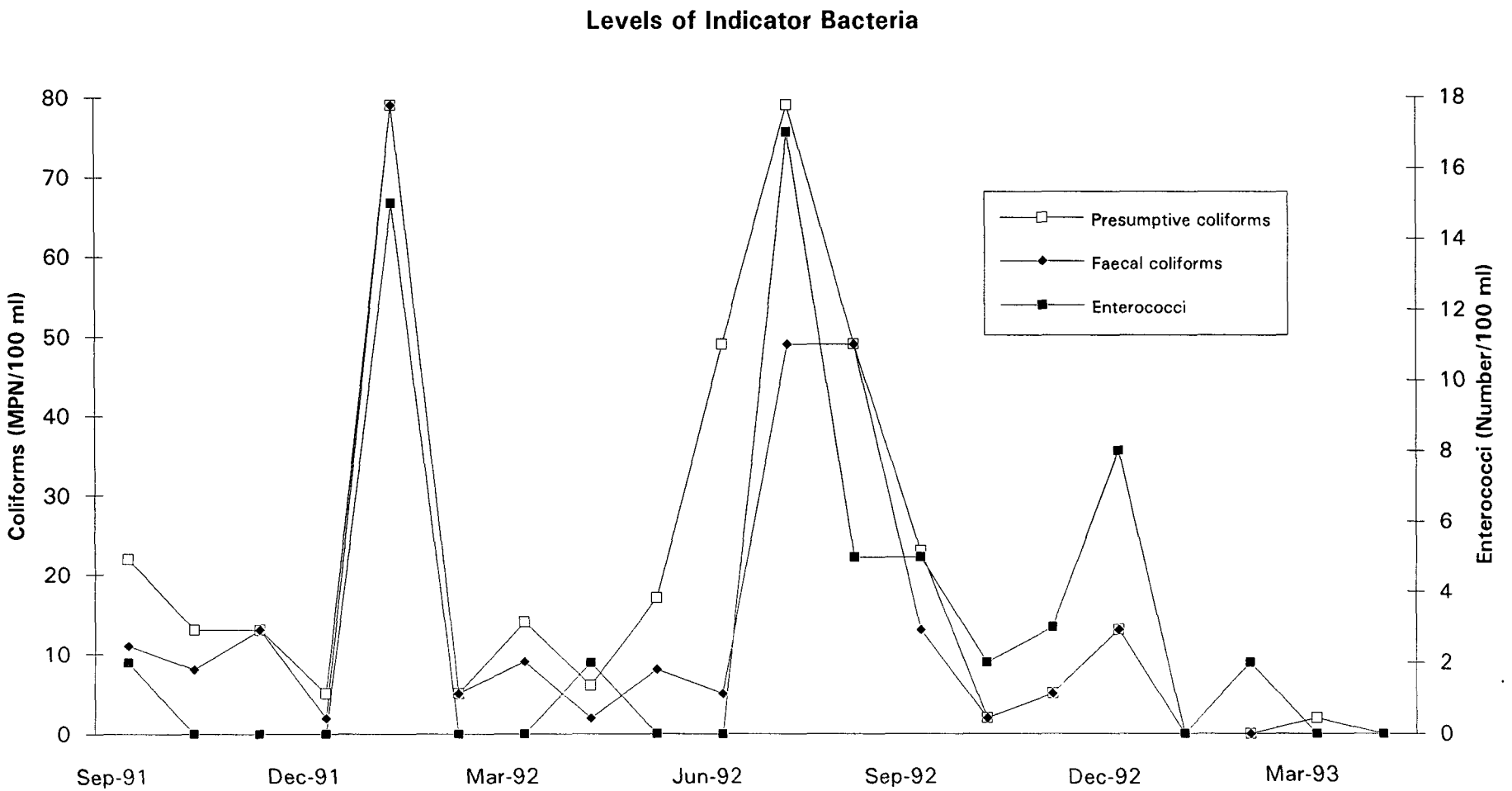

Levels of Indicator Bacteria
Coliforms (MPN/100 ml)
Enterococci (Number/100 ml)
Presumptive coliforms
Faecal coliforms
Enterococci
80
70
60
50
40
30
20
10
0
18
16
14
12
10
8
6
4
2
0
Sep-91
Dec-91
Mar-92
Jun-92
Sep-92
Dec-92
Mar-93

Figure 5.

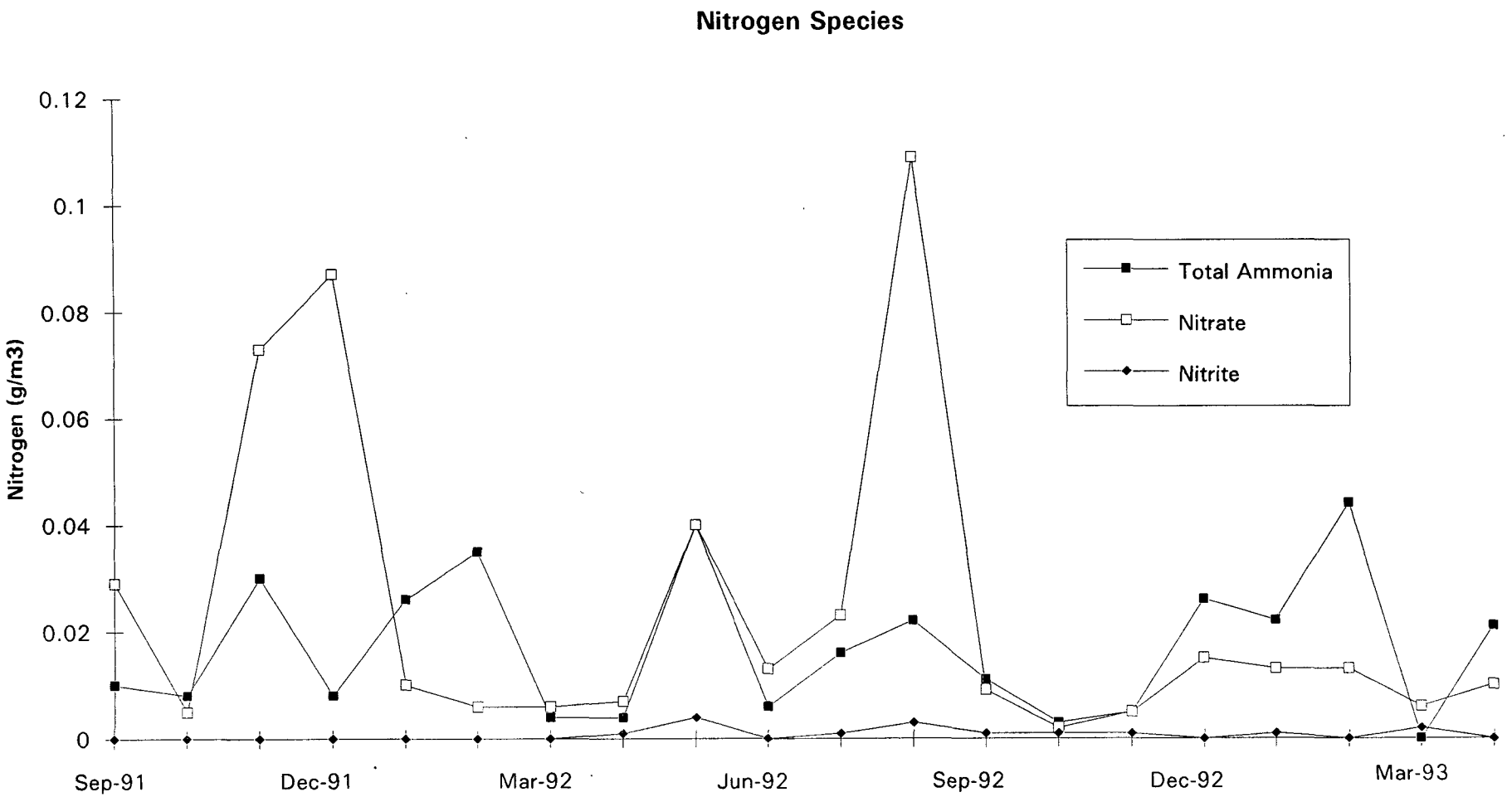
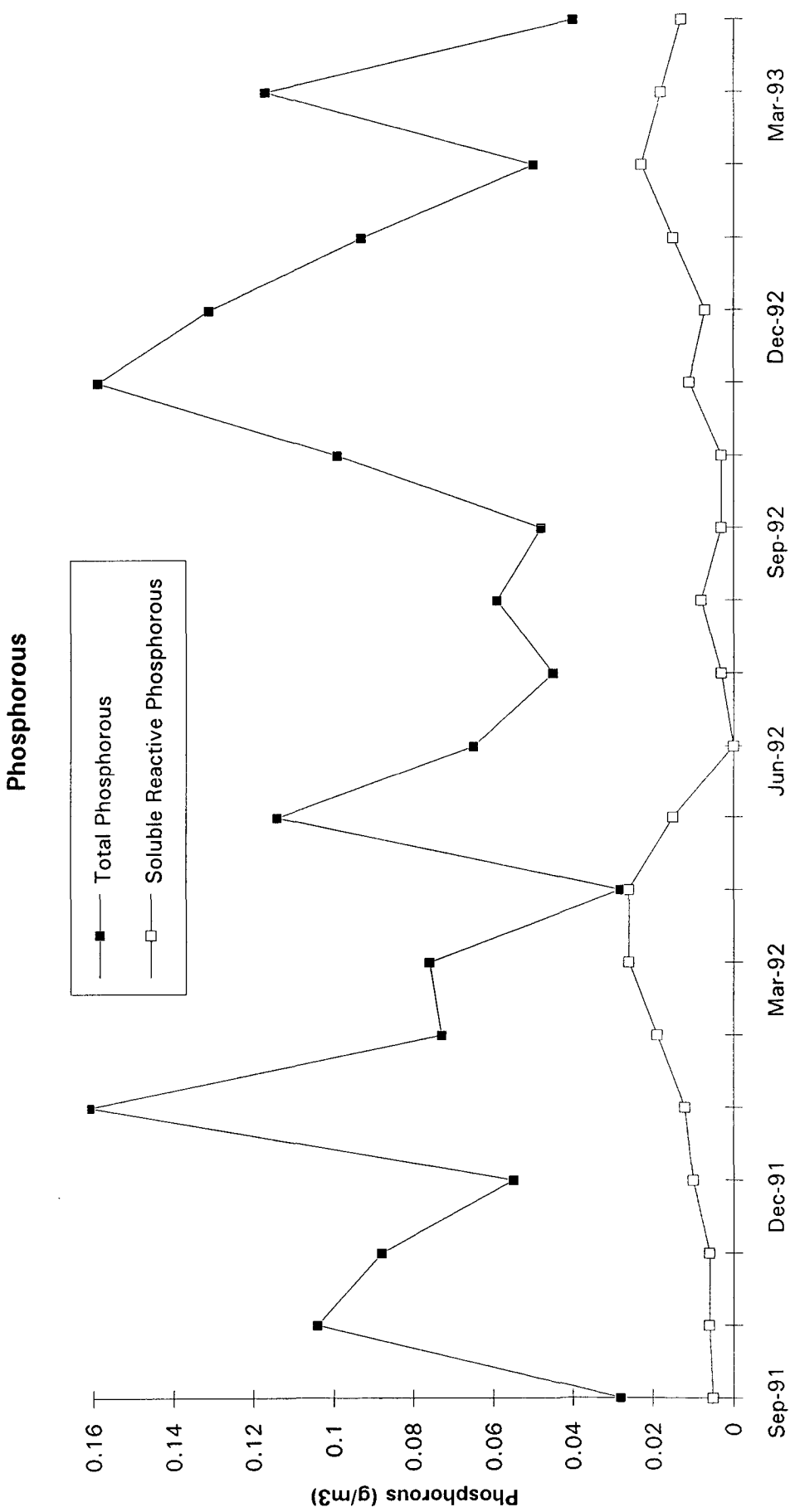

Nitrogen Species
Nitrogen (g/m3)
0.12
0.1
0.08
0.06
0.04
0.02
0
Sep-91
Dec-91
Mar-92
Jun-92
Sep-92
Dec-92
Mar-93
Total Ammonia
Nitrate
Nitrite

Figure 6.


Phosphorous
Total Phosphorous
Soluble Reactive Phosphorous
Phosphorous (g/m3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Sep-91
Dec-91
Mar-92
Jun-92
Sep-92
Dec-92
Mar-93