Title of Activity

SPREP Marine Pollution Monitoring and Control Programme
Baseline Study of the Huon Gulf, Papua New Guinea
Final Report

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1.0 Introduction

1.1 Background

The SPREP Action Plan, adopted in Rarotonga 8-11 March 1982, and the SPREP convention, adopted in Noumea 25 November 1986, identified marine pollution as one of the major problems affecting the quality of the oceans and coastal areas of the South Pacific and requested the development and implementation of pollution control measures.

Since 1984 a large number of pollution monitoring and research projects have been successfully implemented through SPREP in the South Pacific Region. The Intergovernmental meeting on the SPREP Action Plan, Noumea 1988, recommended the consolidation of ongoing pollution research and monitoring projects of SPREP into a co-ordinated monitoring, research and control programme (SPREP/UNEP, 1989).

SPREP-POL is the response of the South Pacific nations to consolidate the on-going pollution research and monitoring projects of SPREP into a regionally co-ordinated monitoring, research and control programme. The major aim of this programme is to provide Governments with recommendations, based upon quality scientific data, for the introduction or improvement of legislation to control pollution of the marine environment.

SPREP-POL consists of interlinked components of research, monitoring, baseline studies, identification of priorities and preparation of assessments. This will lead to the formulation of proposals for pollution control and abatement measures with assistance to governments and administrations in the implementation of these measures and in the evaluation of their effectiveness. The monitoring study of the Huon Gulf will produce the scientific data upon which these pollution control and abatement measures for the area will be based.

1.2 Site Selection

Sample sites were carefully selected to allow the future assessment of land based pollutant sources and quantities, marine pollutant sources, pathways, levels and effects. Table 1 lists the sample sites chosen for inclusion in the Huon Gulf programme of the SPREP-POL and a brief summary of the significance of each site. Figures 1 and 2 detail the study area.

Site Number	Sample Site	Significance/Reason for Inclusion
1	Busu River mouth	A large river to the north of Lae. This river is a major influence on the water quality around Lae.
2	Bumbu River mouth	The Bumbu River drains the residential areas of Lae and the villages in the hinterland to the North of Lae.
3	Voco Point	This area has all the wharf facilities for coastal shipping and village fishing boats. All pleasure craft are launched from the Lae Yacht Club situated at Voco Point.
4	Lae Main Wharf	This area has all the wharf facilities for overseas shipping. The Lae Main Wharf is the largest and most heavily used wharf facility in Papua New Guinea.
5	Landing Bay	This is the embarkation point for local village boats in the area. A large village is also situated at this site.
6	Markham River Mouth	The Markham River forms the major riverine input to the Huon Gulf. The Markham River drains the heavily populated Markham valley. In addition the Bulolo/Watut River system, which has the extensive Wau/Bulolo gold fields in the headwaters, is a tributary of the Markham.
7	Labu Lakes Entrance	This site is at the entrance to an extensive estuarine lake system, opposite to the industrialised Lae area. This lake system is the site of many villages from which the inhabitants derive sustenance.
8	Sugarloaf	This site is adjacent to the area the large container ships use for temporary mooring until space becomes available at the wharf facilities in Lae.
9	Halfway Reef	This reef is adjacent to the main shipping channel in the Huon Gulf, and is situated half way between Lae and Salamaua. This reef is frequented by scuba divers and pleasure craft.
10	Schoolhouse Reef	Situated in Salamaua bay. This site is heavily used by pleasure craft from Lae. Salamaua used to be the largest town in the north of PNG.
11	Narapela Reef	This site is located on the opposite side of the Salamaua peninsula.

Table 1: Huon Gulf sample sites

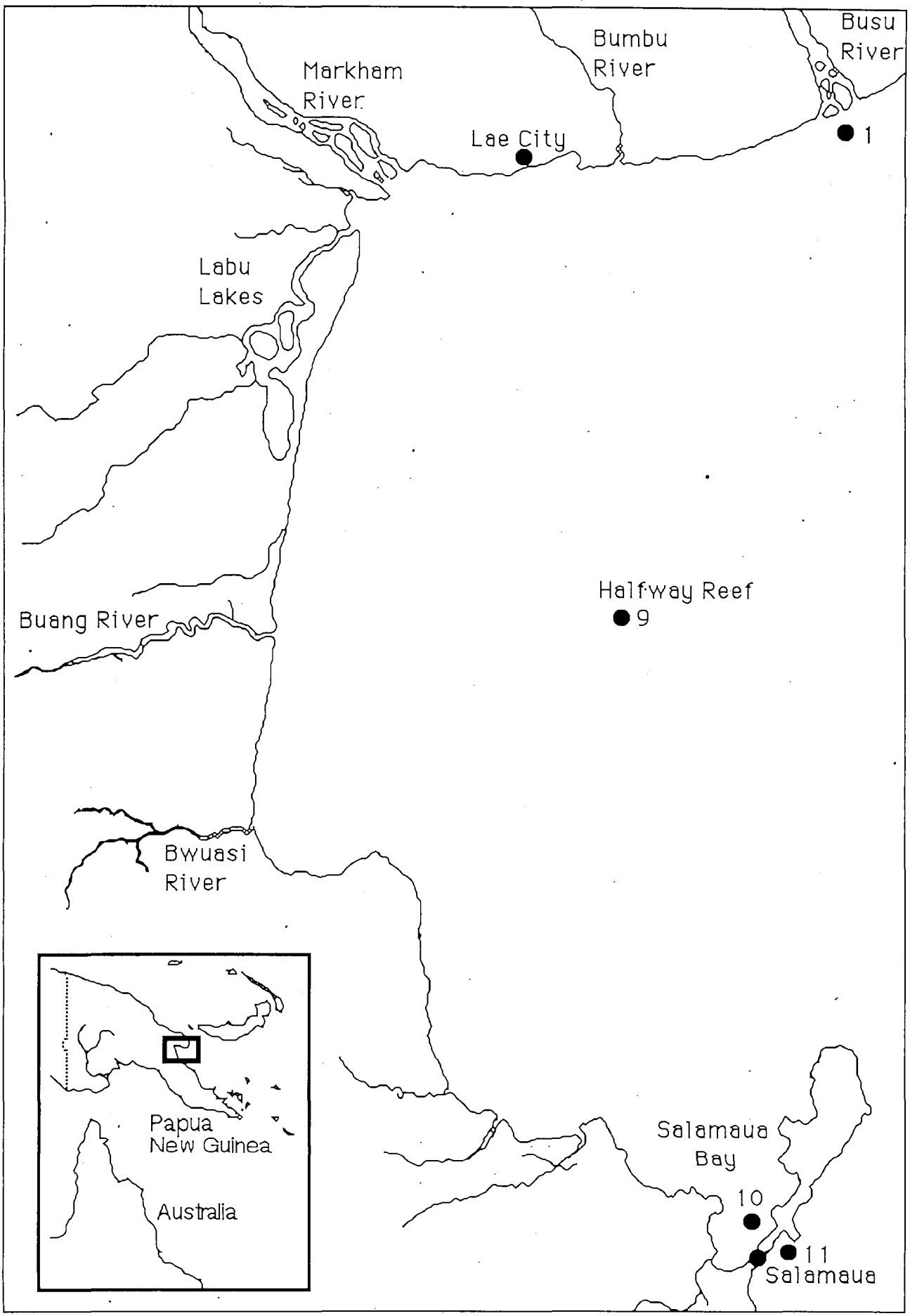


Figure 1: Site location map

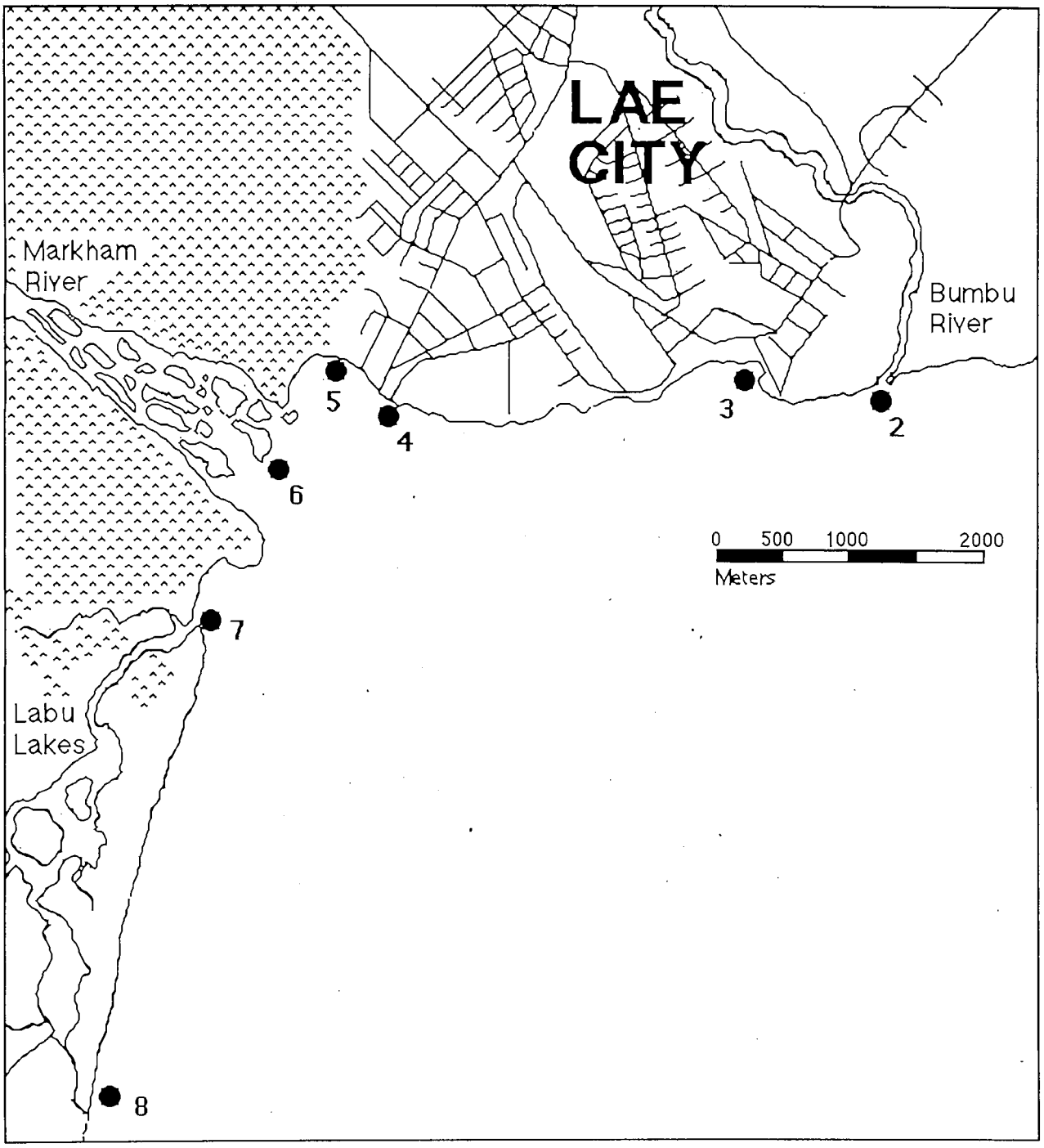


Figure 2: Site location map, detail of Lae vicinity.

A sample site is located at the mouth of each of the major rivers in the study area. The Busu and Bumbu rivers both drain catchments with similar geologies and topology's. The Bumbu River, however, receives runoff from a large section of the residential area of Lae and villages in the hinterland to the north of Lae. The comparison between the results obtained for these two sample sites will allow an assessment of the pollution load from the residential sections of Lae city on the Huon Gulf. It was anticipated that nutrients, microbiological and other parameters influenced by sewage input will be the major pollution problems of the Bumbu River.

Voco Point, the Main Wharf and Labu Wharf sample sites are within the area likely to be influenced by pollution from the industrial sections of Lae city. The industrial sections of Lae mainly comprise light manufacturing, packaging and transportation industry. Between the selected sites there are a number of drains and small creeks receiving effluent from individual industrial sites.

The Markham River forms the major riverine input to the Huon Gulf. This river has an extensive system of tributaries and drains a heavily populated region. The Bulolo/Watut River system, which has the extensive Wau/Bulolo gold fields in the headwaters, drains into the Markham. Mercury will be a possible pollutant of the Markham River due to the gold fields in the catchment area.

Labu Lakes is an extensive mangrove-lined estuarine system. The lakes are narrow, relatively shallow with a general depth of 2 meters, and parallel the coastline for approximately 13 kilometres. A large number of people use the lake system for subsistence collecting fish, crabs and shellfish which are also sold in Lae. The lakes are separated from the sea by a sand bar which restricts the inflow of seawater to the lakes to an opening of less than 50 meters in width. Freshwater enters via numerous small streams running off the adjacent mountains and via seepage from the broad areas of surrounding mangrove and *Nypa* palm swamp. Labu Lakes are only approximately 2 kilometres from the centre of Lae. However, due to the steeply shelving nature of the sea bed around Lae to depths in excess of one thousand meters and the flow of the Markham River, it is anticipated that the lake system is isolated from any pollutant sources located in Lae.

The Sugarloaf site is situated near the area used by large container ships as temporary mooring until space becomes available at the wharf facilities in Lae. This site potentially, would be impacted by the dumping of ballast.

Halfway reef is adjacent to the main shipping channel in the Huon Gulf. It is situated half way between Lae and Salamaua hence the name. The reef is situated on the top of an underwater spire, is 24 meters deep at the shallowest point and roughly 40 meters long and 10 meters wide. This reef is frequented by scuba divers and sports fishermen.

Salamaua is a thin peninsula separating two shallow bays covered with coral reef. It is the site of several villages and many weekend holiday homes of the affluent from Lae. It is heavily used by small pleasure craft. Schoolhouse reef is situated in Salamaua Bay which is the side of the peninsula impacted by human activity. Bottles and cans etc can be seen to despoil the reef. Narapela reef is situated on the opposite of the peninsula approximately 800 meters in a straight line. This side of the peninsula is rarely visited despite its close proximity. The comparison between the results obtained for these two sample sites will allow an assessment of the pollution load from pleasure craft on the local environment. Of particular interest will be tributyltin which is used in antifouling paints.

Notwithstanding the demands placed upon Salamaua by the local inhabitants and people from Lae seeking a break from the demands of city life, no serious pollution problems are expected at these two sample sites. Especially the Narapela Reef side of the peninsula.

The results from these two reef sites are expected to be indicative of the "natural" levels of the measured parameters before human impact in the Huon Gulf region. This will allow a comparison with the levels found from the sites situated at Lae which are clearly impacted by human development. This comparison is important to allow the assessment and highlighting of the relative impact of industry and development in Lae upon the Huon Gulf, since the level of pollution from industry and development in Lae is expected to be relatively minor compared to heavily industrialised regions.

1.3 Previous Studies in the Huon Gulf

Published data from studies examining pollution levels in the Huon Gulf are very sparse. Except for studies centred around the mines developed on Lihir, Misima and Bouganville Islands, the lack of information regarding pollution levels, heavy metal, pesticide, sewerage or otherwise, for the coastal and island region of Papua New Guinea is almost complete. Only four papers deal with samples collected directly from the Huon Gulf.

The first (Balat 1989) deals with oysters from Labu Lakes and the second (Apte et al, 1991) reports metal concentrations in water and suspended sediments from Labu Lakes. Two papers were published from a cruise conducted by the Kagoshima University, Japan, during November and December 1989 (Inoue et al., 1990, Enomoto 1990). A number of papers (Mallard and Hugman 1986, NSR 1984, Pohei 1986) deal with the Wau/Bulolo gold fields situated in the headwaters of the Wau and Bulolo Rivers which drain into the Markham River, which in turn discharges into the Huon Gulf.

Apte et al reported concentrations of copper, cadmium, zinc, lead and nickel in the water and sediments of Labu Lakes. Dissolved metal concentrations were in the following ranges ($\mu g\ L^{-1}$): Cu 0.197-1.253, Cd <0.038-0.057, Ni 0.192-0.485, and Pb <0.060-0.165. Sediment metal concentrations were in the following ranges ($\mu g\ g^{-1}$): Cu 10.1-95.9, Cd <0.867, Ni 20.3-37.5, Pb 3.92-8.83 and Zn 52.8-113.8. Results for suspended sediment concentration, salinity, dissolved oxygen, temperature, chlorophyll-a, pH and sediment organic carbon are also reported.

The results of this work indicate that compared with other estuarine systems, particular in Europe and North America, the metal levels in the Labu Lakes are low and indicative of a relatively pristine environment. This is as would be expected due to the flow of the Markham River effectively isolating possible industrial pollution sources at Lae from the lake system. However, the authors point out that the copper levels at Labu may be significantly augmented by contributions from the Markham River due to tidal pumping, and further studies are required to confirm this.

Balat reported concentrations of copper, zinc, cadmium and lead in mangrove oysters, *Saccostrea forskali*, in the following ranges ($\mu g\ g^{-1}$): Cu 10-177, Zn 9-127, Cd 0.24-1.0 and Pb 0.03-0.69. The mean copper concentration and over 50% of the individual oyster population sampled contained copper levels higher than the Australian Health and Medical Research Council standards for copper of 70 $\mu g\ g^{-1}$ in edible molluscs. These copper results for oyster tissue from Labu Lakes provide impetus to the recommendation of Apte et al to study the effect upon copper concentration in Labu Lakes by the flow of the Markham River.

Inoue et al., (1990) report on the inorganic nutrient concentrations on seawaters collected around Madang, Port Moresby and Lae. Water samples were collected from a total of twelve sites, both at the surface and at a depth of 5 meters, in the Huon Gulf. Nine were from coral areas along the east coast of Salamaua Peninsula, and the three other samples were from the estuarine portion of the Gulf that was visually observed to be influenced by particulate material from the Markham River. The concentrations of inorganic nutrients in the samples obtained from the coral areas were comparatively low, in comparison to those obtained in other tropical regions. The authors did not find significant differences for inorganic nutrients between sample sites or sample depths.

The paper by Enomoto (1990) dealt with a survey of the marine benthic macroalgae. Similarly to Inoue et al., (1990), Enomoto sampled various stations around the Papua New Guinean coast including Salamaua. It was noted that the seawater was clean at the northern point of Salamaua Peninsula, but the water transparency decreased toward the southeastern portion. This was reflected by the decreasing population of corals and benthic macroalgae observed. The author reported that significant quantities of useful marine algae for possible fishery development were not found. The low nutrient levels found by Inoue et al., (1990), and the consequent low primary productivity, would explain these observations.

The work of Mallard and Hugman (1986) was prompted by concerns about the health of residents of the Wau/Bulolo area of Papua New Guinea, due to the continual use of mercury since 1930 in the processing of gold ore. While this work did not involve the collection of samples from the Huon Gulf, the Wau and Bulolo Rivers drain, via the Markham River, into the Huon Gulf. A health survey of the inhabitants of the area, compared to a control group, indicated symptoms consistent to mercury poisoning. However, analysis of mercury in hair and urine did not conclusively support these medical findings. The results reported for mercury in the water and fish from the area, were generally below those considered harmful to health (ie 0.5 µg/l in water and 0.5 µg/g in fish). The authors recommended, due to the relatively small sample sizes and instrumental limitations, a more extensive survey to conclusively establish the exposure levels of miners and inhabitants in the Wau/Bulolo area, to mercury poisoning due to the gold processing activities.

2.0 Materials and Methods

2.1 Sampling

It has been emphasised numerous times that the techniques used in sample collection, preparation, and storage are critical. Errors introduced at these early stages in the analytical cycle, either sample contamination or adsorptive losses of particular analytes, can negate many hours of more complex analytical measurement.

Water samples were collected in acid soaked, distilled deionised water rinsed polyethylene containers. Sulphuric acid was used to treat the polyethylene containers since nitrogen species were to be determined. Sulphuric acid also 'hardens' the polyethylene containers decreasing adsorptive losses of phosphate. Samples for bacteriological analysis were collected in separate sterilised glass bottles.

Surface water samples were collected by operators leaning over the bow of the boat as the boat moved slowly in the direction opposite to the current flow. The operator wore polyethylene gloves. The sample bottle was opened approximately 20 centimetres below the surface when collecting the water sample. This was to ensure any sampling artefacts due to collection of the surface microlayer were not introduced. The bottle was rinsed three times with the water to be sampled before the actual sample was taken. All samples after collection were placed in eskies for transportation to the laboratory. Samples were collected from the various sites so that the maximum time between sampling and laboratory preparation of the sample was less than two hours. Sub-surface water samples were collected using a General Oceanics (Miami, Florida USA) model 1010 Niskin bottle.

Sediment samples were collected with an Ekman dredge (Wildco, Saginaw MI, USA). The dredge was not suitable for many of the sites, especially the fast flowing and turbulent rivers from which bed sediment samples were required. The turbulent nature of the rivers and the high flow, lead to the bed sediment being constantly reworked and suspended. Due to these facts and the difficulties experienced in trying to use the Ekman dredge in these conditions, suspended sediment samples were collected from the various river mouth sampling sites instead of bed sediments.

Difficulties were again experienced in trying to retrieve sediment samples from the reef sites using the Ekman dredge. These sites consisted of hard packed, coarse grained sand. The dredge was not able to penetrate the sand to any depth. In the case when the dredge did manage to penetrate the surface of the sand, it would often not close due to coral debris jamming the jaws in an open position. Samples from these reef sites were therefore collected by scuba divers using a hand dredge.

2.2 Storage Procedures

Sediments were air dried and the less than 2 millimetre fraction retained in polyethylene sample containers for later analysis.

Storage of the water samples before analysis for nutrients has received much attention, with many conflicting reports. The storage of water samples for the determination of total phosphorus and nitrogen presents little problem. Samples are placed directly into glass bottles containing the oxidising mixture (potassium peroxodisulphate, boric acid and sodium hydroxide). The bottles containing the oxidising mixture and sample are then autoclaved to perform the digestion of the samples at some later convenient time. The requirement for storage of samples for dissolved phosphorus and nitrogen species are when difficulties are encountered.

Strickland and Parsons state that quick deep freezing stabilises phosphorus samples for many months. Gilmartin reported, however, that for samples with high microbiological activity, changes in samples were more rapid than those occurring in situ before the samples were stored.

The Scandinavian Council for Applied Research working group on water analysis recommended acidification of the sample with sulphuric acid in a polyethylene bottle. However, this procedure has been criticised on the grounds that it favours hydrolysis of labile polymeric phosphorus species. As pointed out by Grasshoff et al., "it must be concluded that there is no single preservation method that may be recommended for all types of samples and the analyst must examine each situation critically and treat existing information only as a guide".

A brief study was undertaken using various proposed sample preservation strategies, to verify which method was most suitable for the laboratory equipment at our disposal and sampling conditions likely to be encountered. An initial trial on the effect of storage time on the concentration of dissolved phosphorus indicated that over 50% of the dissolved phosphorus was lost after 24 hours storage, even with freezing the sample. A similar loss was again observed after a further 24 hours storage. These initial trials had a number of limitations, and a more detailed exercise was undertaken. The storage of phosphorus was examined using two techniques, freezing and the addition of mercury to the samples. The use of glass or plastic bottles with both preservation techniques was also explored. The results are presented in the following table.

Storage Time (hours)	Sample	Plastic Bottles		Glass Bottles	
		Frozen	$HgCl_2$	Frozen	$HgCl_2$
0	Voco Point 31/08/92	0.03	0.03	0.03	0.03
	Voco Point + 0.1mg/l	0.13	0.13	0.13	0.14
24	Voco Point 31/08/92	0.03	0.03	0.04	0.04
	Voco Point + 0.1mg/l	0.13	0.13	0.13	0.14
48	Voco Point 31/08/92	0.03	0.03	0.03	0.03
	Voco Point + 0.1mg/l	0.13	0.13	0.12	0.13
72	Voco Point 31/08/92	0.04	0.04	0.04	0.04
	Voco Point + 0.1mg/l	0.14	0.13	0.13	0.14

Table 2: Nutrient storage procedure experimental results

Both freezing and the addition of mercuric chloride (final concentration in the sample of 2mg/l) stabilised dissolved phosphorus. The results indicate that the type of material does not affect the storage of phosphorus. Plastic bottles would be preferred due to easier transport in rough sea conditions. The addition of mercuric chloride is the preferred preservative, as large amounts of freezer space are not required. It would be desirable to have a preservation procedure that was capable of stabilising both dissolved phosphorus and nitrogen species. A possible disadvantage of mercuric chloride is poisoning of the cadmium column negating the determination of nitrate.

The overall assessment of these preliminary results was that they were inconclusive and more work is required in the area of sample preservation for dissolved nitrogen and phosphorus species. To negate the effects of sample storage, all sampling was performed in such a way to ensure that laboratory preparation and analysis for dissolved nitrate and phosphorus species was begun a maximum of two hours after the sample was taken.

2.3 Field Analysis Techniques

The measurement of salinity (temperature corrected), dissolved oxygen (salinity compensated) and temperature were performed in the field with a model 90FL field meter (Banksia Scientific, Brisbane Australia). The 90FL field meter is equipped with 30 meters of cable to enable depth profiling. A Hanna Instruments HI8424 portable pH meter was used to measure pH in the field. The field meters were calibrated as recommended by the manufacturers each day before use.

2.4 Laboratory Methods

Appendices 3 to 10 of the second progress report on the SPREP Marine Pollution Monitoring and Control Programme Huon Gulf Baseline Study (Benko and Walsh, 1992), contain detailed laboratory methods used for analysis during this study. A summary of each laboratory analysis method is given below.

Dissolved phosphorus, or more correctly dissolved reactive phosphorus, was determined by colorimetry. The orthophosphate ions present in the sample react with a solution acidified with sulphuric acid containing ammonium molybdate and potassium antimonyl tartrate. This forms 12-molybdophosphoric acid, which is then reduced with ascorbic acid to an intensely coloured phosphomolybdenum complex in which antimony is incorporated. The colour of the solution formed is measured spectrophotometrically and is proportional to the amount of orthophosphate present. The acid conditions used may cause partial hydrolysis of condensed phosphates, and/or some of the more labile organic complexes if present. For these reasons, the determinand is referred to as reactive phosphorus instead of orthophosphate. "Dissolved" is defined operationally as that present in the filtrate that has passed through a 0.4μm filter. Total phosphorus was determined similarly after a sub-sample had been digested in an autoclave with a mixture of potassium peroxodisulphate, boric acid and sodium hydroxide.

Nitrite was quantitated by reacting nitrite ions present in the sample with an aromatic amine to form a diazonium compound which can then couple with a second aromatic amine to form an azo dye. The amount of azo dye present is proportional to the initial concentration of nitrite present. The azo dye has a high molar extinction coefficient allowing very sensitive spectrophotometric measurement of the quantity present. Nitrate was determined similarly after being reduced to nitrite ion in the presence of cadmium metal at pH 8.5.

Total coliform organisms were quantitated using the membrane filter technique. A portion of the test sample is filtered through a sterile filter which retains the micro-organisms present. The filter is placed on M. Endo Broth MF base medium, which selectively favours the growth of total coliform organisms, and is incubated for the prescribed period to allow the colonies to grow. After the incubation period, all pink to dark red coloured colonies with a metallic surface sheen were counted as total coliforms. Faecal coliforms were determined similarly, however, MF-C Broth base medium was used instead, and all blue coloured colonies are counted as faecal coliforms. Faecal streptococci were also quantitated by the filter membrane technique using Slanetz and Bartley medium, with the red colonies being counted as faecal streptococci.

The biological oxygen demand (BOD) determination consisted of placing the sample in a full airtight bottle and incubating the bottle at 20°C for five (5) days. Dissolved oxygen is measured initially and after incubation. The BOD is calculated from the difference between the initial and final dissolved oxygen readings.

Metals in the sediment samples were determined after acid digestion with flame atomic absorption spectrophotometry or graphite furnace atomic absorption spectrophotometry as appropriate depending on the concentration of metal of interest in the sample. The sediment samples were air-dried, homogenised and sieved through a 2mm screen. The fraction that passed through the screen was collected, and a sub-sample was accurately weight (approximately 0.5 gm) into a teflon beaker. Nitric acid is added and the beaker heated to remove most of the organic matter. Then a mixture of perchloric, hydrofluoric and nitric acids is added to complete the digestion. Finally, the residue is re-dissolved in hydrochloric acid and made to volume. All sample preparation and analysis steps for the determination of sediment metal content were performed in a class-350 clean-room laboratory.

A Lovibond colour comparator, Hach 2100A turbidimeter, Metrohm E512 pH meter and Jenway PCM3 conductivity meter were used for the laboratory measurement of physical parameters.

3.0 Results and Discussion

Appendix 2 tabulates all the analysis results for this study for water and sediment samples. Appendix 1 presents this data in graphical form.

3.1 Sediments

Table 16 appendix 2 presents the results obtained for the analysis of the metals cadmium, copper, lead and zinc in the sediment samples. This data is presented graphically in appendix 1, figures 1 to 15.

Figure 4 compares the data obtained during this study for copper, lead and zinc in sediment against concentrations in sediments both from sites known to be undisturbed, and by those known to be affected by human activities. The undisturbed sites include the Urr Estuary (1 in the legend), undisturbed coastal sediments from the Arctic coast (2 in the legend), and sediment from the New South Wales coast (3 in the legend). These undisturbed "reference" sites appear on the figure as green lines. Sites known to be affected by anthropogenic metal inputs include the southern California coast (4 in the legend), Long Island Sound/Raritan Bay (5 in the legend), the Derwent Estuary Australia (6 in the legend), San Francisco Bay (7 in the legend), Septiba Bay Brazil (8 in the legend) and the average of 27 estuaries from the UK (9 in the legend). These "polluted" reference sites appear on the figure as the red lines. The results obtained for the Huon Gulf samples during this study appear on the figure as the blue lines (labelled site 1 to site 11 in the legend).

The copper results for the Huon Gulf samples in figure 4 can be seen to fall into two distinct groups. One group consists of sites 9 to 11, while the other contains the remaining sites. Sites 9, 10 and 11 are the reef sites, while the remaining sites are from river mouths or the Lae waterfront. This grouping of the copper results corresponds to the geologic nature of the sediments. Sediment from sites 9, 10 and 11 is predominantly coarse, white sand particles containing shell fragments. Sediment from the remaining sites are predominantly fine, dark silts containing varying amounts of organic matter

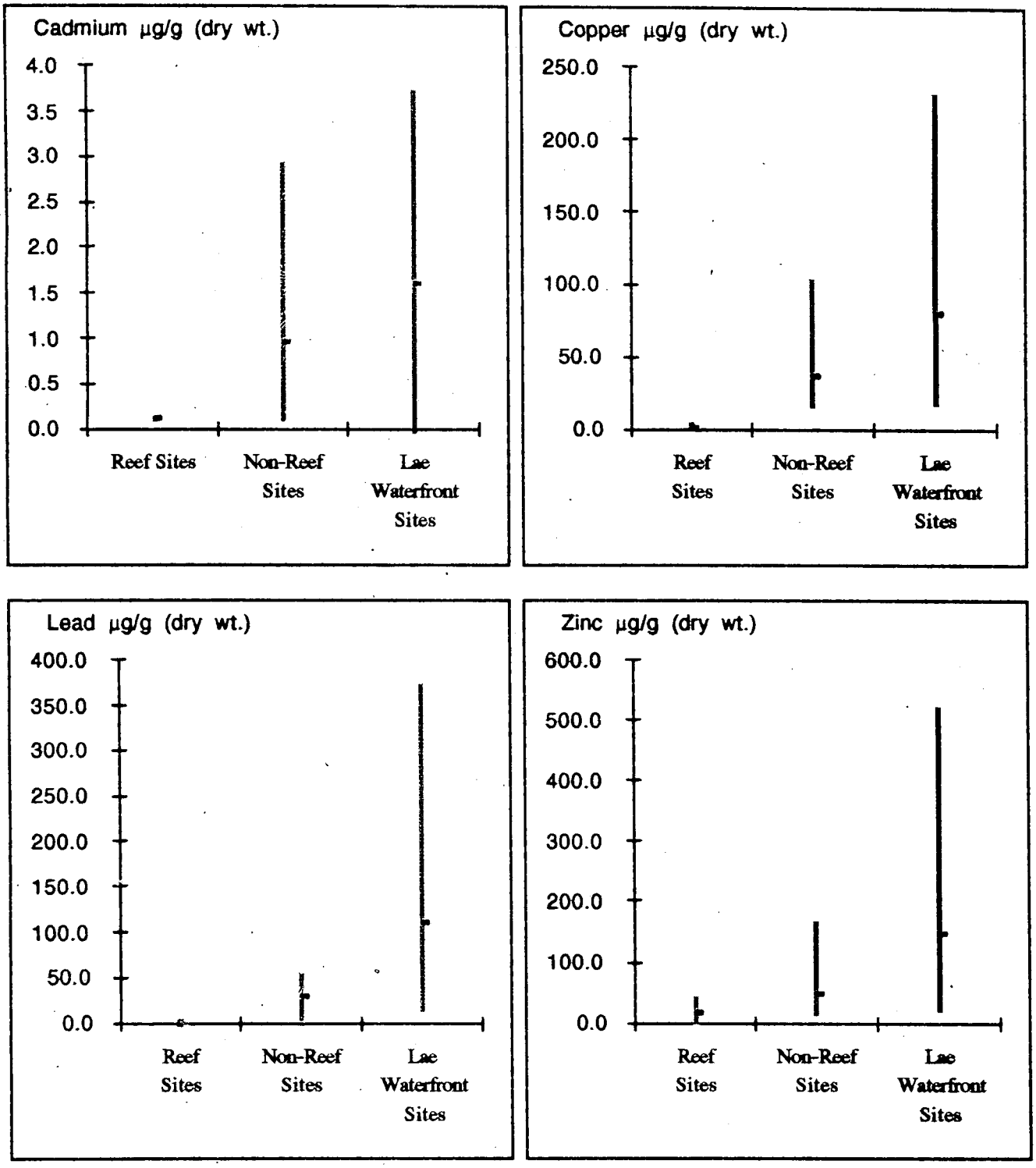


Figure 3: Mean and Range for Cadmium, Zinc, Lead and Copper Based Upon Grouping the Eleven Huon Gulf Sample Sites into the Three Categories, Reef Sites, Non-Reef Sites and Lae Waterfront Sites.

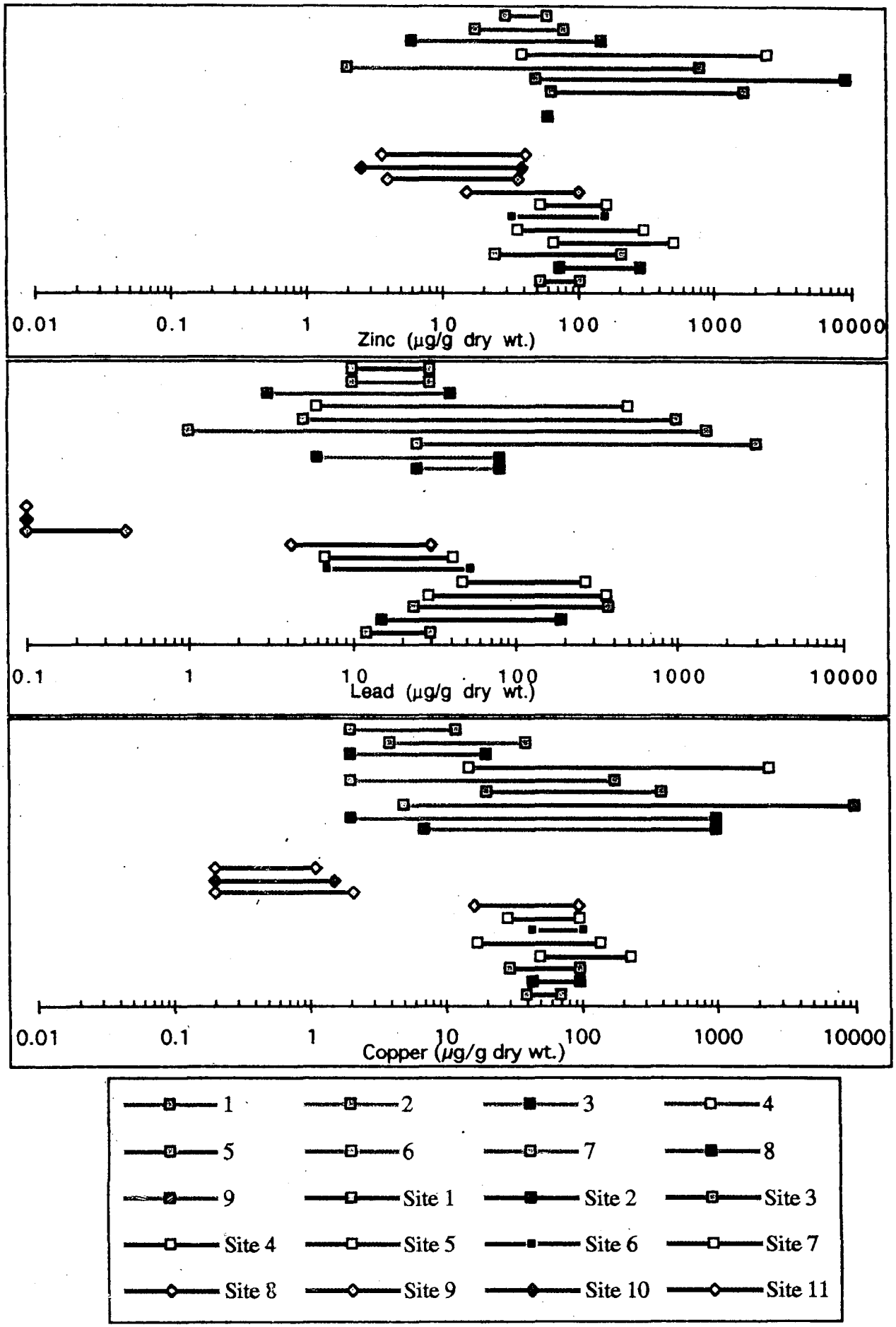


Figure 4: Sediment Results from this Study (blue) Compared to Known Polluted (red) and Undisturbed Sites (green) (After Luoma, 1990).

The copper results for the "reef" sites (9, 10 and 11) in figure 4 fall in the region below that obtained for other undisturbed sites. This reflects the expected relatively pristine condition of the sediments from these sites and the large amount of coarse sand in these sediments. The other Huon Gulf sites from the Busu, Bumbu and Markham Rivers, and the Lae Waterfront show elevated copper levels in sediments compared to both the "reef" sites and that obtained for other undisturbed sites listed in figure 4.

The large elevation in copper levels, approximately two orders of magnitude, between the "reef" sites and the other Huon Gulf sites could be largely explained by the gross difference in the geologic nature of the sediments from these locations. The coarse sands from the "reef" sites, composed mainly of silicate material, would be expected to be low in metals compared to the dark silts from the other sites, derived from terrestrial weathering, having large surface areas and associated organic matter that could bind trace metals.

This hypothesis that the elevated copper levels are largely due to the geologic sedimentary composition is supported by the results obtained for the Busu River. The Busu River, site 1, has a similar catchment geology to the Bumbu and Markham Rivers. However, the Busu River drains a region devoid of industrial development and only sparsely populated by villagers with a predominantly subsistence agriculture. The copper results for site 1 in figure 4 do not show any major deviation from the other "non-reef" sites considering statistically variability. Taking the results from site 1 as a baseline for the "non-reef" sites, only sites 4 and 5 show potentially elevated copper levels.

Figure 15 appendix 1 plots the average and the range of the copper sediment results by site for the sediment samples collected. This graph once again shows that the copper results fall into two distinct groupings, the "reef" and "non-reef" sites, as found in figure 4. These groupings were explained in terms of the distinct differing geologic nature of the sediments found, and not due to anthropogenic inputs.

The initial copper sediment results (Benko and Walsh 1992) for the Huon Gulf sites indicated that the "non-reef" sites could be further segregated into two sub-groups, one group comprised of sites 4 and 5, and the other containing the remaining "non-reef" sites. The rationale behind this was based upon taking the results of site 1 (the Busu River), for reasons discussed previously, as a baseline for sediment derived from terrestrial weathering in the Huon Gulf.

Using this baseline, the copper sediment results for sites 2, 3, 6, 7 and 8 were statistically consistent with the results obtained for site 1. However, the absolute mean and range of the results for sites 4 and 5 show that the sediment copper concentrations are elevated for both these sites compared to site 1. These results indicated that sites 4 and 5 had sediment copper concentrations elevated by a factor of 2 to 3 due to anthropogenic inputs. This conclusion based upon the results of the first three sampling excursions is not supported by the increased amount of data now available. Figure 15 appendix 1 shows that the mean and range of copper results for the "non-reef" sites do not differ significantly. However, site 4 does show a large range indicating occasional high levels of copper, possibly due to anthropogenic inputs.

Similar to the copper results, the zinc results for the Huon Gulf samples in figure 4 can be seen to fall into two distinct groups. One group consists of sites 9 to 11, the "reef" sites, while the other contains the remaining sites. The sediment zinc results for the "reef" sites fall within the range of that obtained for the undisturbed sites, as shown on figure 4. The zinc results for the "non-reef" sites are generally above, or at the upper limit of the range of results obtained for the undisturbed sites, as shown on figure 4. This grouping of the zinc sediment results can, as for the copper results, largely be explained in terms of the gross differences in geological composition of the sediments comprising the two groups.

As for the copper results, figure 15 appendix 1 shows that the zinc results for the "non-reef" sites fall into a number of sub-groups. For reasons previously detailed, site 1 can be used as a baseline for sediment derived from terrestrial weathering in the Huon Gulf. Zinc results for sites 6, 7 and 8 are statistically consistent with that obtained for site 1. However, sites 2, 4 and 5, in terms of absolute mean, have elevated zinc sediment concentrations compared with site 1.

Unlike the copper and zinc results for the Huon Gulf samples in figure 4, the lead results can be seen to fall into three distinct groups. One group consists of sites 9, 10 and 11, the "reef" sites, similarly for the copper and zinc results. The second group consists of sites 1, 6, 7 and 8, while the third group consists of sites 2, 3, 4 and 5 which are situated along the Lae waterfront.

The lead results for the "reef" sites fall well below the region obtained for undisturbed sites in figure 4, while the lead results for the second group of sites falls within this region. These results indicate the sites contained within the second group together with the "reef" sites are consistent with results obtained for sites not impacted by human activities.

The absolute difference in lead results between the second group and the "reef" sites could be largely explained in terms of the gross difference in geologic nature of the sediments between these locations. The lead results for the "Lae waterfront" sites are above the region obtained for undisturbed sites in figure 4, and fall in the upper regions of the ranges obtained for lead in sediment from sites impacted by human activity.

Figure 15 appendix 1 plots the average and the range of the lead sediment results by site for the sediment samples collected. This graph once again shows that the lead results fall into three distinct groupings, the "reef", "non-reef" and "Lae waterfront" sites, as found in figure 4. The lead results displayed in graph figure 15 and figure 4 indicate that the "Lae waterfront" sites, ie., sites 2, 3, 4 and 5, have elevated sediment lead concentrations.

Site	Reference	Cu µg/g	Pb µg/g	Cd µg/g	Zn µg/g
Average near shore sediment	Aston	48	20	-	95
Mean Crustal Abundance	Bowen	50	14	0.11	75
Labu Lakes, PNG	Apte et al.	10-96	4-9	<0.9	53-114
Lagaip River, PNG	NSR	245	22	0.11	146
Strickland River, PNG	NSR	22	17	-	88
Fly River, PNG	NSR	58	15	1.7	120
Fly River Delta, PNG	NSR	26	23	3.0	93
Reef Sites	This Study	0.8* (0.2-2.1)	0.2* (<0.05-0.4)	<0.05*	15* (2.5-41)
Non-Reef Sites	This Study	38* (16-103)	28* (4.2-53)	1.0* (0.1-2.9)	46* (15-163)
Lae Waterfront Sites	This Study	79* (18-230)	110* (15-370)	1.6* (0.1-3.7)	146* (24-520)

* - mean concentration, with range in parentheses

Table 3: Metal content of sediments from other riverine and estuarine systems within Papua New Guinea.

The preceding discussion shows that the eleven (11) Huon Gulf sample sites can be divided into three categories, reef sites (sites 9, 10 & 11), non-reef sites (sites 1, 6, 7 & 8) and Lae Waterfront sites (sites 2, 3, 4 & 5). Figure 3 presents the mean and range for cadmium, zinc, lead and copper based upon these three categories.

Using t-tests, the non-reef site category showed a significant difference ($p<0.01$) from the reef site category for each of the metals. Similarly, the Lae Waterfront site category showed a significant difference ($p<0.01$) from the reef site category for each of the metals. A significant difference ($p<0.05$) was found between the Lae Waterfront site category and the non-reef site category for the metals zinc and copper, while lead showed a significant difference at the 99% confidence limit.

Table 3 compares the metal results obtained for the sediments from the three Huon Gulf site categories with sediments from other riverine and estuarine systems within Papua New Guinea, together with data for the mean crustal abundance and an average near shore sediment. It can be seen that the results for the non-reef sites compare closely with the data for mean crustal abundance and average near shore sediment, except for cadmium which appears to be elevated compared to average crustal abundance.

The results for lead and cadmium for the Lae Waterfront sites are approximately an order of magnitude higher than those for both mean crustal abundance, and average near shore sediment. Results for copper and zinc for the Lae Waterfront sites are approximately double that for mean crustal abundance, and average near shore sediment.

The previous discussion indicates that the Lae waterfront has been contaminated by anthropogenic inputs of copper, zinc and lead, with enrichment factors of between 2 and 10. However, since no direct evidence exists regarding the metal content of sediments in the Huon Gulf prior to industrialisation and urbanisation, the conclusion that contamination has occurred, based upon various comparisons with data reported in the literature, must be viewed with caution.

Sediments formed prior to the industrial period, which are now buried beneath later deposits, are often used to determine baseline levels of metals in sediment to determine enrichment factors due to anthropogenic inputs. However, these sediments have been subject to a wide variety of geochemical processes (Burton and Liss, 1976), and as a result may have lost part of the associated heavy metal load. Geochemical processes can in fact concentrate trace metals in sediment. Other factors such as bioturbation make the use of sedimentary deposits for comparative purposes in interpreting possible anthropogenic inputs to sediments difficult.

Another possibility in the previous discussion of the Huon Gulf sediment data, was to use the heavy metal contents of the average shale, deep-sea clay or nearshore sediment. Deep-sea sediments are enriched in concentrations of metal such as Cu, Ni, Pb, Zn and Cd due to natural processes, and are unacceptable as a background reference for coastal or estuarine sediments (Luoma, 1990). The average shale and nearshore sediment represent averages, whereas in river sediments local mineralisation in the drainage basin can result in naturally high levels of some metals. As can be seen in table 3, the Lagaip River is an order of magnitude higher in copper compared to other PNG riverine systems, and appears enriched by a factor of 5 over the average near shore sediment and mean crustal abundance. A further complication is that the mineralogical composition of the sediment may differ from that of the average shale or near shore sediment. A good example is organic matter, which is an excellent scavenger for a number of metals, is more abundant in river deposits than in marine sediments. This was the reason used to explain the differences in sediment metal concentrations between "reef" and "non-reef" sites in the Huon Gulf.

Thus it can be seen that determining the extent of anthropogenic metal contamination in a sediment is difficult due to the lack of suitable baseline values. However, the establishment of a suitable baseline is the first prerequisite in determining the extent of anthropogenic inputs. Using dated sediment cores or average values from representative portions of the earth's crust require assumptions about sediment stability and lack of diagenetic alteration of the distribution of metals. Metal concentrations from localities that appear to be relatively free from human activities and are hydrologically similar to those under study appear to be the most useful in forming baselines.

However, figure 4 shows that individual metal concentrations in whole sediments from "undisturbed" estuaries and coastal systems can differ by an order of magnitude within the same system. Thus natural variability must be taken into account in determining background conditions from such systems to be used for comparative purposes.

Salomons and Forstner (1984) suggest that uniformity in grain size, composition, and origin are important to obtain an ideal comparative basis for environmental studies. The insensitivity of comparing metal concentrations among whole sediments of different textures and or composition has been well established (Luoma, 1990). This was observed in the comparison of "reef" and "non-reef" sites during this study, and that the "reef" sites were not suitable as a baseline for the interpretation of sediment metal levels in the "Lae Waterfront" sites. This comparability on the basis of uniformity in grain size, composition and origin has important implications for the entire SPREP-POL programme, as sediment metal results are to be compared from across the entire South Pacific region.

There are a number of methods that can be used in establishing comparability which include (Luoma, 1990);

- Identifying homogeneous populations of sediment
- Separation of fine-grained sediments
- Normalisation
- Regression Techniques

Identification of homogeneous subgroups of sediments was used in the interpretation of the Huon Gulf sediment data, in that, commonalities within subgroups were determined by graphical inspection. Separation of metal values into log-normally distributed populations to determine the cumulative frequency of metal concentrations is the general method used for identification of homogeneous subgroups. This method assumes that environments with similar degrees of enrichment will fall into the same population distributions (Luoma, 1990). However, difficulties in achieving distinct separations with natural sediments has limited the use of this technique.

Salomons and Forstner (1984) state that separation of fine-grained sediments (<63 μm fraction) is an economical and effective method for establishing comparability, especially when surveillance of the distribution of metal contamination is the goal. Such procedures reduce biases introduced by large particles with low surface areas and increase sensitivity in detecting contamination.

Table 4 reports the Pearson correlation matrix results for the sediment metal results by site. The corresponding scatterplot matrices are presented in figure 40-49 appendix 1.

Site 1

	CD	CU	PB	ZN
CD	1.000			
CU	-0.041	1.000		
PB	-0.218	-0.004	1.000	
ZN	-0.496	-0.128	-0.100	1.000

Site 2

	CD	CU	PB	ZN
CD	1.000			
CU	-0.378	1.000		
PB	-0.137	-0.053	1.000	
ZN	-0.304	0.183	0.588	1.000

Site 3

	CD	CU	PB	ZN
CD	1.000			
CU	0.543	1.000		
PB	-0.089	-0.112	1.000	
ZN	0.056	-0.122	0.632	1.000

Site 4

	CD	CU	PB	ZN
CD	1.000			
CU	0.227	1.000		
PB	0.636	0.565	1.000	
ZN	0.731	0.541	0.869	1.000

Site 5

	CD	CU	PB	ZN
CD	1.000			
CU	0.270	1.000		
PB	0.381	0.600	1.000	
ZN	0.128	0.276	0.634	1.000

Site 6

	CD	CU	PB	ZN
CD	1.000			
CU	0.032	1.000		
PB	-0.226	0.116	1.000	
ZN	0.144	-0.163	0.156	1.000

Site 7

	CD	CU	PB	ZN
CD	1.000			
CU	0.162	1.000		
PB	-0.096	-0.124	1.000	
ZN	-0.243	-0.105	0.071	1.000

Site 8

	CD	CU	PB	ZN
CD	1.000			
CU	0.343	1.000		
PB	-0.240	-0.426	1.000	
ZN	0.365	0.408	-0.156	1.000

Site 9

	CD	CU	PB	ZN
CD	1.000			
CU	.	1.000		
PB	.	0.216	1.000	
ZN	.	0.343	-0.056	1.000

Site 10

	CD	CU	PB	ZN
CD	1.000			
CU	.	1.000		
PB	.	0.355	1.000	
ZN	.	0.426	0.234	1.000

Site 11

	CD	CU	PB	ZN
CD	1.000			
CU	0.168	1.000		
PB	0.681	-0.100	1.000	
ZN	-0.054	0.558	-0.193	1.000

Table 4: Pearson correlation matrix results for sediment metal results by site.

The scatterplot matrix is a convenient summary that shows the relationships between each metal. The intersection of a column and row is the scatterplot of the row metal on the vertical axis against the column metal on the horizontal axis. Superimposed on each cell is the linear regression line. The size and shading of each point in the individual scatterplots depicts the influence of that point in the scatterplot on the correlation coefficient ie., the amount the correlation would change if that point were deleted. The plotting of such influences helps to determine whether a linear fit to the scatterplot is relatively robust or is dependent on just a few points. Positive influences are represented by hollow symbols and negative influences by filled symbols.

Examination of table 4 shows that only site 4 appears to have any significant correlations between metal concentrations. The scatterplot matrix for site 4 is reproduced below. Omitting points that have overt influences upon individual correlations, shows that the only relatively robust relationship is that between lead and zinc.

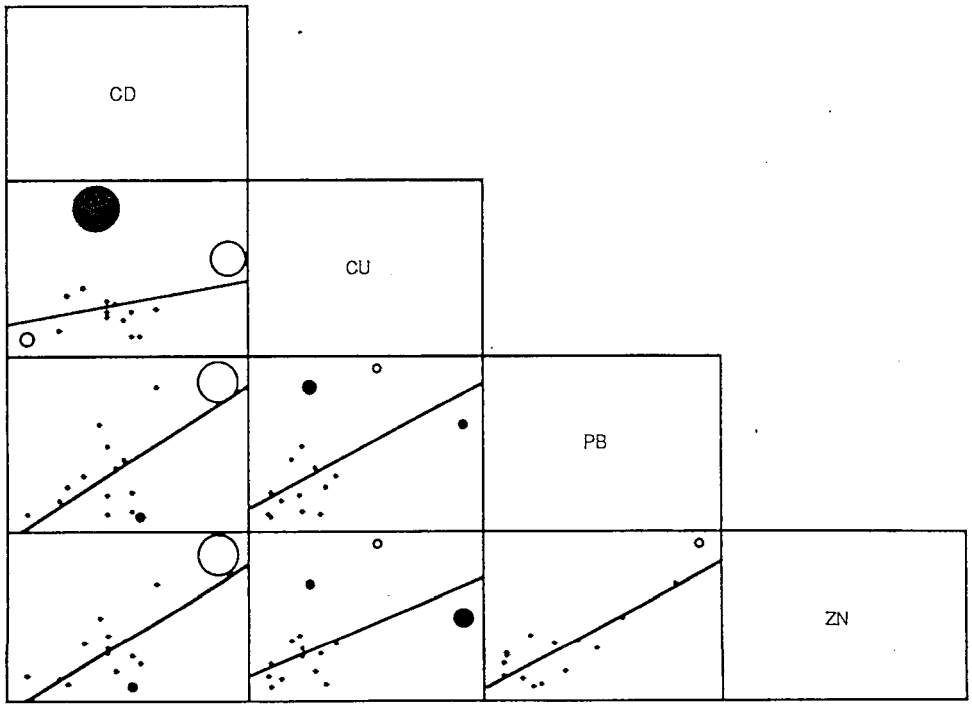


Figure 5: Scatterplot matrix for sediment metal results from site 4.

3.2 Waters

3.2.1. Bacteriological Analysis

Figure 57 and 58 appendix 1 present total and faecal coliform results from sampling performed by the Lae City Authority during the period 24th September 1985 to the 30th May 1990 and analysis by this laboratory. The sampling points form a geographical cross-section of the entire Lae city waterfront. As can be seen, the entire Lae waterfront is polluted by sewage input. Points of particularly high coliform organism counts are the Main Wharf area and the mouth of the Bumbu River. Both these areas receive large amounts of run-off from domestic sewage from numerous squatter settlements. The scales on figure 57 and 58 may lead to the conclusion that the Markham River does not suffer to a great extent from sewage pollution. The Markham River is also highly contaminated from sewage input making it unfit for human consumption by the PNG Drinking Water Standards, it is only when compared to the extremely high sewage pollution problem of the Main Wharf and the Bumbu River that the relative importance diminishes. The total and faecal coliform counts in the Markham River are not surprising considering that the Markham River receives the sewage input from the population of the entire Markham Valley and the Wau/Bulolo area.

Interpretation of the data is difficult. The sampling was performed by the Lae City Authority from the shore at the various sites and no records of the time of day the sample was taken, weather conditions, wind direction etc were kept. All these factors influence the total and faecal coliform count, and interpretation of the time series without this data is impossible. For instance, the 'night-bin' disposal station is situated at Stewart Park. The contents of the 'night-bins' are simply dumped into the ocean at this site. Therefore if dumping was occurring preceding sampling, and the tide and wind were in the correct direction, very high results for total and faecal coliform counts would occur. Conversely, if sampling was performed late in the morning after dumping had finished and the tide receded with off-shore winds, low total and faecal coliform counts would result. This highlights the need for coordinated monitoring by various Governmental and private authorities that SPREP is trying to foster, otherwise, much time, effort and money is simply wasted.

Figures 66 to 90 present the microbiological parameter results obtained. Faecal streptococci were measured as there is evidence in the literature that these organisms survive longer in salt water, therefore, being a better indicator of sewage contamination.

In general, total and faecal coliform counts were higher in the surface samples than the samples taken from a depth of 5 meters. Jacobs and Ellis (1991) state that an occurrence of faecal coliform/total coliform (FC/TC) ratios of greater than 0.1 reflects a water body which is polluted by sewage, although this may be largely of animal origin. All the sample stations except for sites 9, 10, and 11 had FC/TC ratios greater than 0.1 for the surface samples. Only sample sites 2 to 6 has FC/TC ratios greater than 0.1 for the samples taken from a depth of 5 meters. All ratios are calculated using the average of the results for the samples collected during the period 03/06/92 to 11/11/92.

Faecal coliform/faecal streptococci (FC/FS) ratios provide information on possible sources of the sewage contamination. A FC/FS ratio of greater then 4:1 is considered indicative of pollution derived from domestic wastes composed of human excrement, whereas, FC/FS ratios less than 0.7 suggest sewage pollution due to animal origin (APHA, 1985). All sample stations recorded a FC/FS ratio greater than 4:1 except for sites 3, 4 and 5 for the surface samples. Only sample site 4 has a FC/FS ratio less than 4:1 for the samples collected at a depth of 5 meters.

Interpretation of the FC/FS ratios needs to take into account the following precautions (APHA, 1985);

- streptococcal densities can be altered significantly if water pH is above 9.0 or below 4.0
- sample as close as possible to the pollution source because faecal streptococci have relatively short lives outside the animal host. Points downstream where travel time from pollution sources exceeds 24 hours will provide erroneous ratios
- differentiating between human and animal sources of sewage must be carefully made in waters sampled from marine and estuarine systems
- ratios should not be used when the faecal streptococcus counts are below 100 colonies/100mL.

Narrative PNG criteria for the protection of aquatic life state that median faecal coliform organisms should be less than 100 colonies/100mL as calculated for greater than 5 samples collected over a 30 day period. Sites 1 to 6 exceeded this criteria for faecal coliforms. While PNG does not have criteria for total coliform organisms in water, except for potable waters which is inappropriate for comparison with the marine and estuarine waters collected, USEPA criteria for protection of aquatic life were exceeded for sites 1 to 7.

3.2.2 Nutrients and General Parameters

Tables 3 to 6, appendix 2 and figures 59 to 65, appendix 1 present the results of the measurement of salinity, dissolved oxygen and temperature in a transect from the mouth of the Markham River to Halfway Reef in the Huon Gulf. These results shows that the Markham River extends a large influence on the Huon Gulf. Halfway Reef is approximately 15 kilometres from the Mouth of the Markham River. The salinity transect results (graph 3) show that even at this distance, there is still a layer of partially mixed fresh water up to three meters deep. Factors such as salinity, dissolved oxygen and total suspended solids have a large influence on the fate and transport of pollutants, especially trace metals.

Tables 10 to 11, and figures 28 to 39 present the physical parameter results obtained to date. The results show that the waters of the Lae city waterfront are highly turbid containing relatively large amounts of suspended material. This has impact on the biological productivity of the waters. The highly turbid nature of the water means little light penetrates below the top few centimetres, which limits the growth of algae and phytoplankton. Further, the large amounts of settling sediment smother newly recruited shellfish. It is not surprising that no shellfish are found attached to rocks or piers situated on the Lae city waterfront.

In general, total suspended solids are approximately equivalent for samples collected at the surface, and samples collected at a depth of 5 meters for all sample sites except site 6, the Markham River Mouth. This indicates all the sample sites were relatively homogeneous, with respect to suspended solids, except for the Markham River mouth which was indicative of a salt-wedge estuary. Similar results were obtained for turbidity.

Station		NH_3-N mg/l	NO_2-N mg/l	NO_3-N mg/l	PO_4-P mg/l	Sil.-Si mg/l
St.1	S	0.08	0.001	0.001	0.01	0.433
	B	0.11	0.002	0.001	0.01	0.437
St.2	S	0.15	-	0.002	0.03	0.922
	B	0.11	0.003	0.003	0.01	0.347
St.3	S	0.09	-	0.001	0.03	1.166
	B	0.10	-	0.001	0.01	0.374
St.4	S	0.09	-	0.002	-	0.845
St.5	S	0.09	-	0.003	-	0.833
	B	0.07	-	-	0.04	0.921
St.6	S	0.07	0.002	0.004	0.02	0.480
St.7	S	0.04	0.003	0.003	0.02	1.563
St.8	S	0.09	0.003	0.004	0.04	9.510

S: Surface, B: Bottom, -: not detected

Table 5: Inorganic nutrient contents at Salamaua peninsula (Inoue et al., 1990)

Tables 13 to 15 appendix 2 presents the chemical parameter results obtained to date. These results indicate that there is no significant problem with nutrient pollution input, and compare well to the results obtained by Inoue et al., which are presented in table 5. In general, total phosphorus concentrations were higher in the surface samples than the samples collected at a depth of 5 meters for all sample sites. Similar results were obtained for nitrate, with nitrate concentrations in the samples collected at a depth of 5 meters generally being at the limit of detection.

4.0 Conclusions

Regionally based and coordinated environmental pollution monitoring is of prime importance. This will limit the expenditure of resources on projects that generate numbers instead of data, as exemplified by the Lae City Authority bacteriological data. Funding of pollution monitoring programmes and baseline studies by bodies such as SPREP is important, as local authorities generally do not have the money or expertise to realise the need for such exercises. This is shown by the construction of a major cement factory on the Lae City waterfront without detailed prior environmental impact assessment.

The results obtained to date for bacteriological analysis of water samples collected from the Huon Gulf show that the Lae City waterfront is grossly contaminated by sewage. Narrative PNG criteria for the protection of aquatic life for faecal coliform organisms were exceeded at sites 1 to 6. While the sampling, which was performed on a monthly basis, does not allow strict interpretation against the water quality criteria which are stated in terms of more intense sampling performed over periods of generally 30 days, USEPA and ANZEC standards for total coliforms were also exceeded. The FC/FS and FC/TC ratios tentatively suggest that the sewage is predominantly derived from domestic wastes composed of human excrement, except for site 4 (the main wharf area).

The bacteriological results show that Papua New Guinea, at least in the vicinity of Lae, is failing to apply standard water quality control methods developed over almost a century in Europe and North America. Domestic sewage inevitably carries a variety of human pathogens, and the high levels of total and faecal coliforms found in the coastal waters of Lae give rise to even greater concerns, considering that this coastal marine sewage pollution is the result of inputs from a small number of fresh water creeks and rivers draining the Lae city area. Due to mortality induced by the increased salinity and natural dilution with the seawater, even higher levels of total and faecal coliforms are to be expected in the fresh water creeks and rivers. The majority of the population of Lae rely upon these rivers and creeks for bathing and laundering purposes, although drinking water is predominantly from the reticulated supply. The plans to promote tourism directed towards the sunny and warm-water beaches will be hampered by the polluted seawater surrounding Lae.

A comprehensive surveillance programme should be established in conjunction with the Lae City Authority, the WaterBoard and the Department of Health to identify, and facilitate the elimination of the sources, of contamination to the coastal and fresh waters of the Lae City area. To develop a surveillance programme to enable protection of health, it is vital that all those factors which indicate the quality of water should be reported.

This will avoid difficulties in data interpretation as found in the Lae City Authority bacteriological data, and allow clear identification of causes and effects, giving information suitable to base remedial action upon.

Further, the surveillance agency should be adequately funded to enable the identification and evaluation of all conditions that pose a danger to human health, and health of the environmental in general, on an ongoing routine basis.

Sediment metal results indicate that the Lae Waterfront has possibly been contaminated by anthropogenic inputs of copper, zinc and lead, with enrichment factors of between 2 and 10. However, due to the lack of suitable baselines, unknown natural variability of system, and the limited data set, the significance of the concentrations of copper, zinc and lead found is uncertain.

This uncertainty is largely due to the nature of the sampling and analysis programme undertaken, as it has been well established that comparing total metal concentrations between whole sediments of different textures and or compositions is of limited utility (Luoma, 1990). It is recommended that instead of bi-monthly grab samples, a comprehensive programme based upon normalisation to a conservative element such as aluminium, combined with separation and direct analysis of the <63 μm sediment fraction should be implemented. This will give a sound basis upon which to establish comparability of sediments and allow firm conclusions about possible metal pollution problems and abatement measures.

4.1 Future Work

The results obtained for bacteriological analysis of water samples collected from the various sites in the Huon Gulf show that the Lae city waterfront is grossly contaminated by sewage. In most cases, the FC values obtained were above those considered acceptable. Considering the great variation in the Huon Gulf, the effects of contaminants on the system itself and on bathers and shellfish consumers is also expected to vary. Some special conditions due to the effects of wind, tidal amplitude and volume of sewage discharge, could create conditions of great risk to human health. The presence of a significant amount of suspended material in the water, especially organic matter, provide a substrate to which bacteria can attach and thrive. Streptococci contamination would be a major concern.

Domestic sewage inevitably carries a variety of human pathogens, and the high level of total and faecal coliforms found in the coastal water gives rise to even greater concerns, considering that this coastal marine sewage pollution is the result of inputs from a small number of fresh water creeks and rivers draining into the Lae city waterfront.

Due to mortality induced by the increased salinity and natural dilution with the seawater, even higher levels of total and faecal coliforms are expected in the fresh water creeks and rivers. The majority of the population of Lae rely upon these rivers and creeks for bathing and laundering purposes, although drinking water is predominantly from the reticulated supply or rainwater.

It is recommended that a further detailed study is undertaken on the bacteriological quality of the various fresh water creeks and rivers in the Lae city area. Such a study would quantitate the extent of the undoubted bacteriological contamination and locate major point sources. The effects of wind, tidal amplitude and volume of sewage discharge would also be investigated. Such information would give local authorities the knowledge as to which areas to target to achieve the greatest improvement in bacteriological water quality with the limited funds at their disposal.

Water samples collected for nutrient methods development showed a large temporal variation between days. This indicates that a more intensive sampling programme with a greater frequency is required to determine the actual variability of the system. Such a programme would involve bi-daily (high and low tides) water sampling for a week to examine the temporal homogeneity of the sample area with regards to nutrients. Such sampling could then be repeated at various times of the year to investigate seasonality.

The recently purchased total organic carbon analyser and anodic stripping voltammeter would allow the future determination of trace metals and total organic carbon in seawater. Total organic carbon is used as a prime indicator of hydrocarbon pollution. This is pertinent as Lae has a major petroleum products unloading facility operated by the Shell, BP and Mobil oil companies. Trace metal pollution is of obvious importance, in particular, considering that a cement factory is currently operating on the Lae Waterfront. Such future work would focus on targeting of pollution point sources.

An investigation into the levels of tributyl (TBT) in the waters, sediment and shellfish of the Huon Gulf is currently underway. Appendix 3 details the methods development and initial literature survey completed to date. Due to the bathometry and hydrology of the Markham River and the Huon Gulf, TBT is not expected to be a major problem in the Lae area. However, enclosed harbour sites such as Port Moresby, Madang and Rabual are potential areas in which TBT concentrations may be of concern. Once the

method development phase is completed, it is hoped that the sampling can be increased to encompass these other PNG sites.

The results of the sediment metal analysis indicate that the Lae waterfront has been contaminated by anthropogenic inputs of copper, zinc and lead. However, this conclusion is based upon various comparisons with data reported in the literature of known unpolluted sites since there is no direct evidence regarding the metal content of sediments in the Huon Gulf prior to industrialisation and urbanisation of the area. Therefore, this conclusion must be viewed with caution. Unfortunately, the total metal contents of sediments that were determined is known to be of limited utility for the comparison of metal concentrations, among whole sediments of different textures and or composition. This was observed during this study in the comparison of "reef" and "non-reef" sites, in that the "reef" sites were not suitable as a baseline for the interpretation of sediment metal levels in the Lae waterfront. This lack of comparability on the basis of uniformity in grain size, composition and origin has important implications for the entire SPREP-POL programme.

There are a number of methods that can be used in establishing comparability which include (Luoma, 1990);

- Identifying homogeneous populations of sediment
- Separation of fine-grained sediments
- Normalisation
- Regression Techniques

In order to produce conclusive evidence as to the possible pollution of the Lae city waterfront, and establish rigorous baseline levels that can be used for comparing metal results from other areas, a more intensive sediment metal analysis programme should be instigated that includes the following;

- Determination of "bioavailable" metals and metal speciation using selective extraction procedures.
- Determination of metals normalised to grain size distribution and major element (Al and Fe) concentration.
- Location of metal pollution point sources that may account for the observed increased levels in the Lae city waterfront. This would then allow the targeting of remediation measures.
- Establishment of seasonal, within and between site variability in both metal concentration and grain size distribution.

Another area of future work is the continuation of the study initiated due to concerns about the health of residents of the Wau/Bulolo area, due to the continual use of mercury in the processing of gold ore. Mallard and Hugman (1986) reported medical findings consistent with mercury poisoning of the residents. However, due to the limited sample sizes in their survey, mercury in the hair and urine did not conclusively support these medical results. The authors recommended a more intensive survey to establish the exposure levels of these miners and inhabitants of the area. This is an area of major concern since such gold mining with mercury is still extensively practised. It has been reported in the literature that such practices in countries like Brazil and Indonesia have had major impacts both on human health and on the ecosystem.

5.0 References

APHA, American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 16th Edition, 1985.

Apte, S.C., Akoitai S., Bobonga W., Kabi R., Timi D., Rambis J., Yapis W., Yogonda M, 1991. Trace Metal Distribution in Labu Lakes, An Estuarine Ecosystem in Morobe Province, Papua New Guinea, Science in New Guinea, 17, p63-72

Balat, N, 1989. A preliminary Investigation of Heavy Metal Concentrations in Mangrove Oysters from Labu Estuary, Papua New Guinea

Bowen, H.J.M (1979) Environmental Chemistry of the Elements, Academic Press, London.

Gilmartin, M., (1967) Limnol. Oceanogr. 12, 325-328

Grasshoff K (Ed) 1983, Methods of Seawater Analysis, Verlag Chemie, Weinheim.

Inoue A., Nanba S.,Frohm T., (1990) Kagoshima Univ. Res. Centre S. Pac., Occansional Papers No 20, 20-24

Jacobs J.L., Ellis J.B., (1991), Bacterial water quality in urban receiving waters, Wat. Sci. Tech. 24, 2, p113-116.

Luoma, S.N (1990) Processes affecting metal concentrations in estuarine and coastal marine sediments in Furness R.W., Rainbow P.S (Eds) Heavy metals in the marine environment, CRC Press.

Mallard A.E., Hugman S.J., 1986. The Impact of Mercury on The Bulolo River Valley. Department of Chemical Technology, Report CT/13 University of Technology Lae, Papua New Guinea.

Nordforsk (1971) Interkalibrerign av metoder for bestamning av fosfor, Publ. 6.

Salomons and Forstner (1984) Metals in the Hydrocycle, Springer-Verlag, Berlin.

Strickland, J.D.H., Parsons T.R., (1968) A practical handbook of seawater analysis, Fish. Res. Bd. Ca. Bull. 167.

SPREP/UNEP, Annex III, Report on the Workshop on Development of a Marine Pollution Assessment and Control Programme, Sydney, 16-20 January 1989

6.0 Financial Report

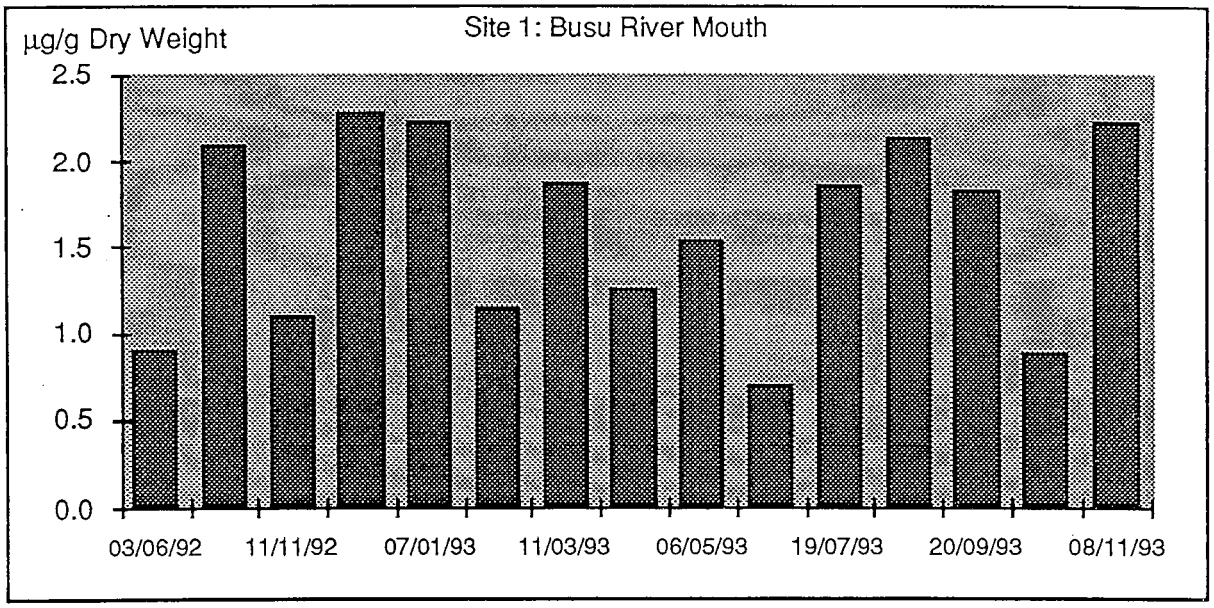
Received US$20,000.00 @ 1.0446 = Kina 18,970.02 which was deposited into the ANZ Bank, Lae on the 06/03/92.

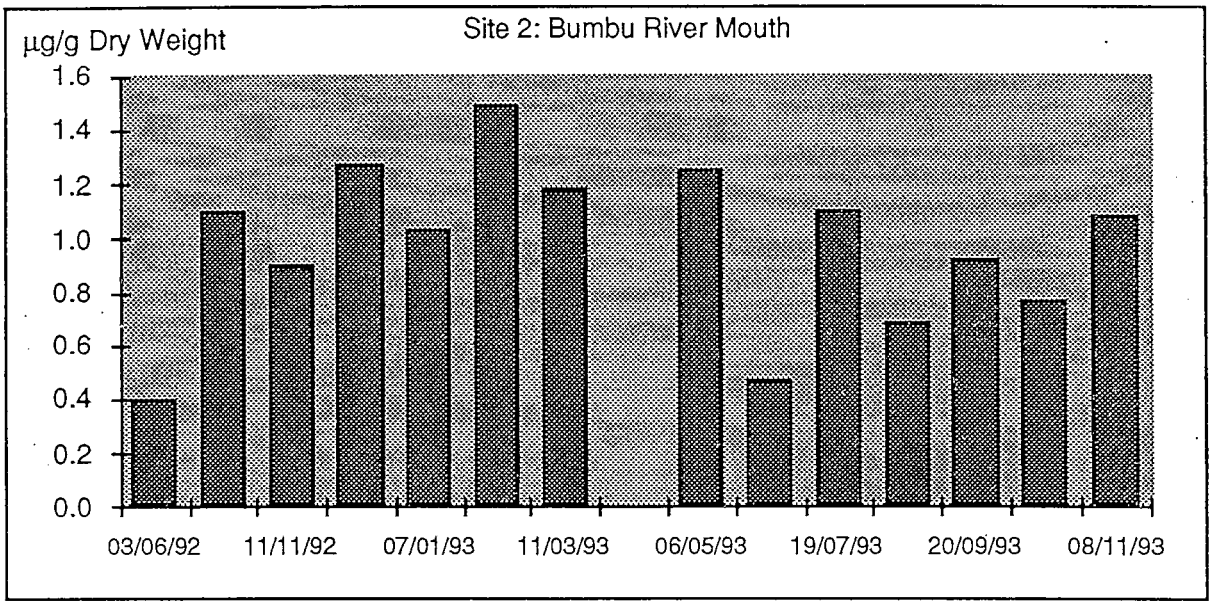
Expenditure to date is detailed in the following table.

Expenditure Category	Amount (Kina) Year 1: 1991	Year 2: 1992	Year 3: 1993
Equipment			
90FL Field meter & accessories		2843.95	
Apple LC-II computer		2893.00	
Materials/Supplies			
4 x 250g peroxodisulphate		480.00	
Reference Material (std sediment) from IAEA			300.00
Stainless steel for construction of sediment sampler			214.00
Travel/per diem	0.00	0.00	0.00
Report Preparation (progress rpt #1)		100.00	
Report Preparation (progress rpt #2)		100.00	
Report Preparation (final rpt #3)			300.00
Personnel costs			
Vivan Kanawi (3 months TA-1)	1287.50		
Analysis costs to end 1992 @ NAL full commercial rates = K16578.00 less 75% discount		4144.50	
Analysis costs 1993 @ NAL full commerical rates = K 24288.00 less 75% discount			6072.00
Others			
Hire of sampling boat		1540.00	0.00
Totals	1287.50	12101.45	6886.00
Grand Total			20274.95

Financial Delegate

W. Benko
Chief Chemist





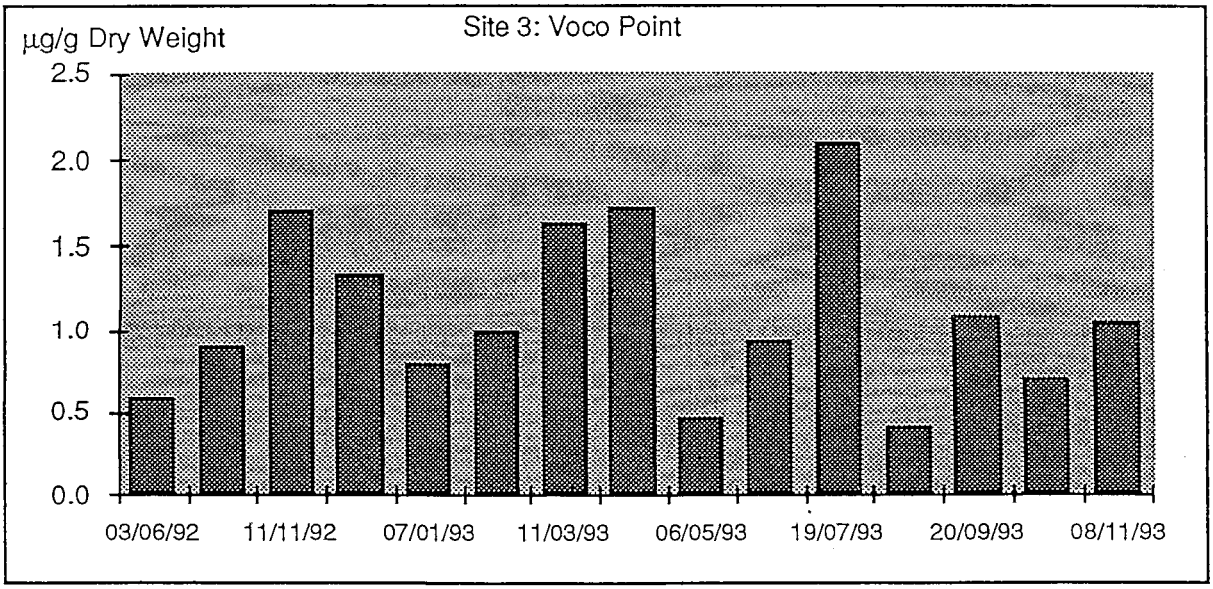
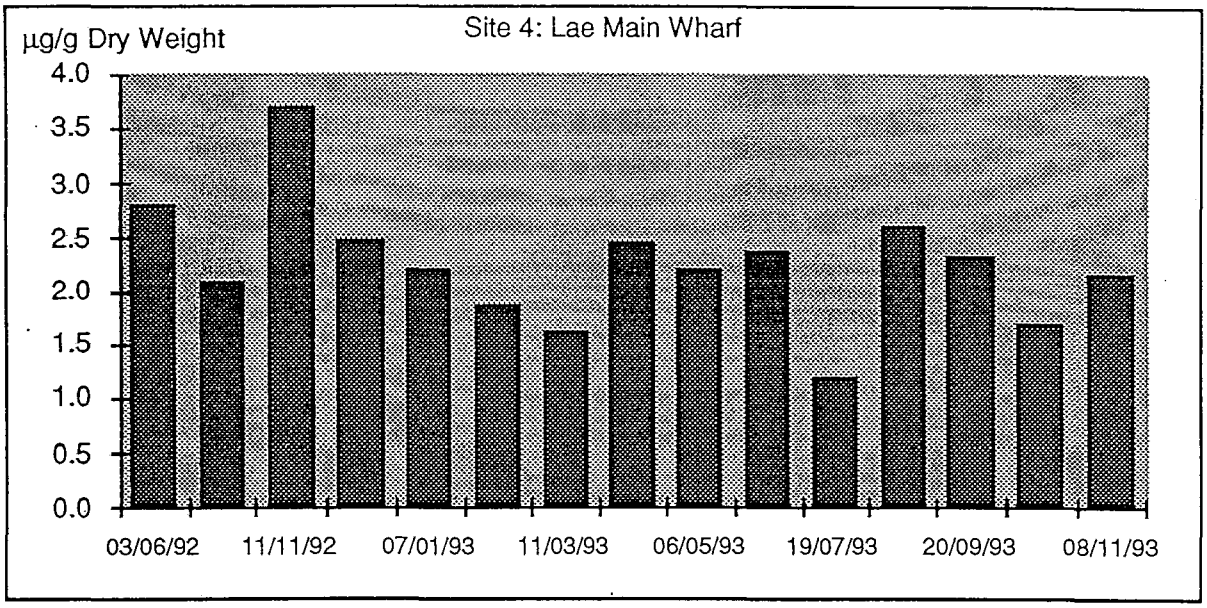
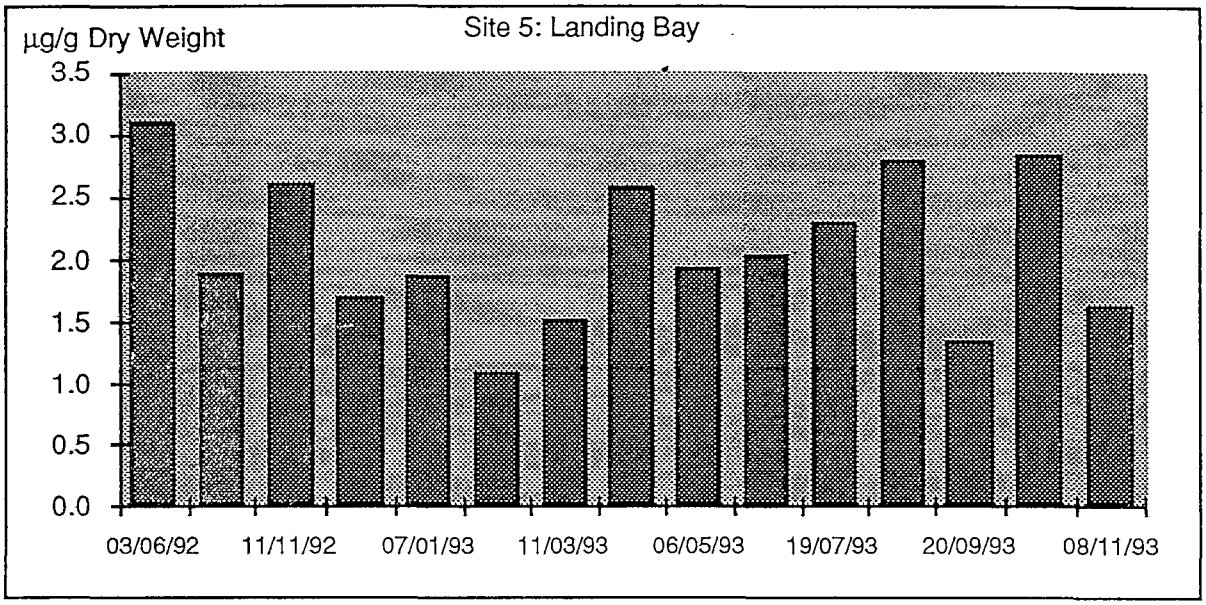


Figure 1: Total Cadmium in sediment samples versus sample date for sites 1 to 3.





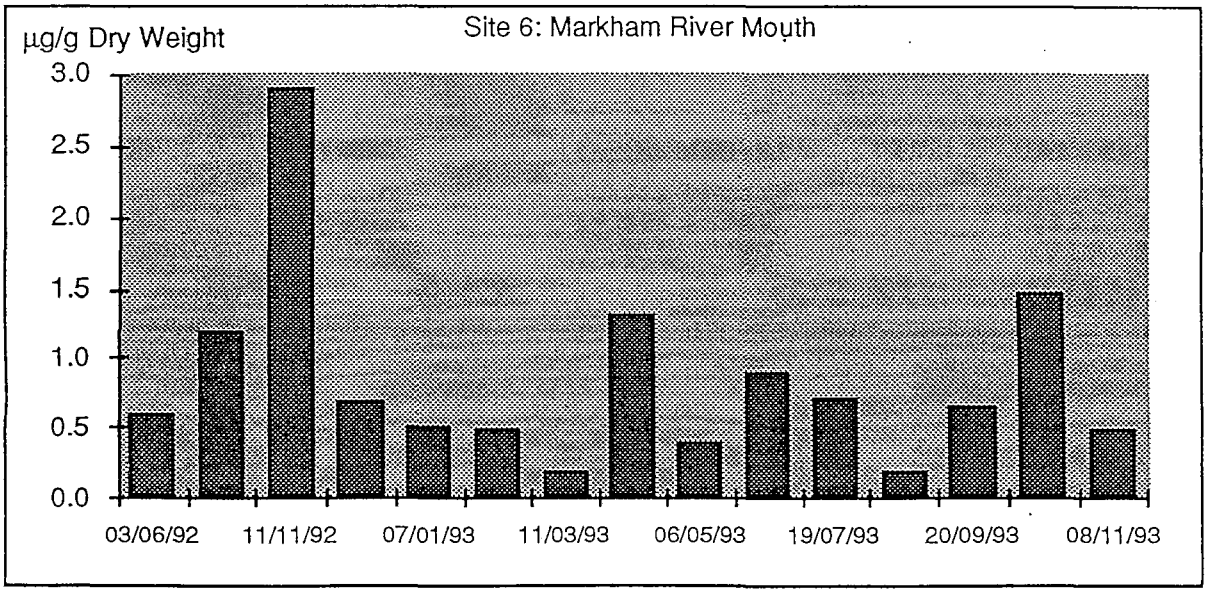


Figure 2: Total Cadmium in sediment samples versus sample date for sites 4 to 6.

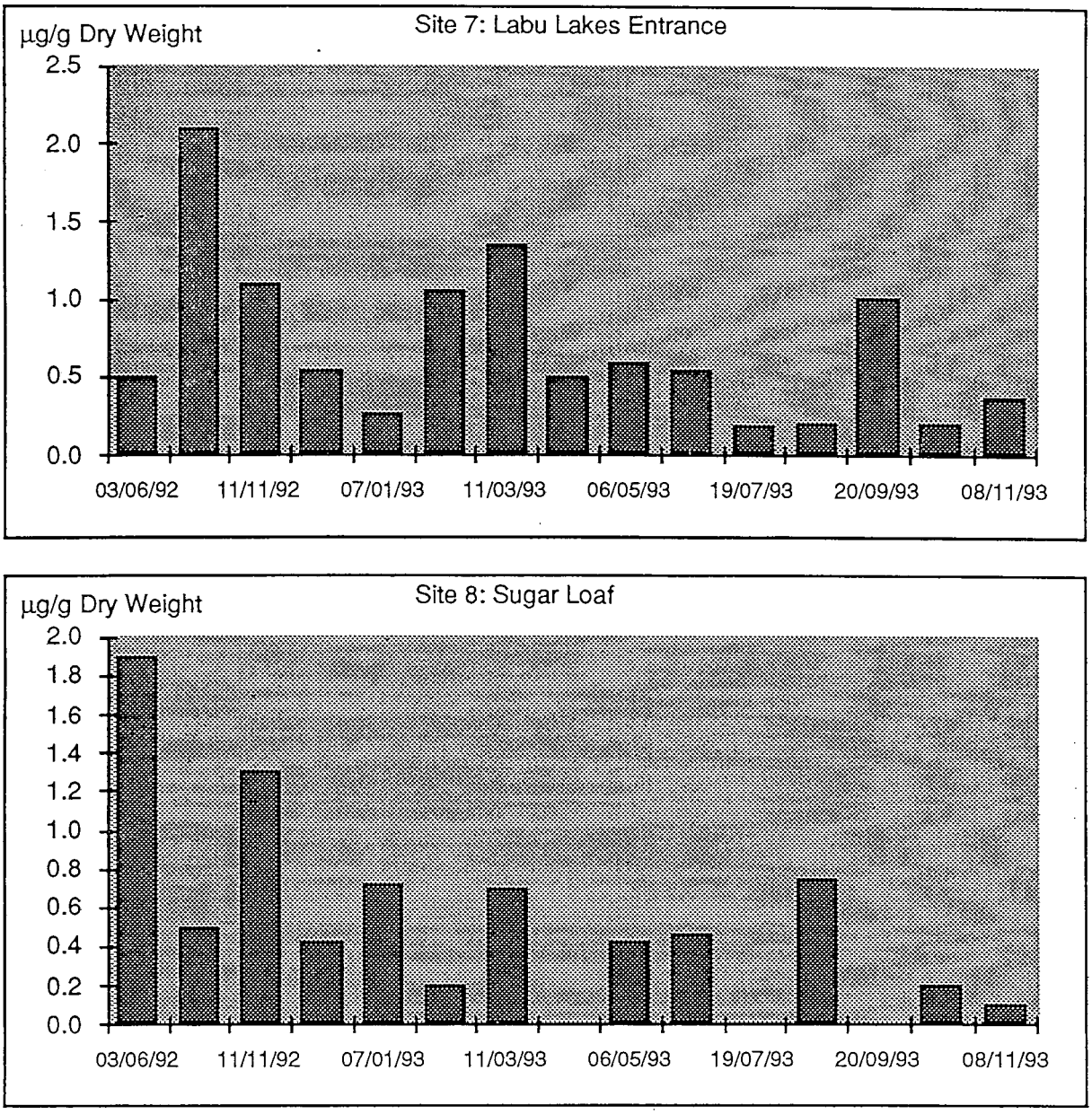
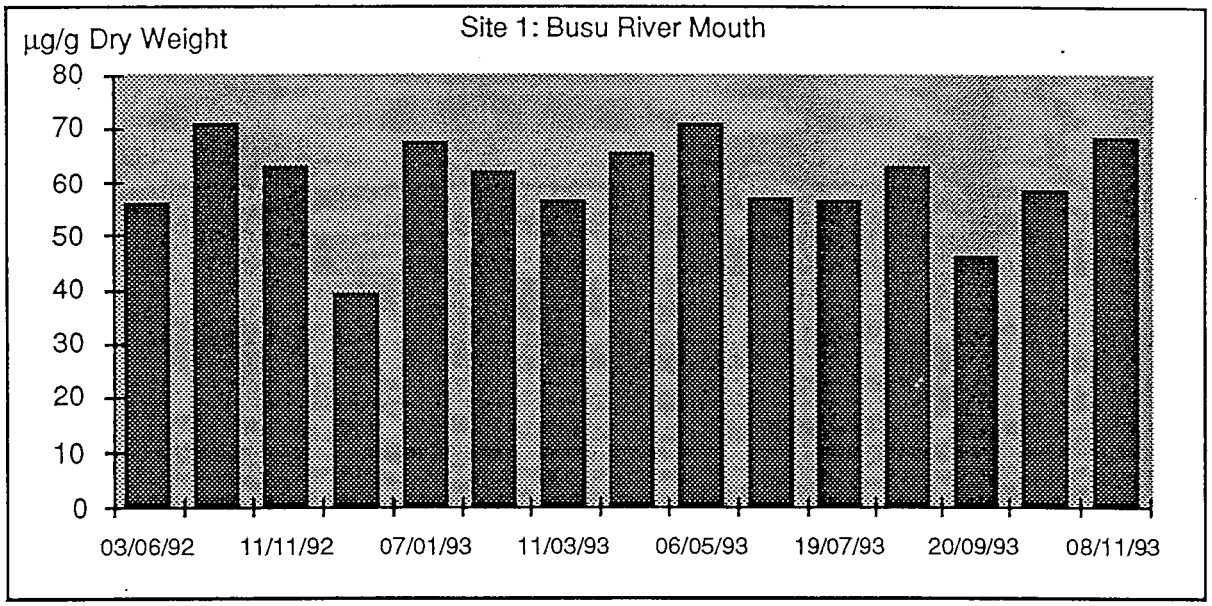
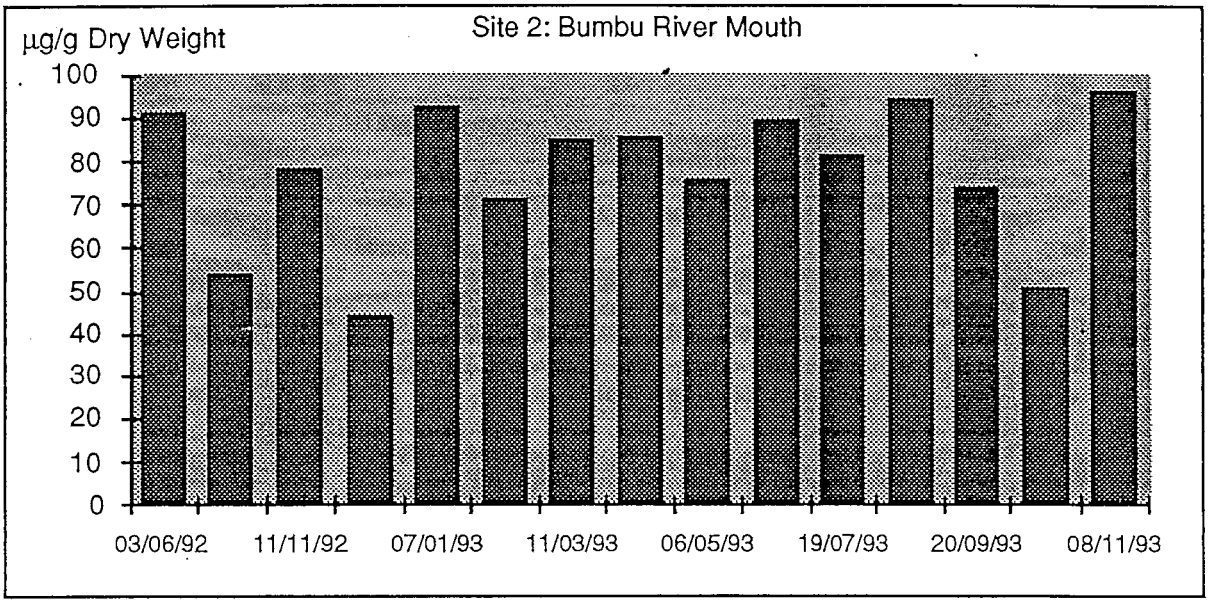


Figure 3: Total Cadmium in sediment samples versus sample date for sites 7 to 8.





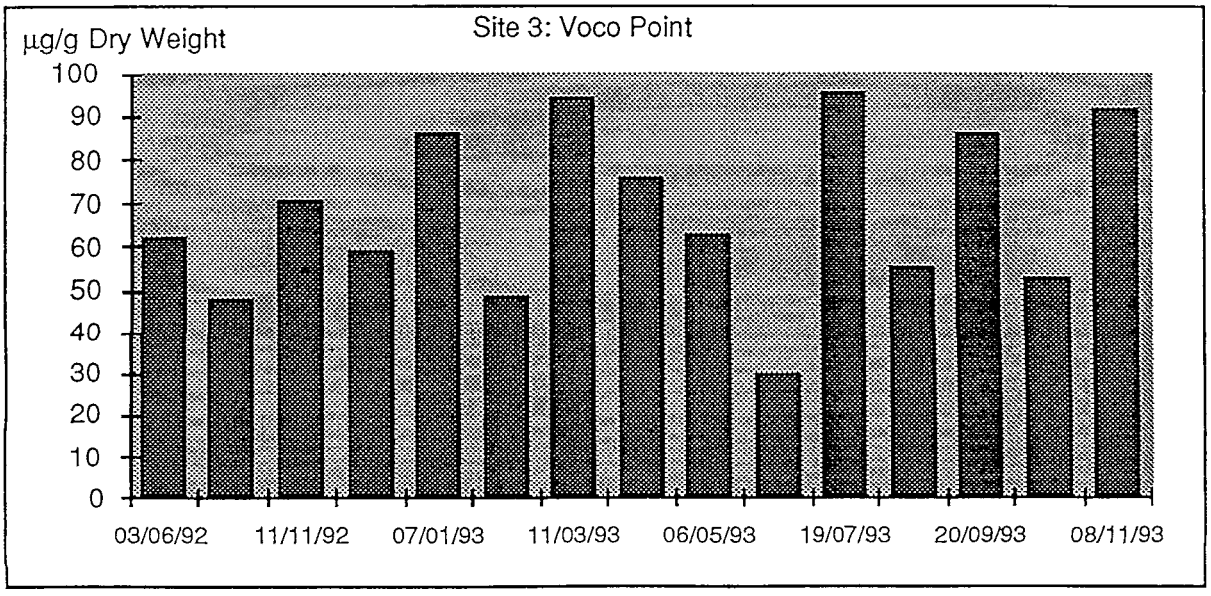
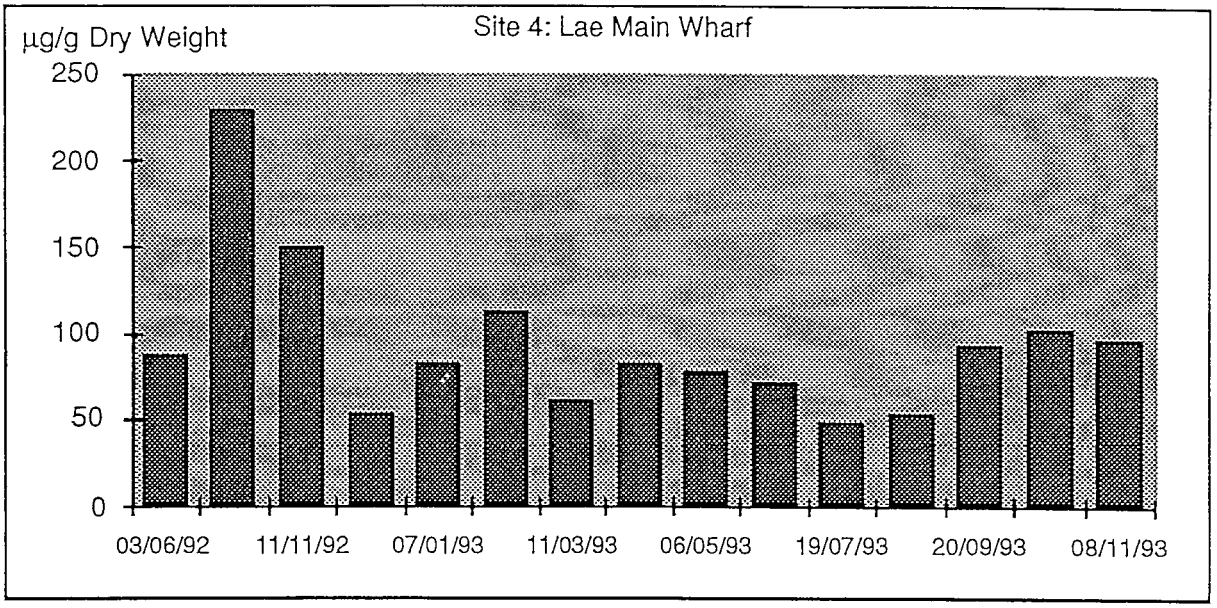
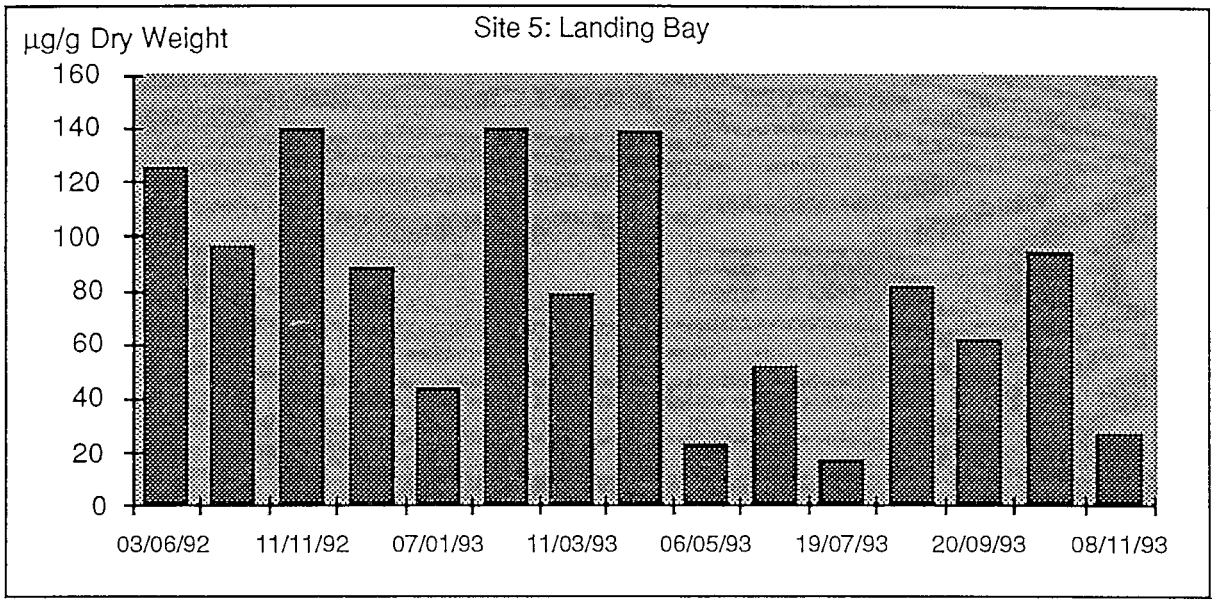


Figure 4: Total Copper in sediment samples versus sample date for sites 1 to 3.





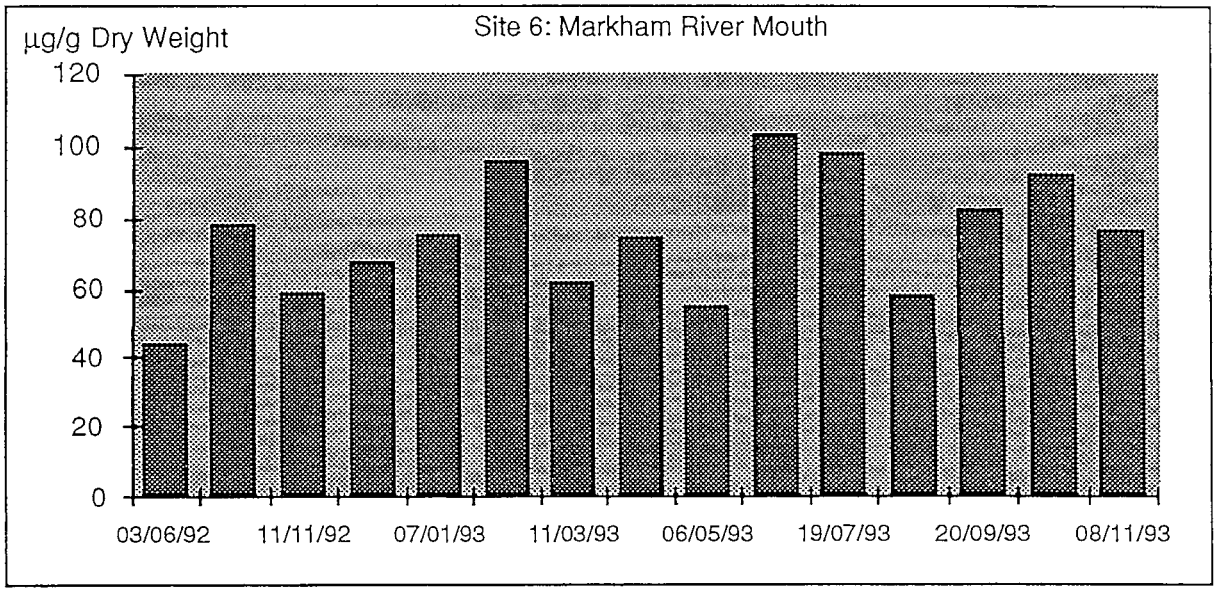
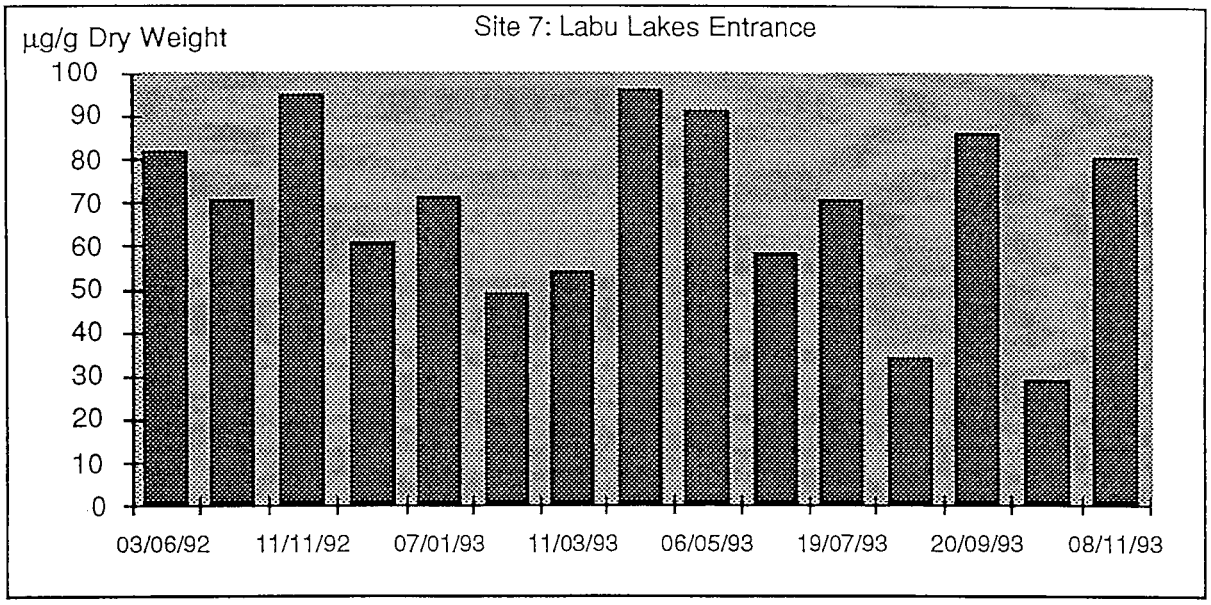
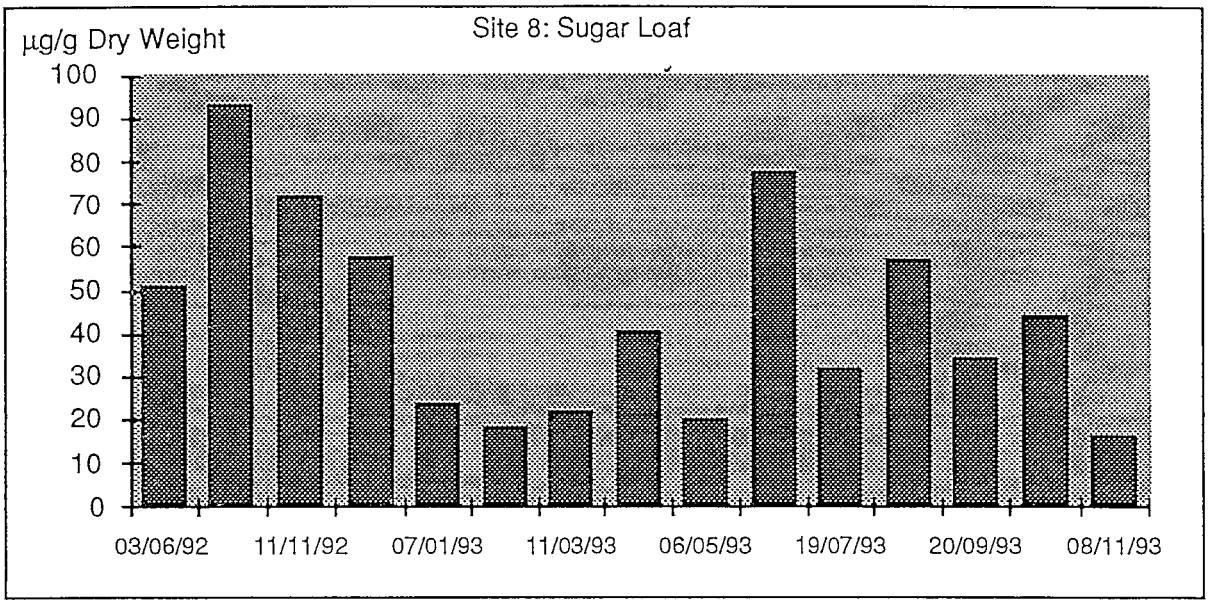


Figure 5: Total Copper in sediment samples versus sample date for sites 4 to 6.





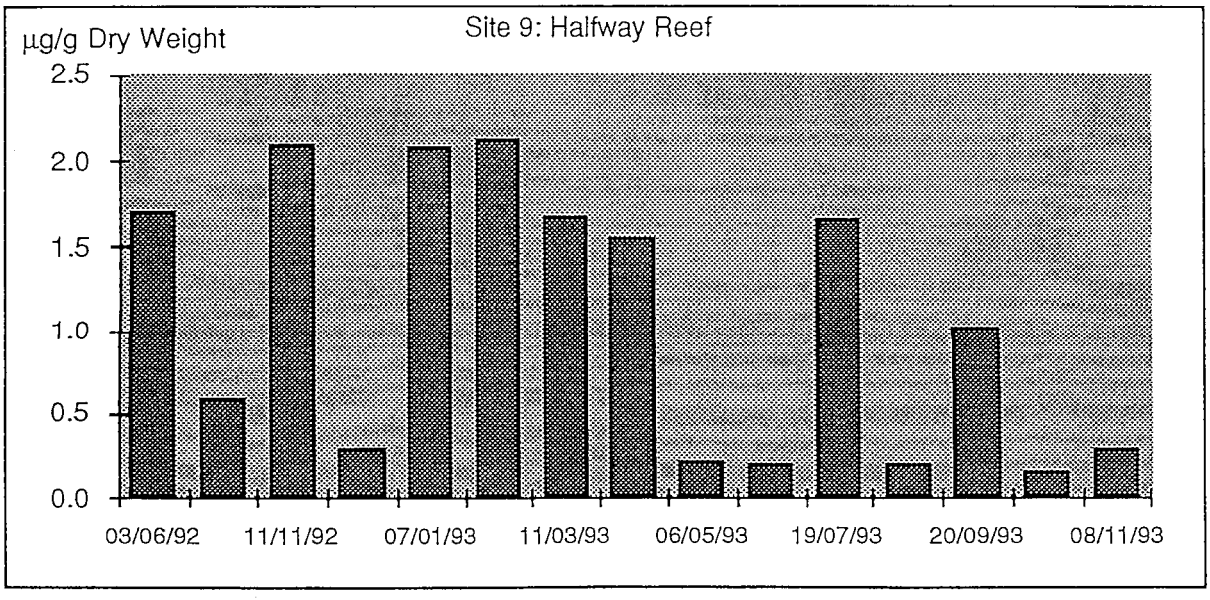


Figure 6: Total Copper in sediment samples versus sample date for sites 7 to 9.

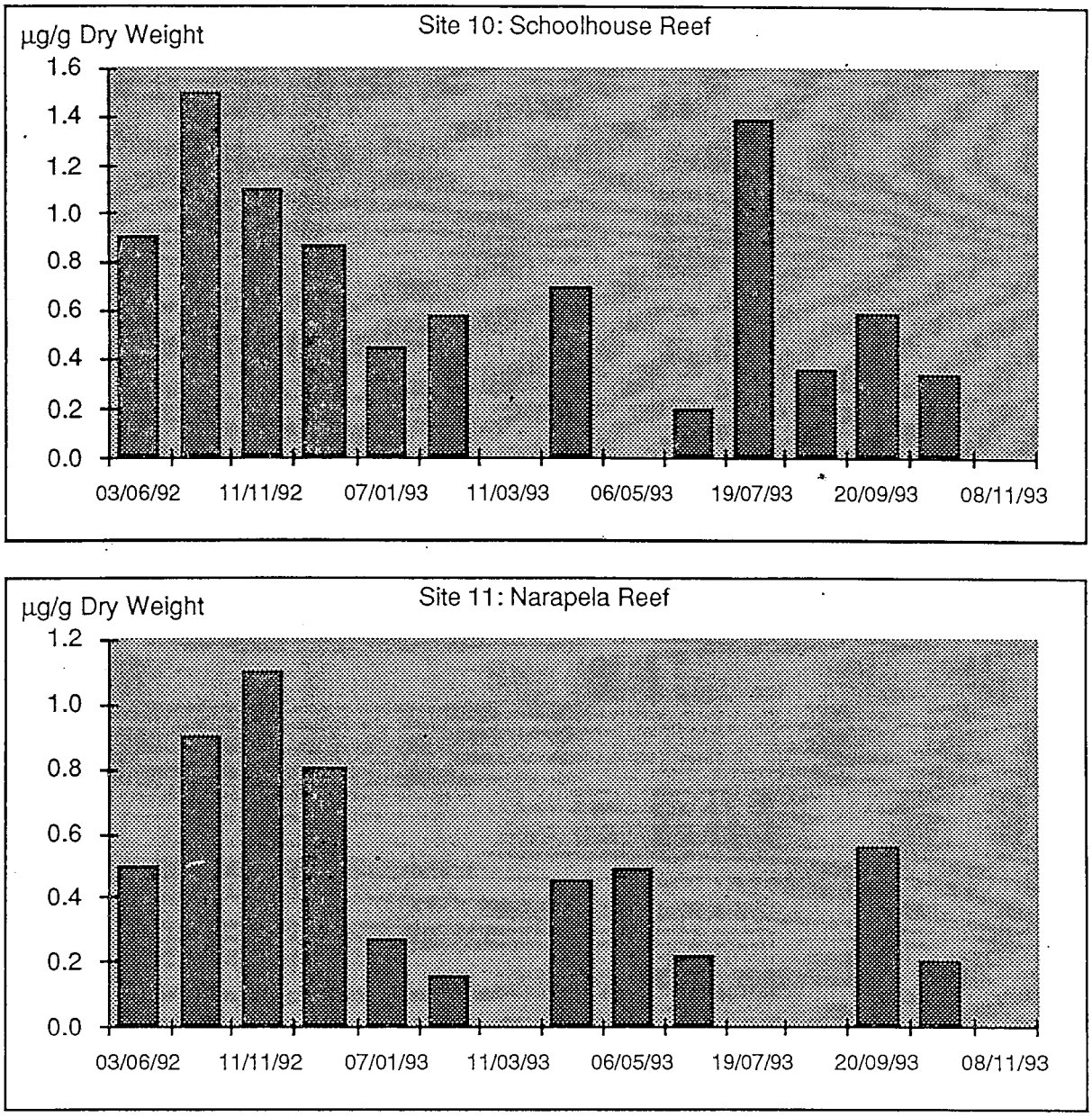
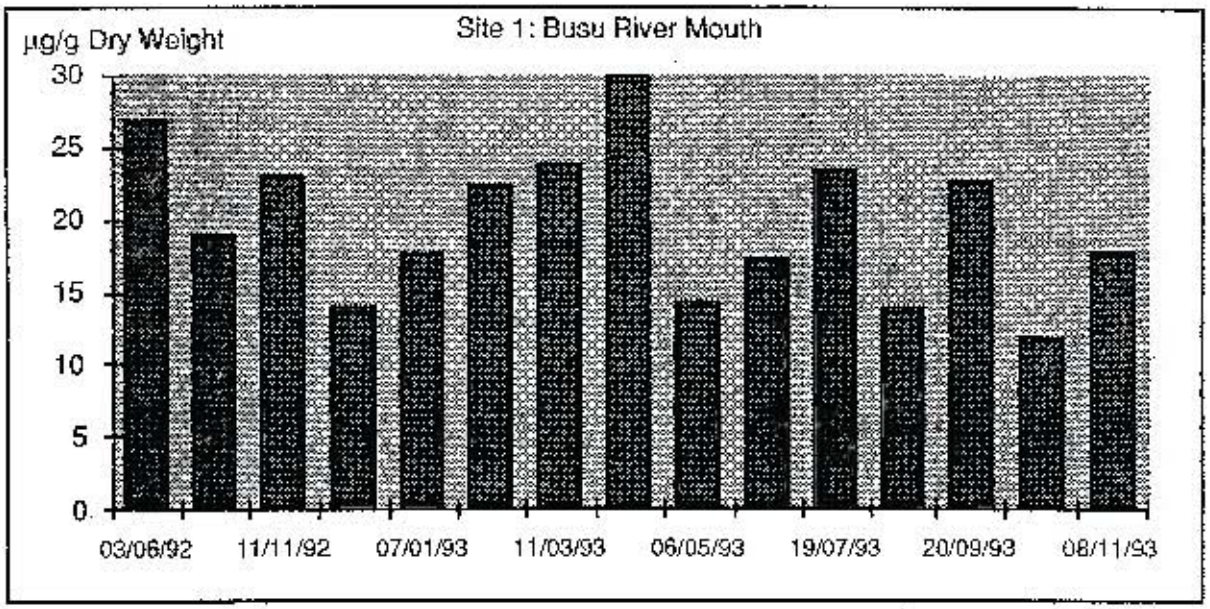
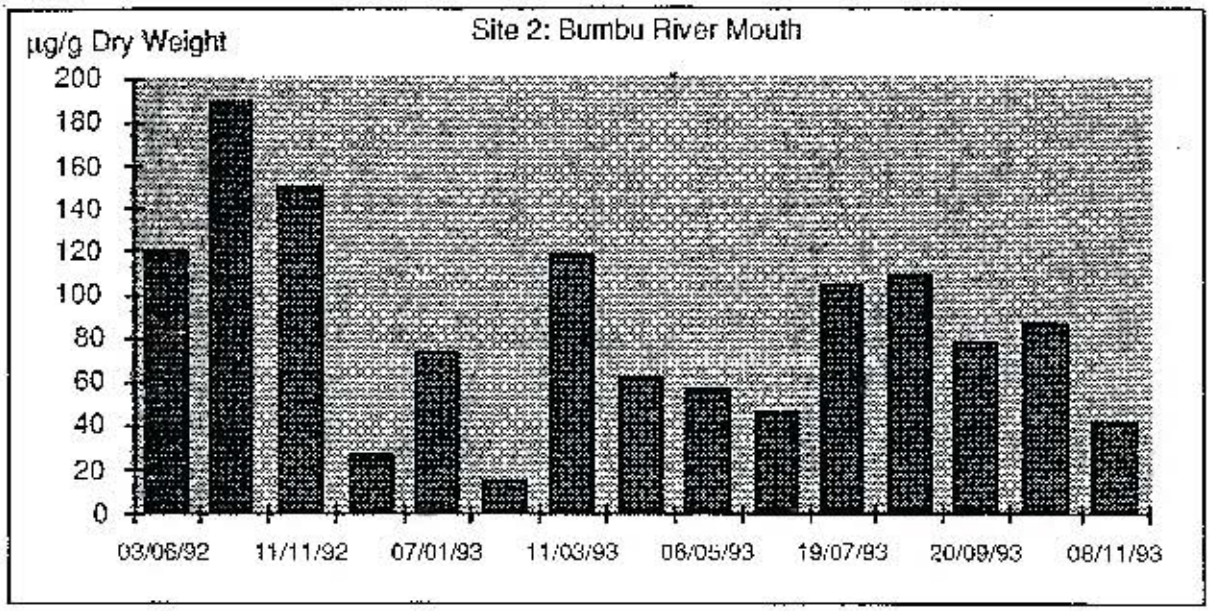


Figure 7: Total Copper in sediment samples versus sample date for sites 10 and 11.





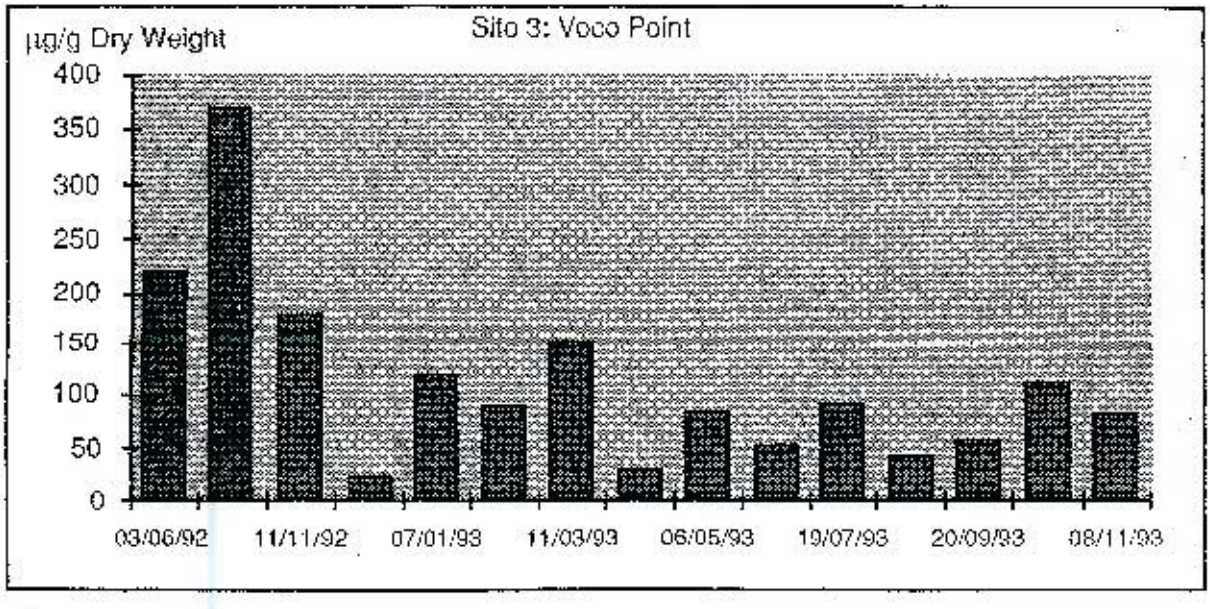
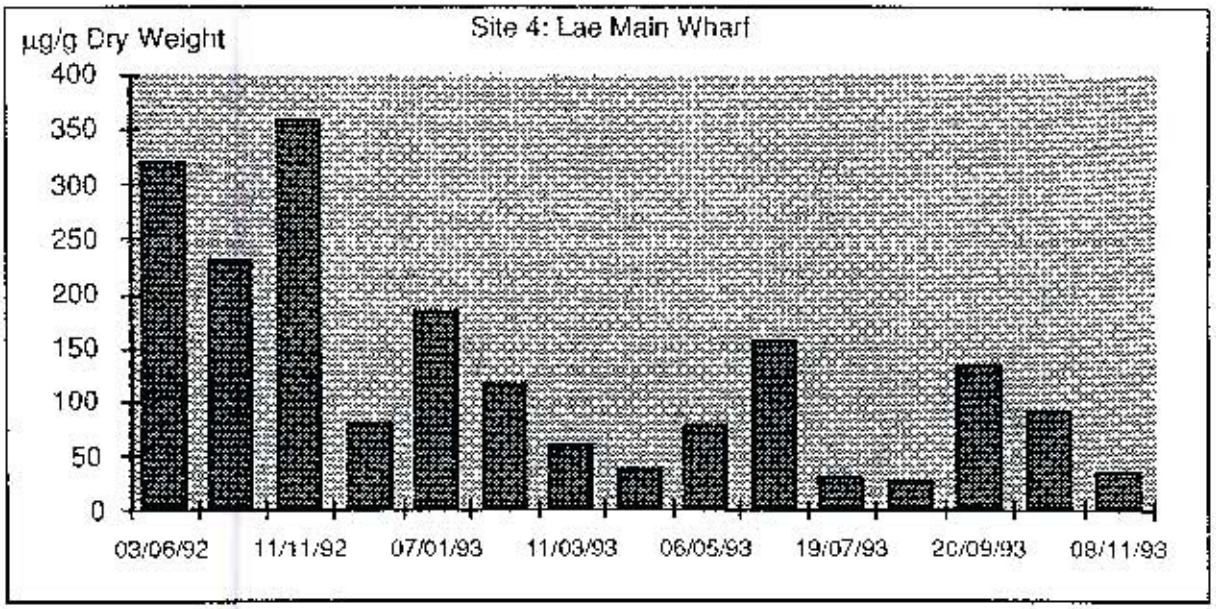
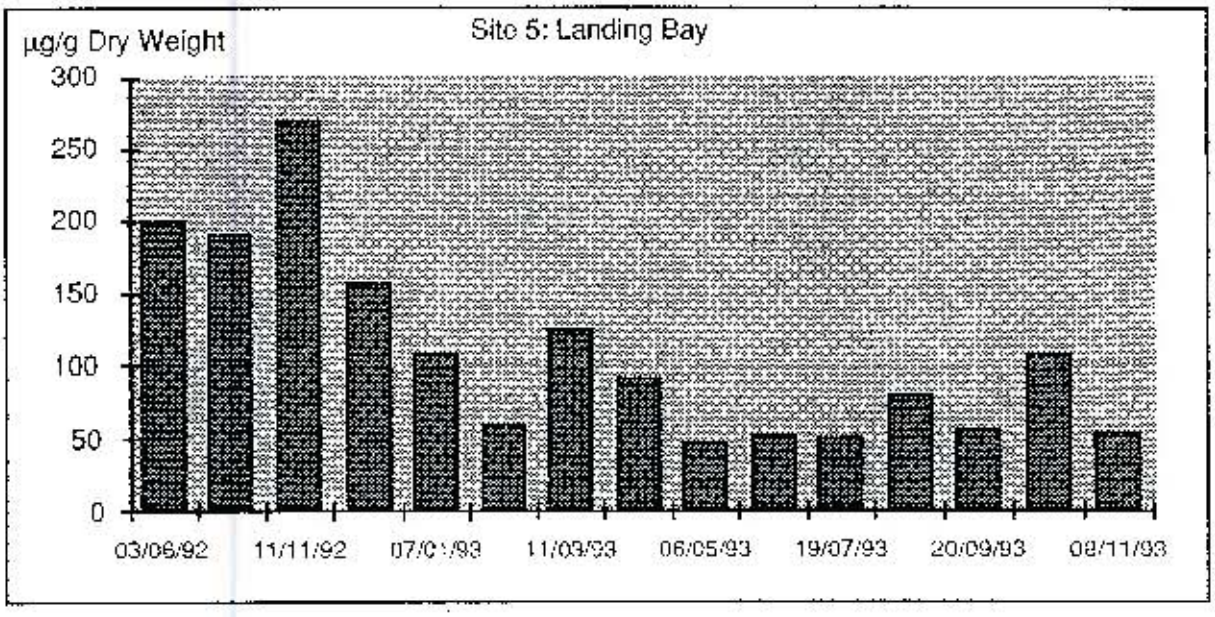


Figure 8: Total Lead in sediment samples versus sample date for sites 1 to 3.





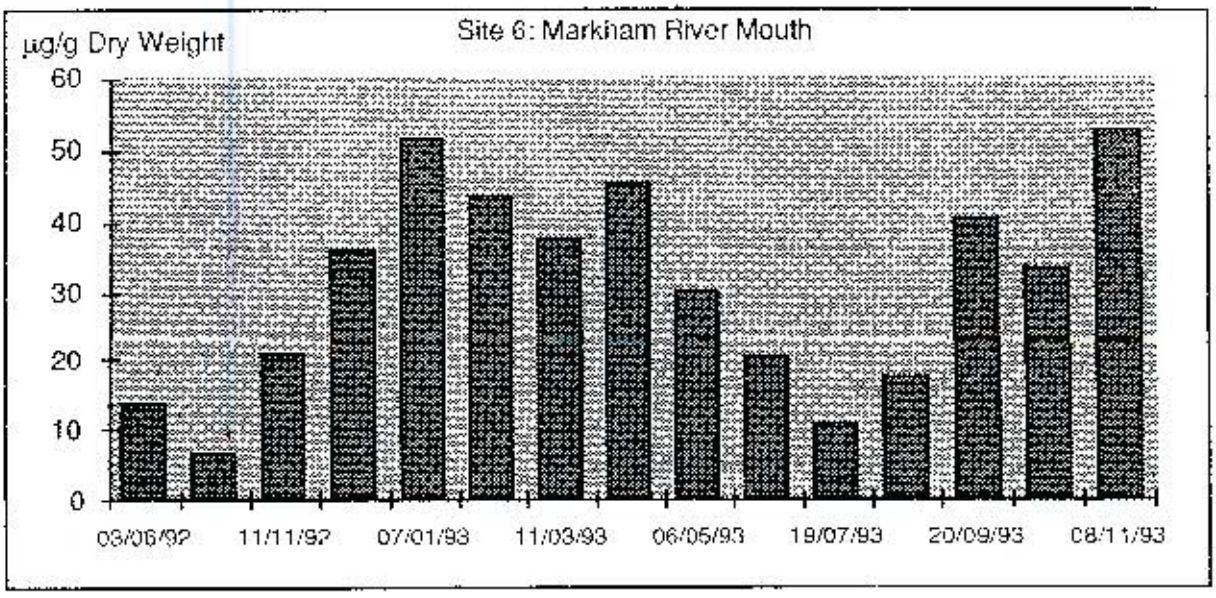
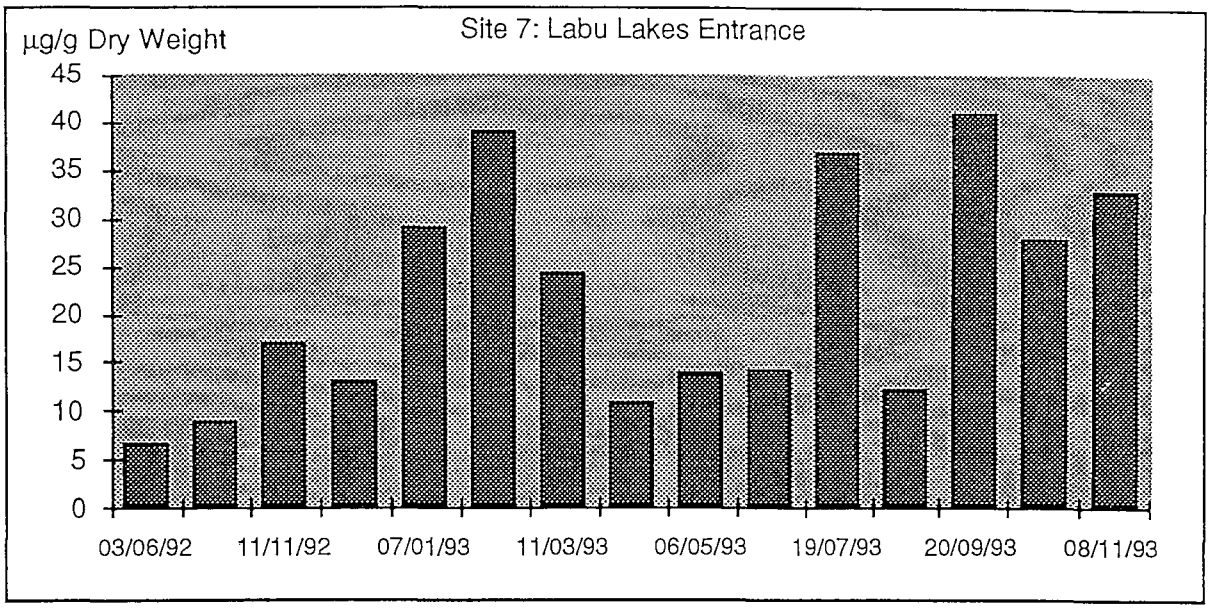
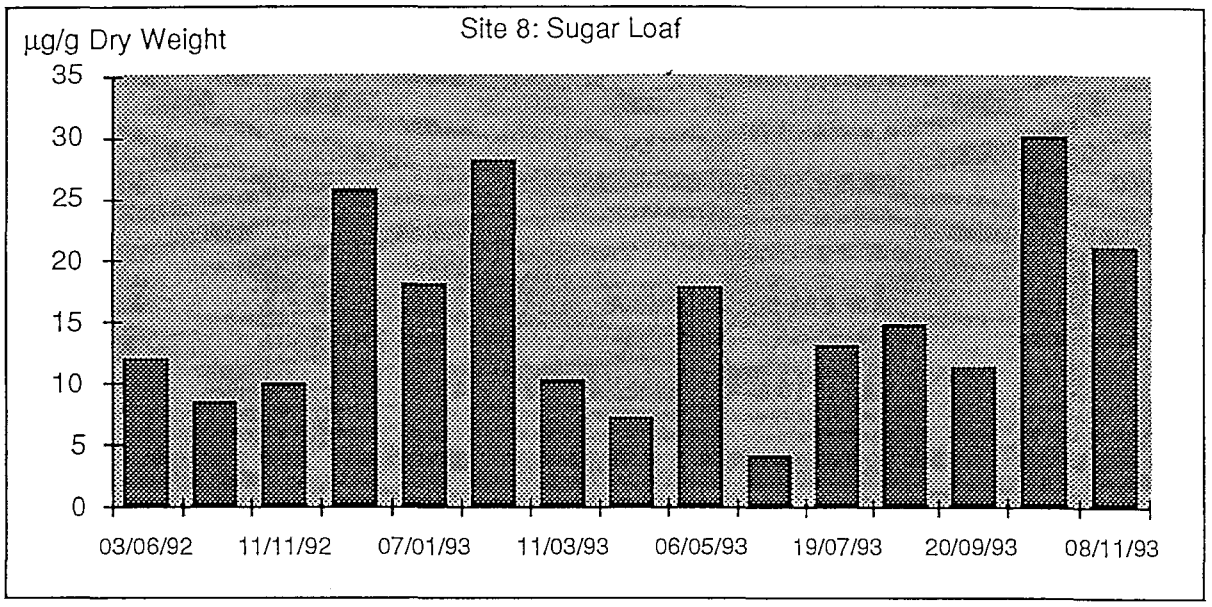


Figure 9: Total Lead in sediment samples versus sample date for sites 4 to 6.





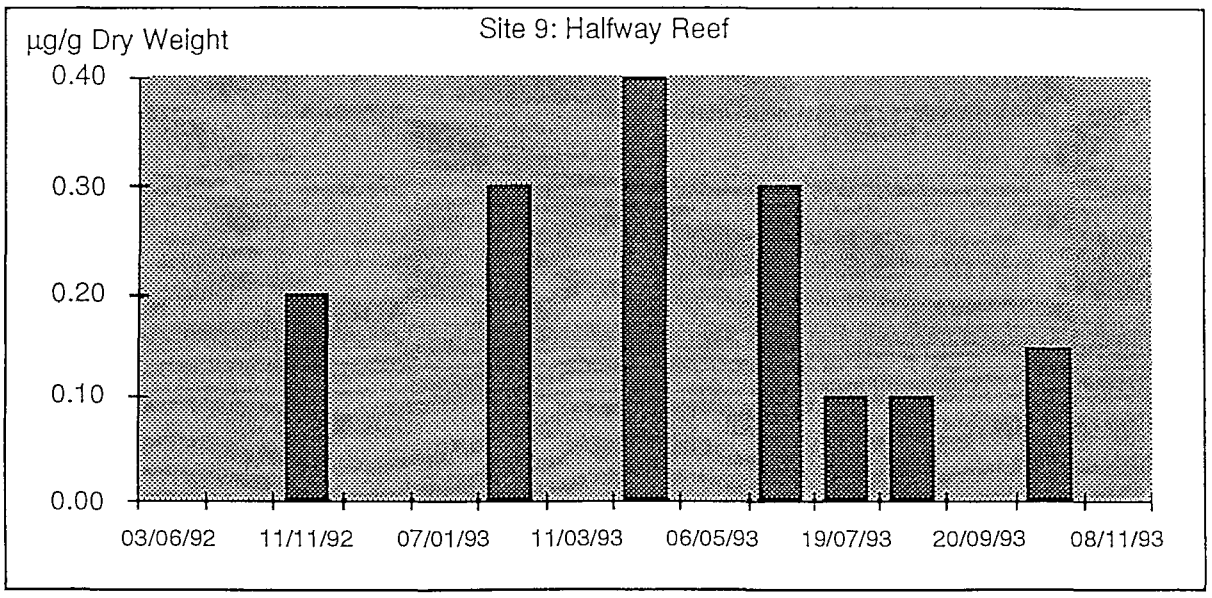
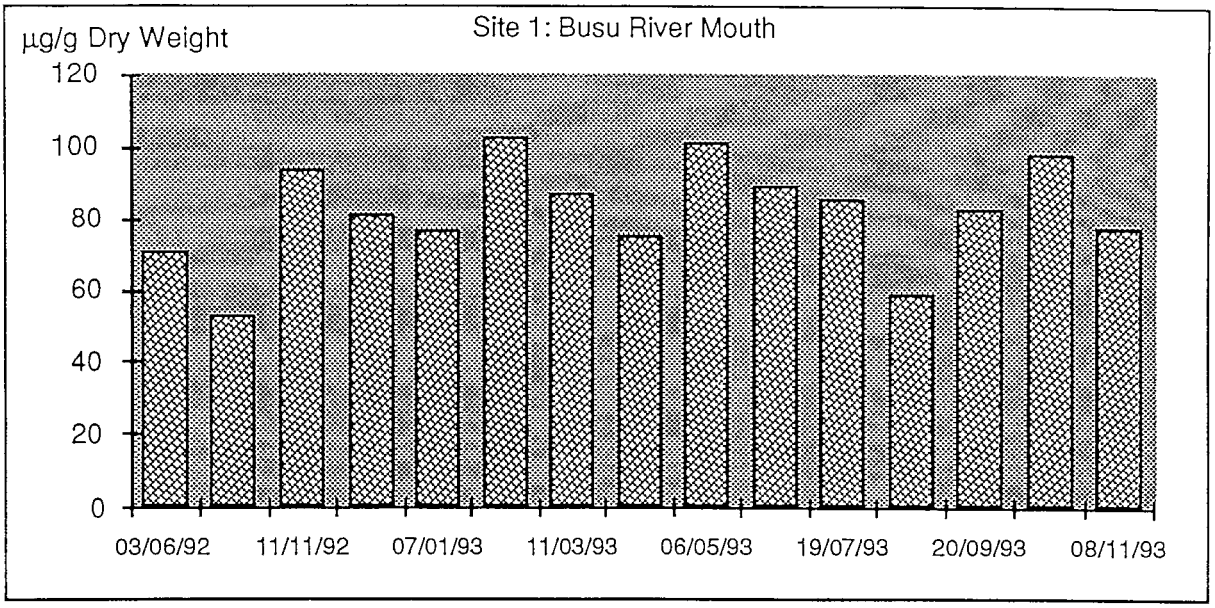
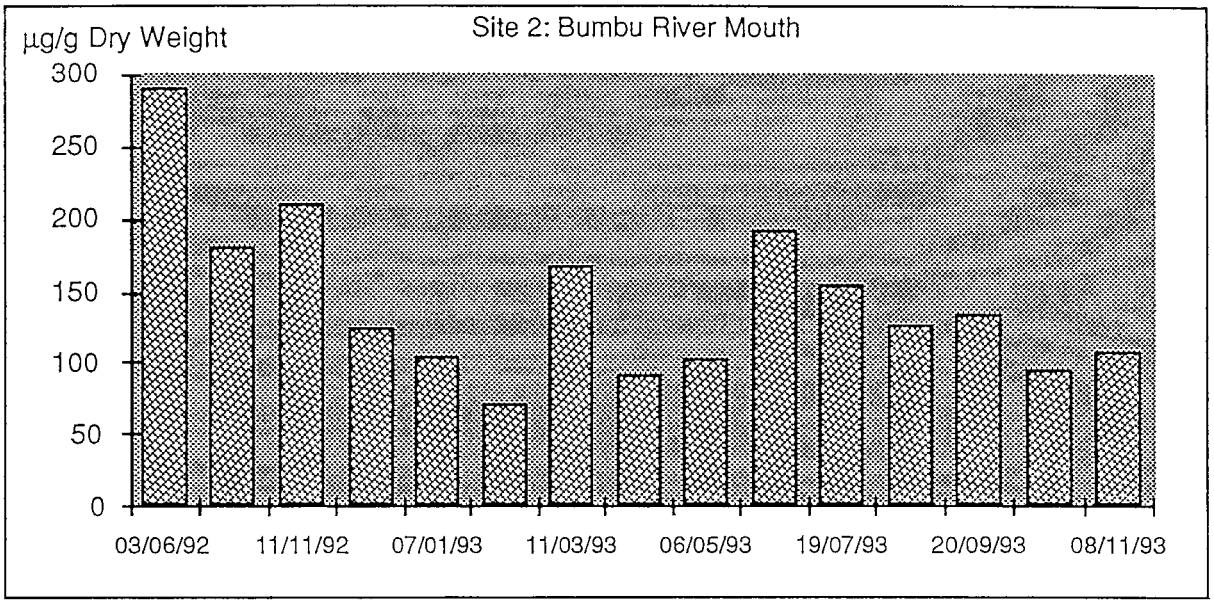


Figure 10: Total Lead in sediment samples versus sample date for sites 7 to 9.





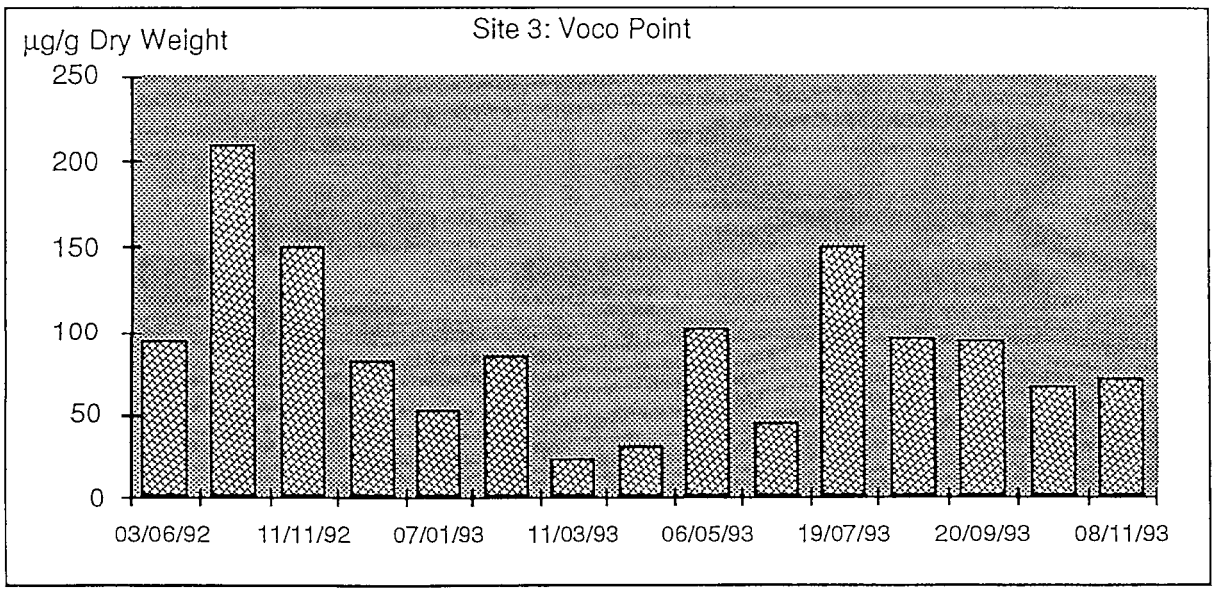
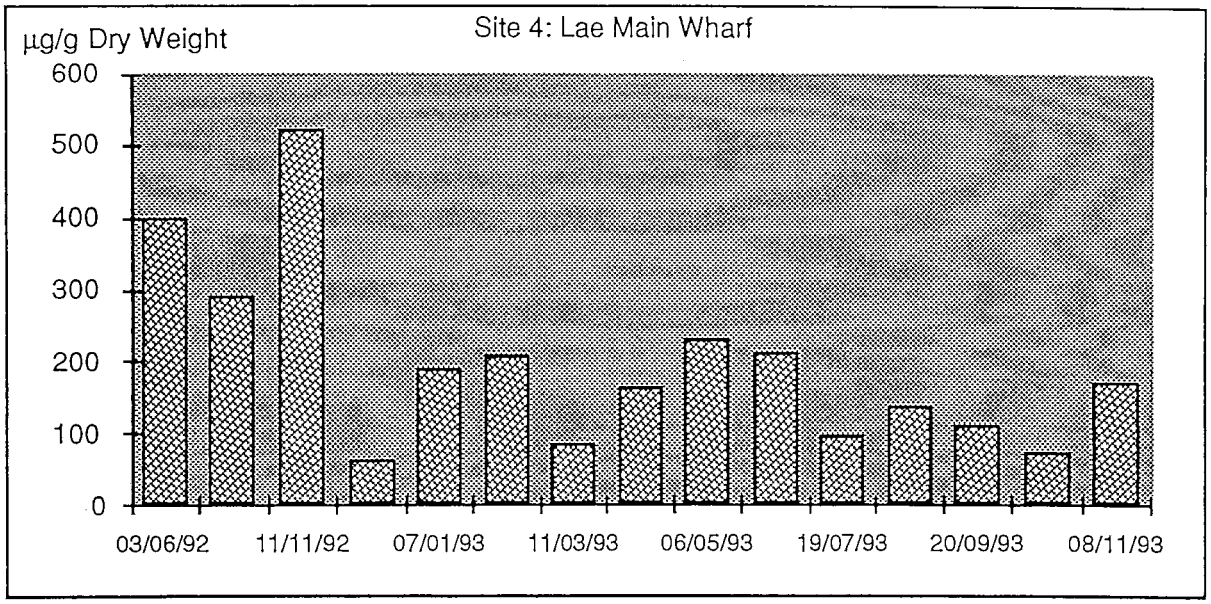
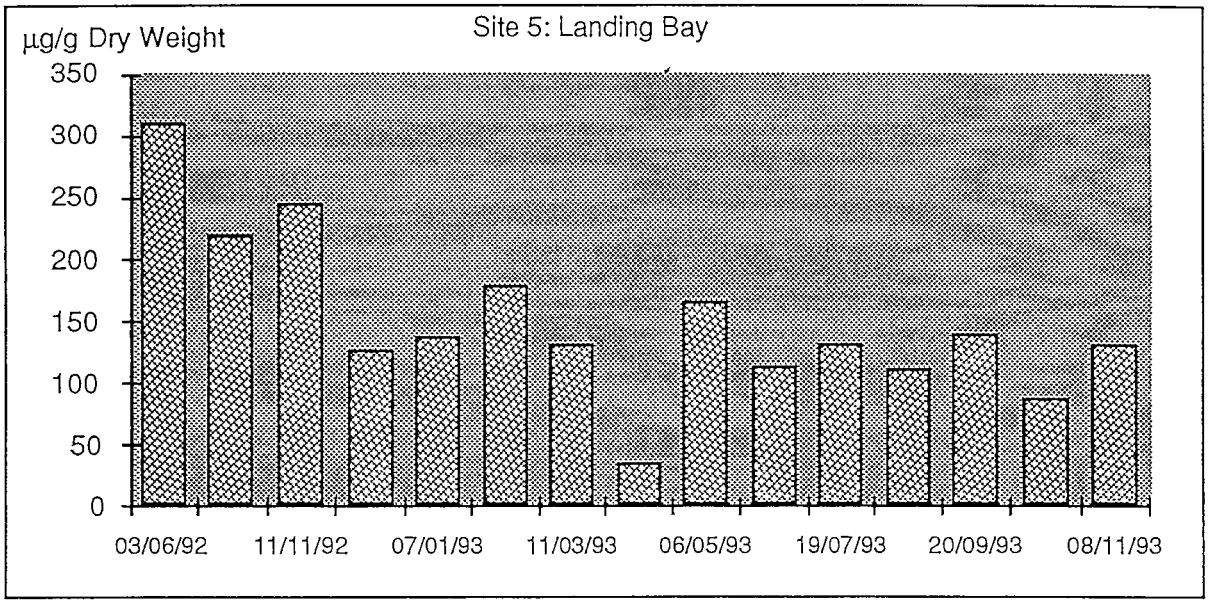


Figure 11: Total Zinc in sediment samples versus sample date for sites 1 to 3.





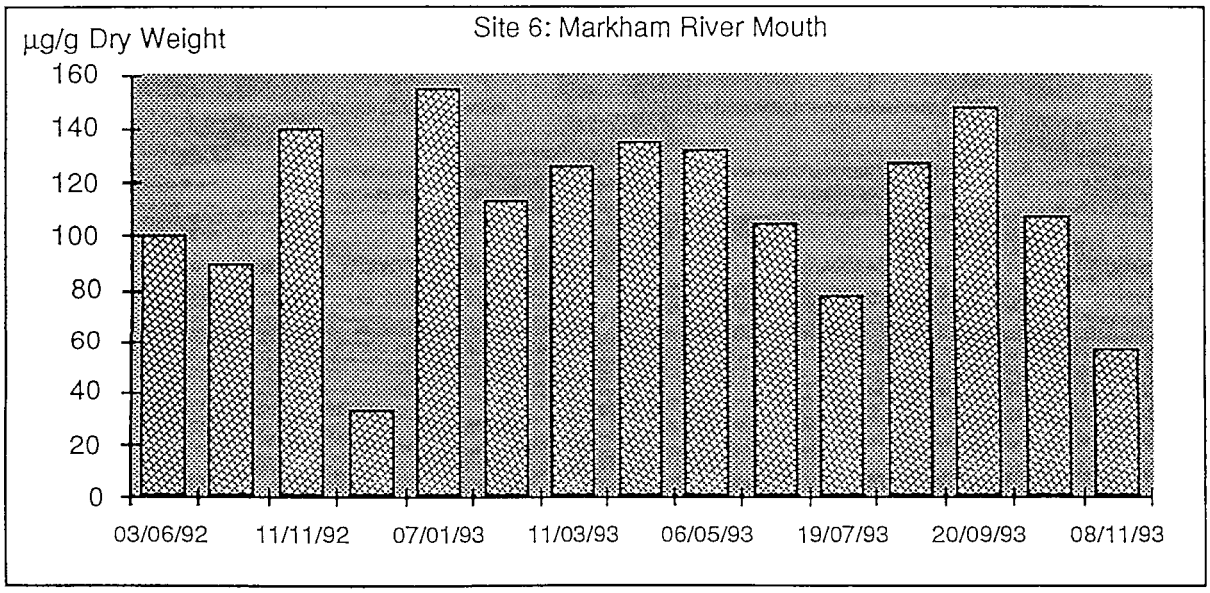
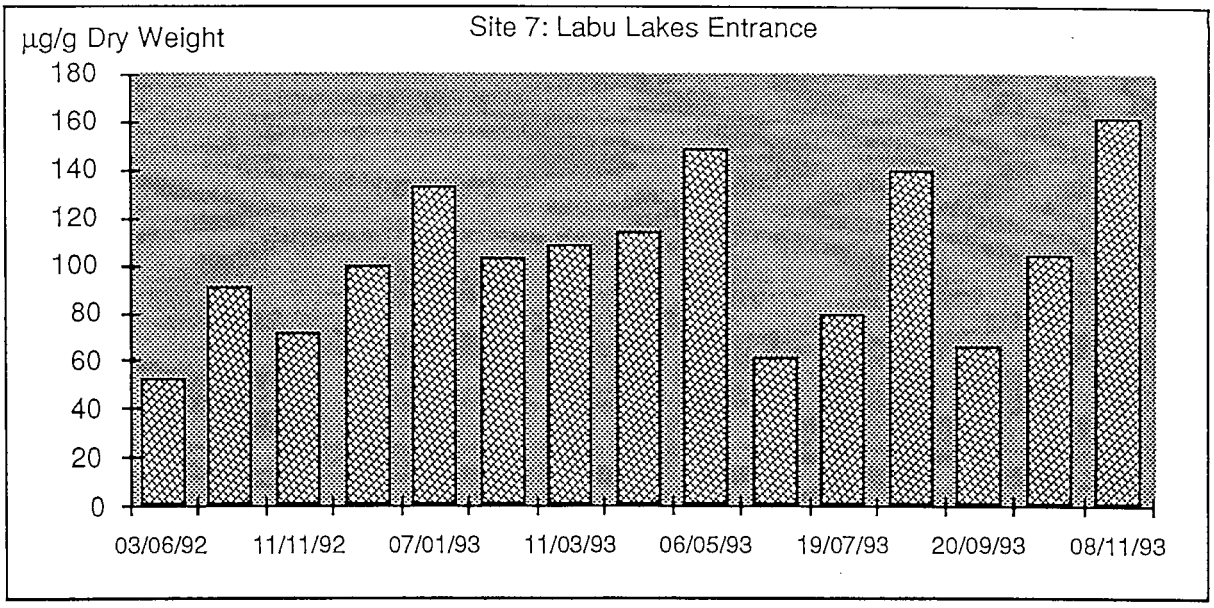
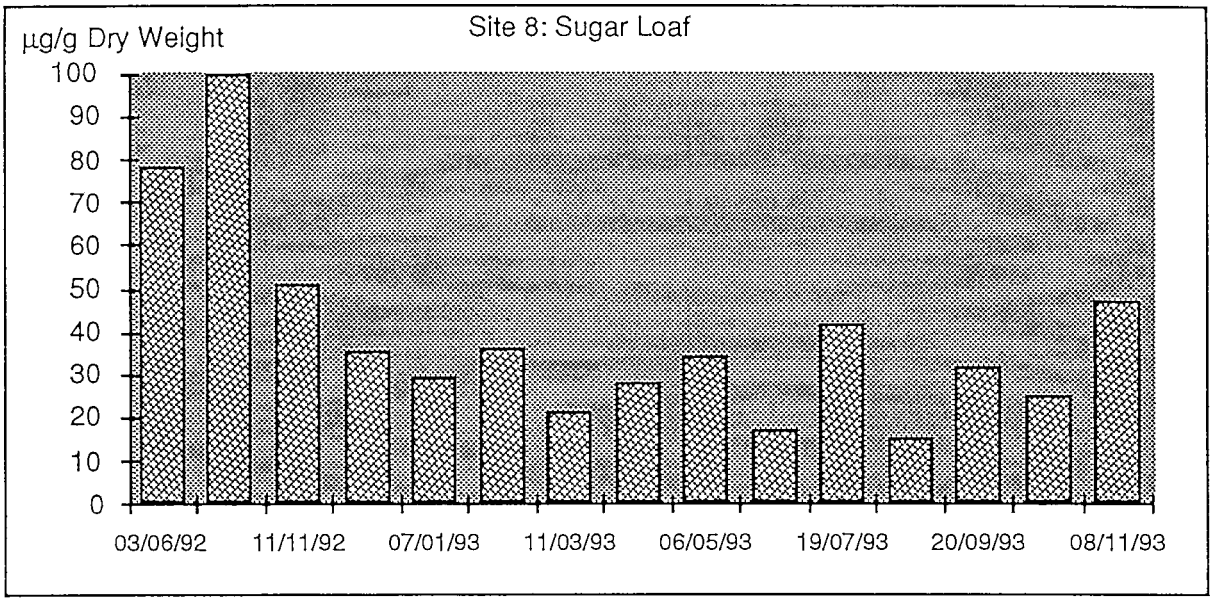


Figure 12: Total Zinc in sediment samples versus sample date for sites 4 to 6.





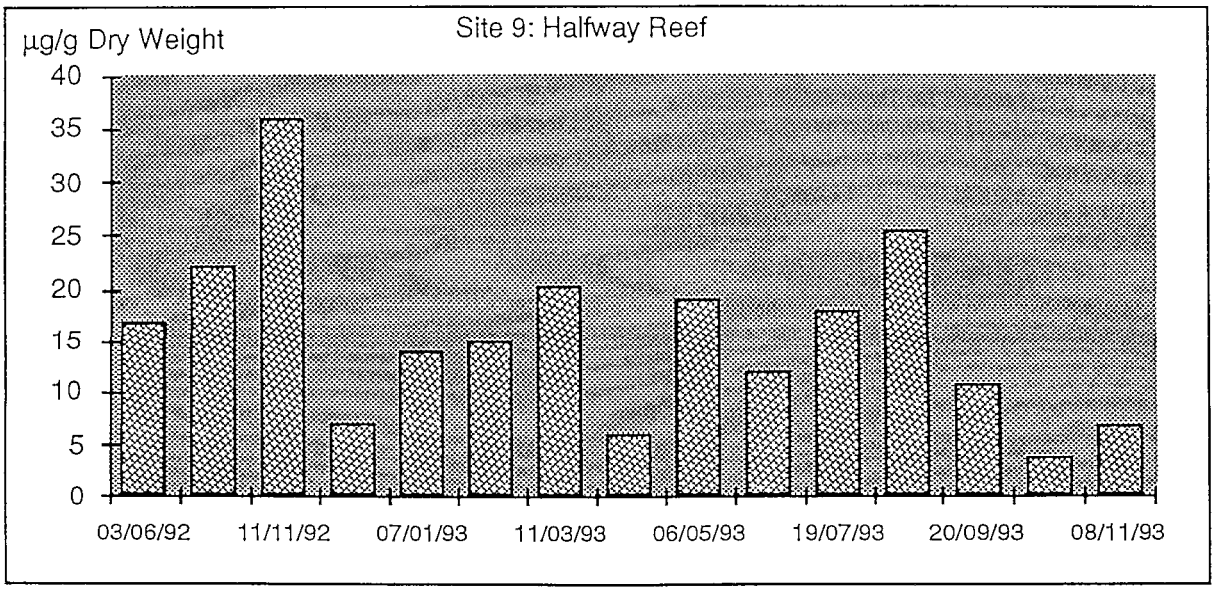
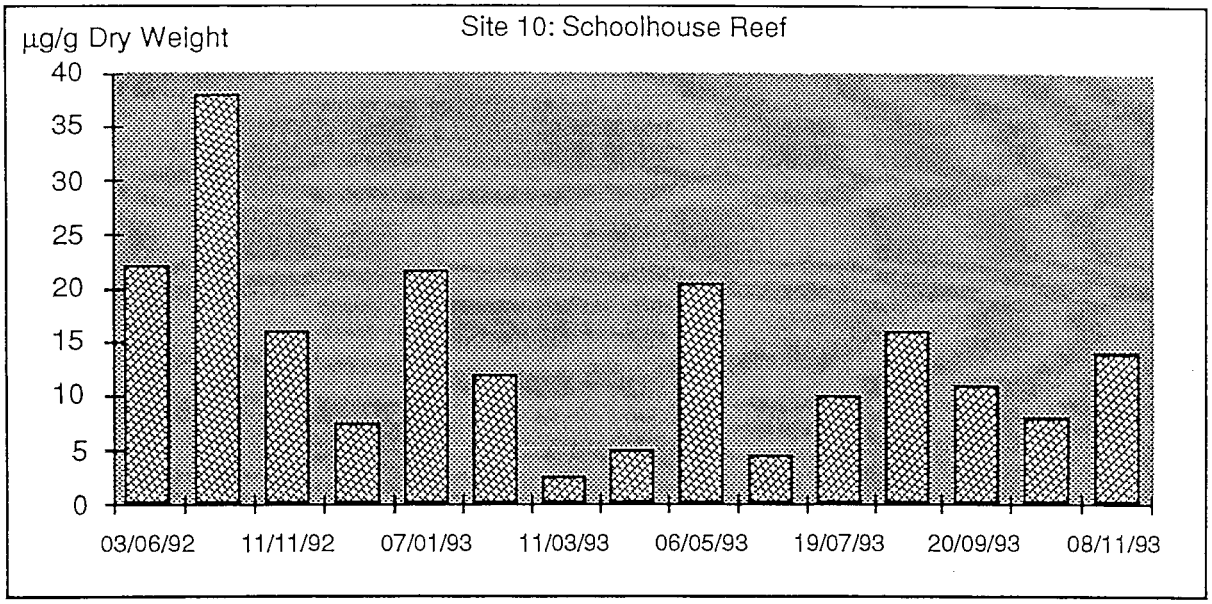


Figure 13: Total Zinc in sediment samples versus sample date for sites 7 to 9.



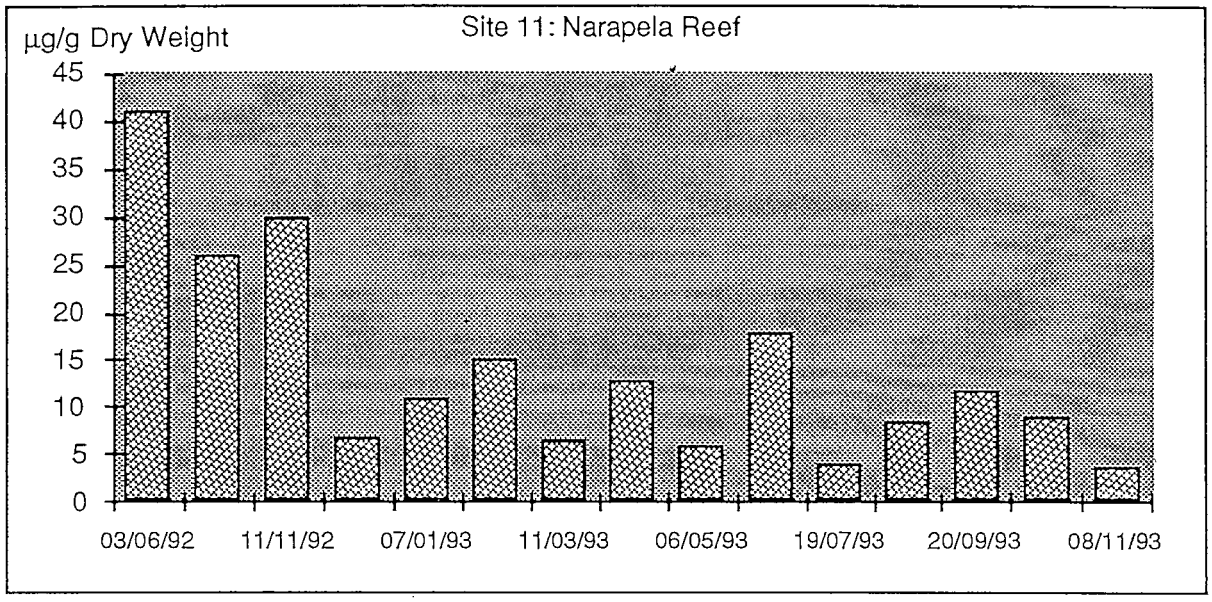


Figure 14: Total Zinc in sediment samples versus sample date for sites 10 and 11.

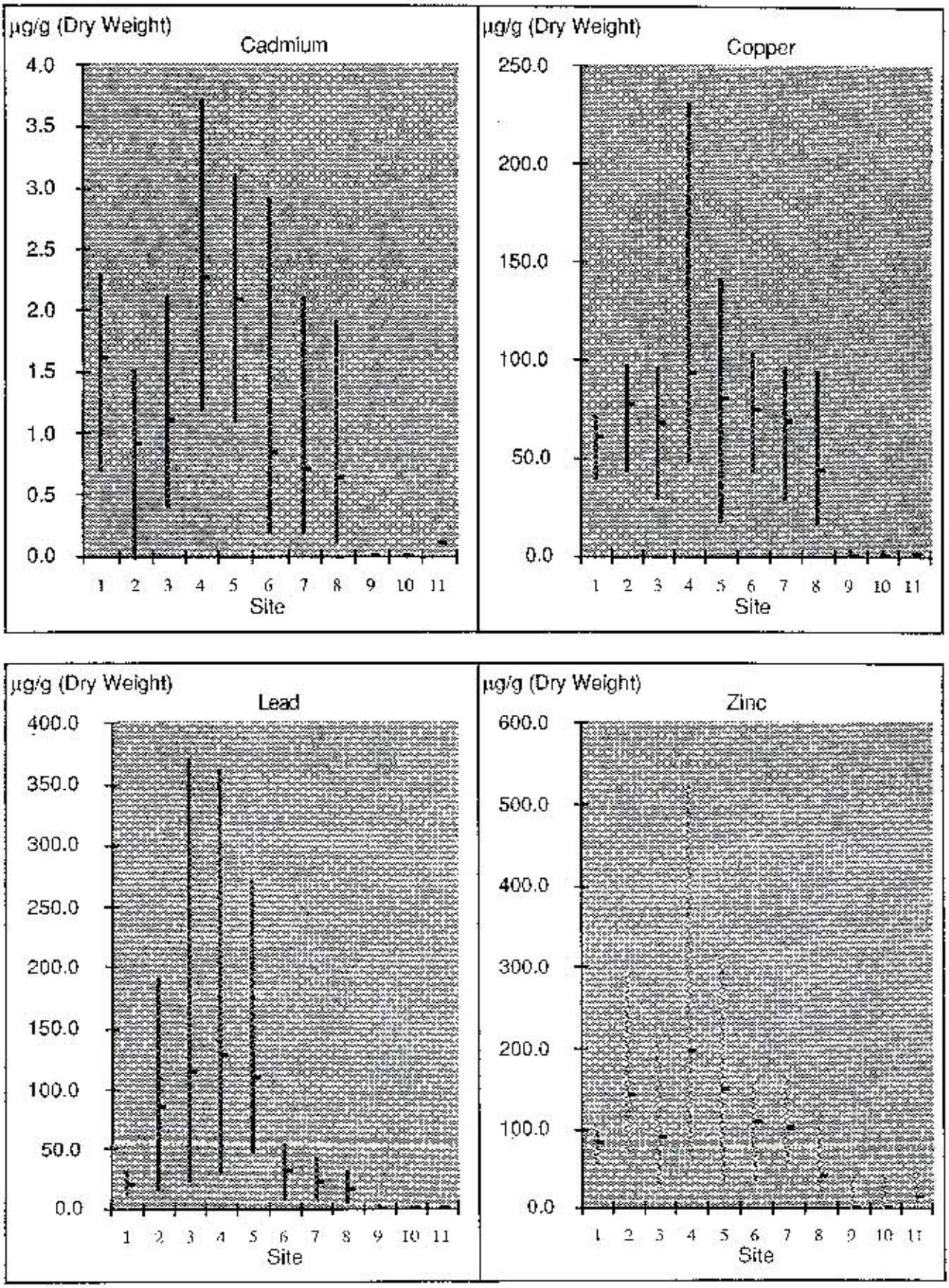
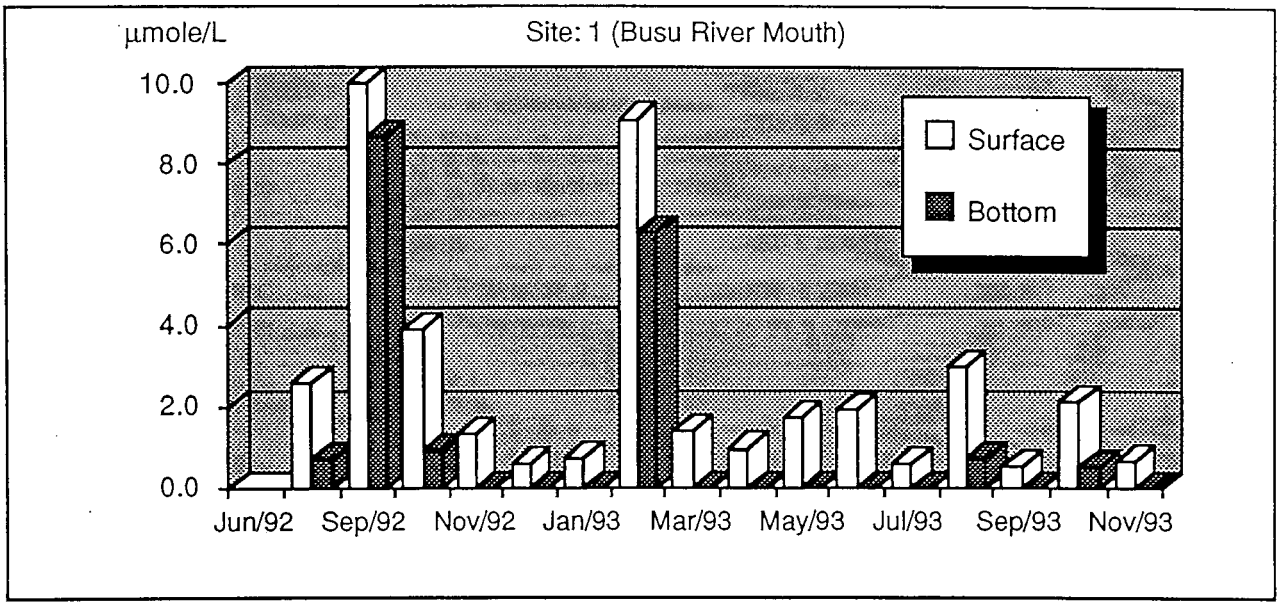
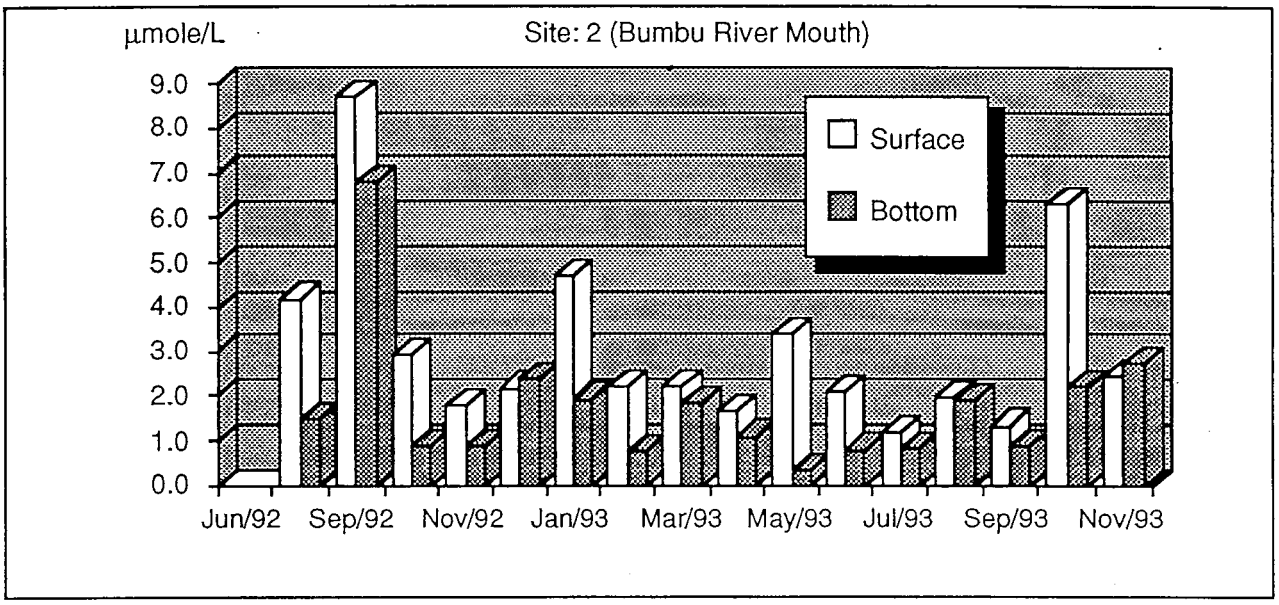


Figure 15: Average and range of total copper, lead, cadmium and zinc in sediment samples.





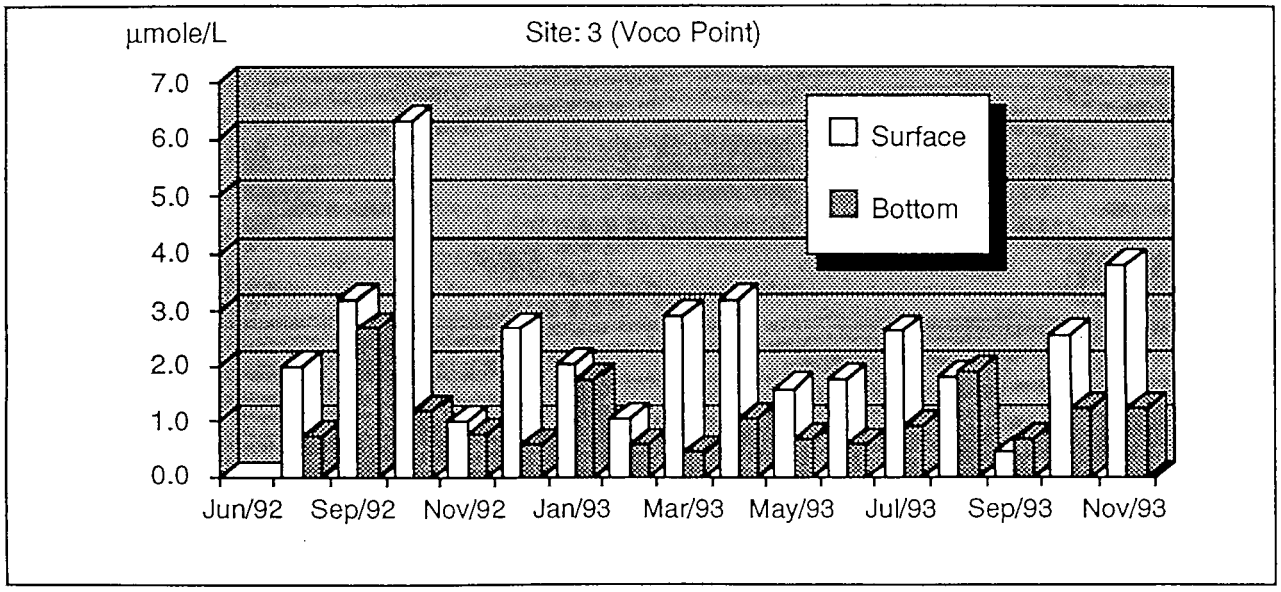
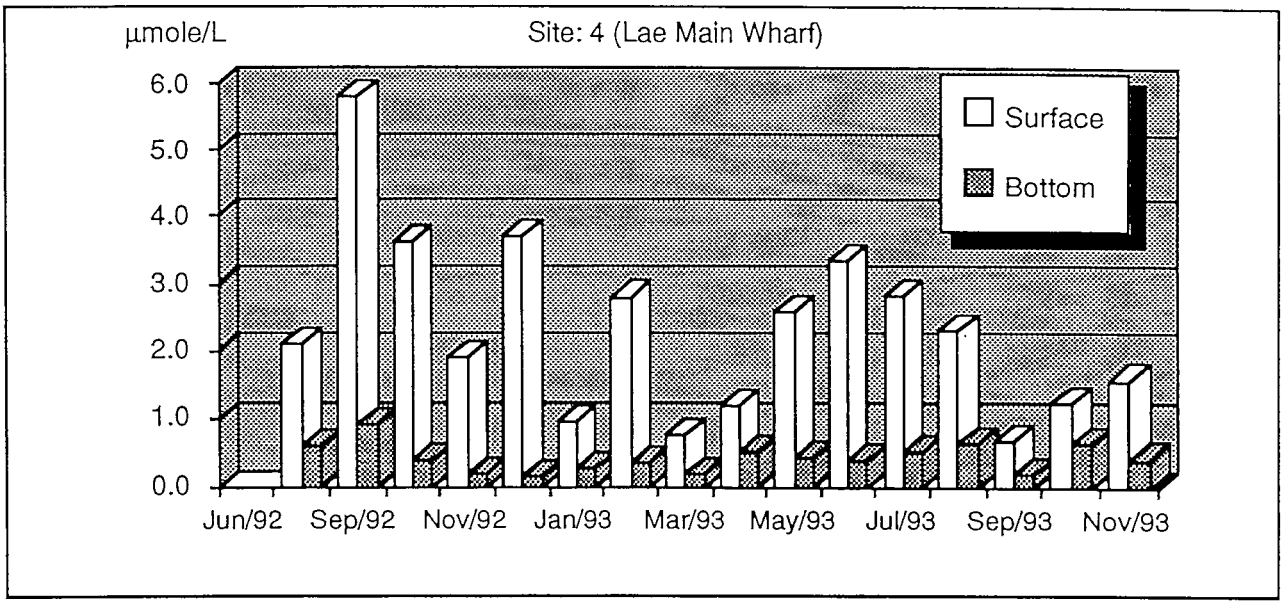
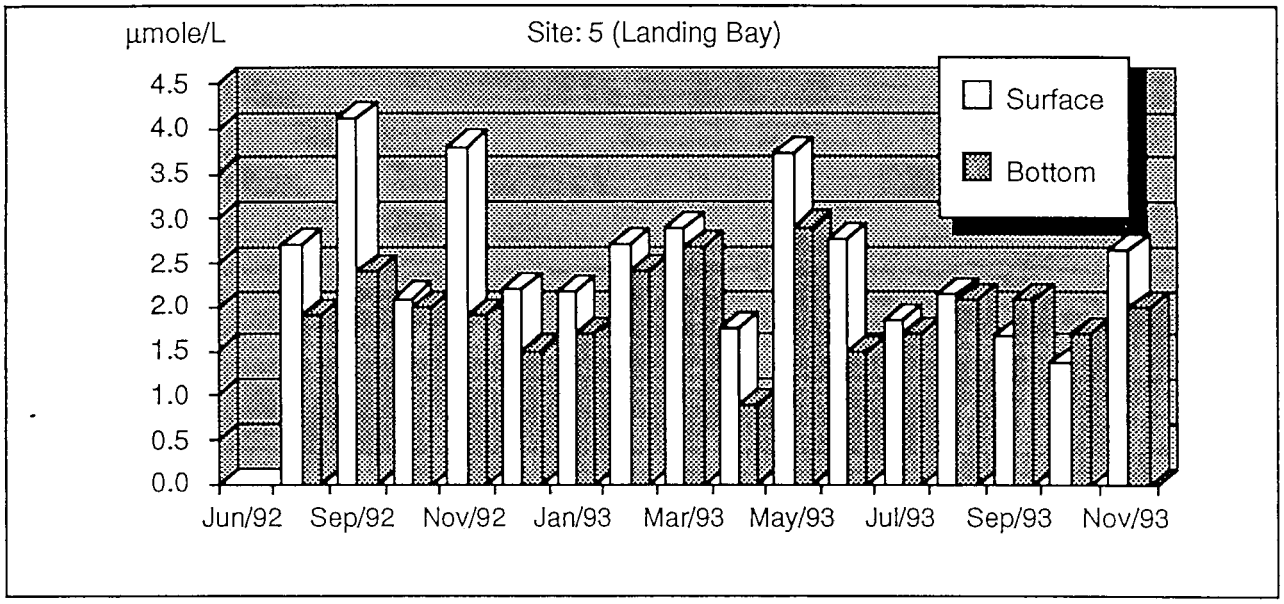


Figure 16: Total Phosphorus versus sample date for sites 1 to 3.





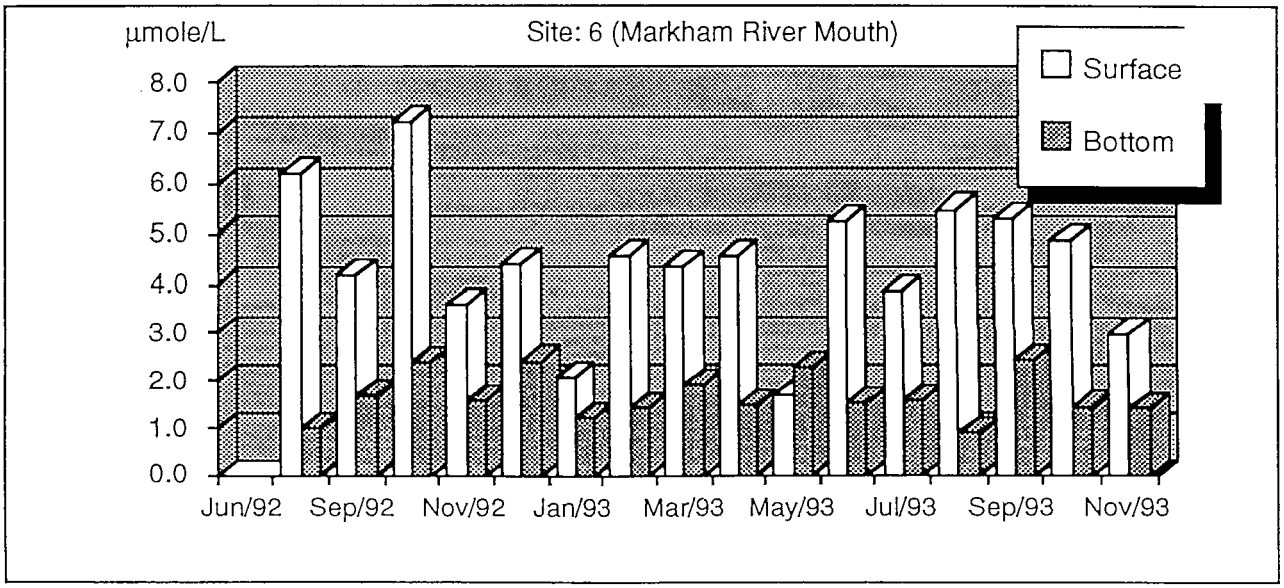
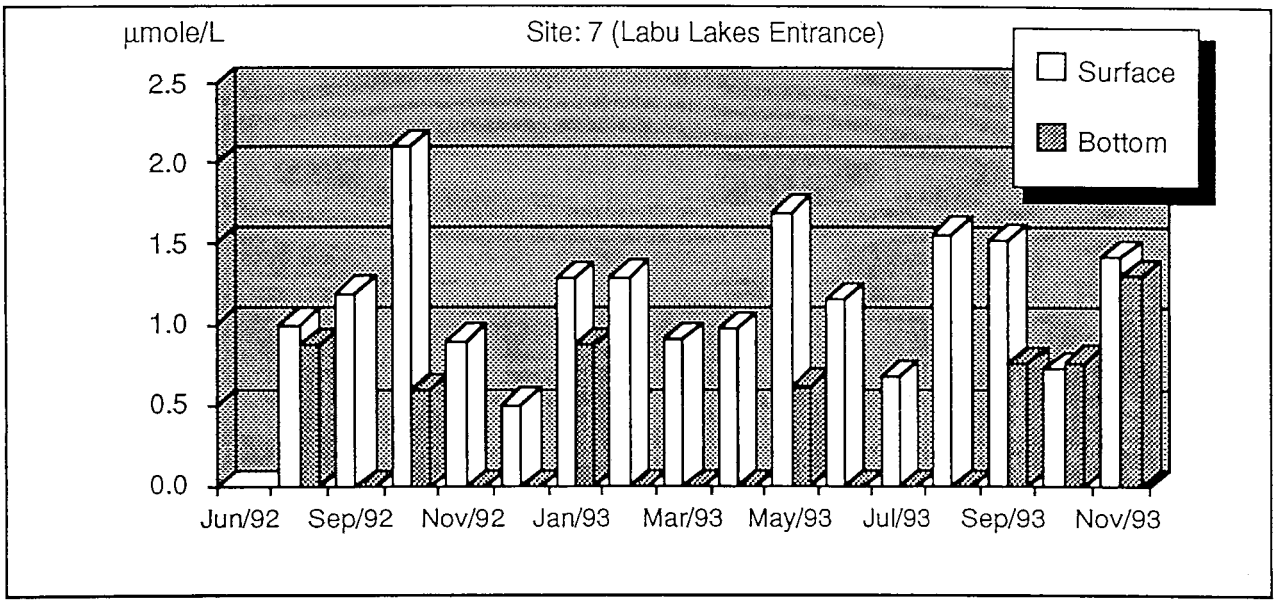
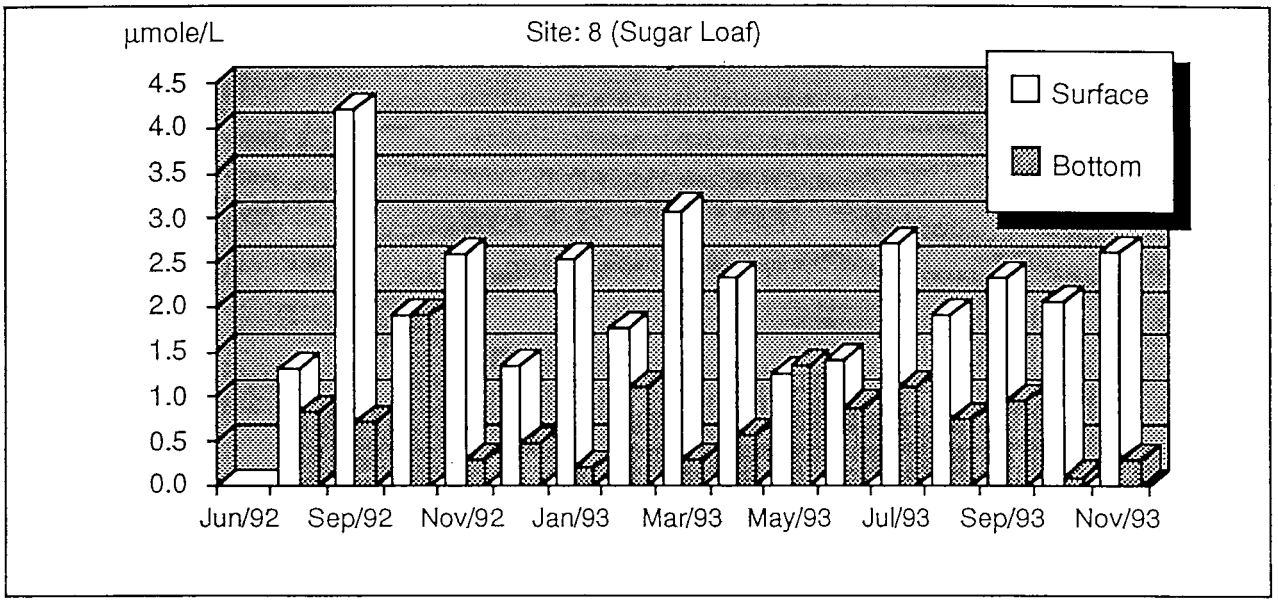


Figure 17: Total Phosphorus versus sample date for sites 4 to 6.





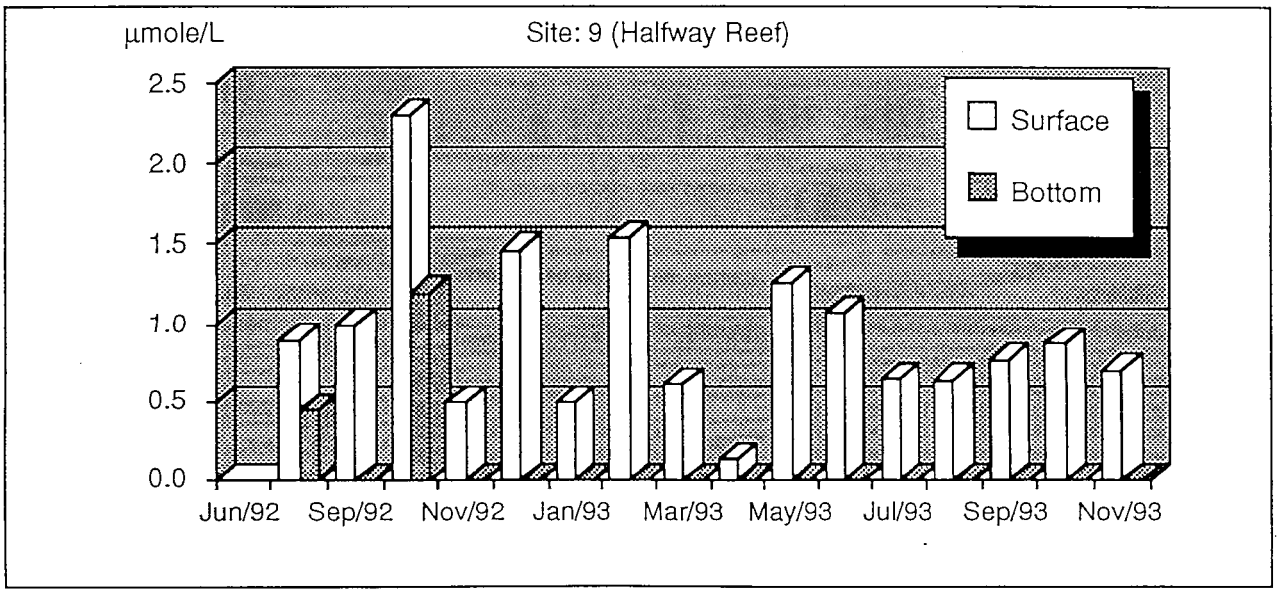


Figure 18: Total Phosphorus versus sample date for sites 7 to 9.

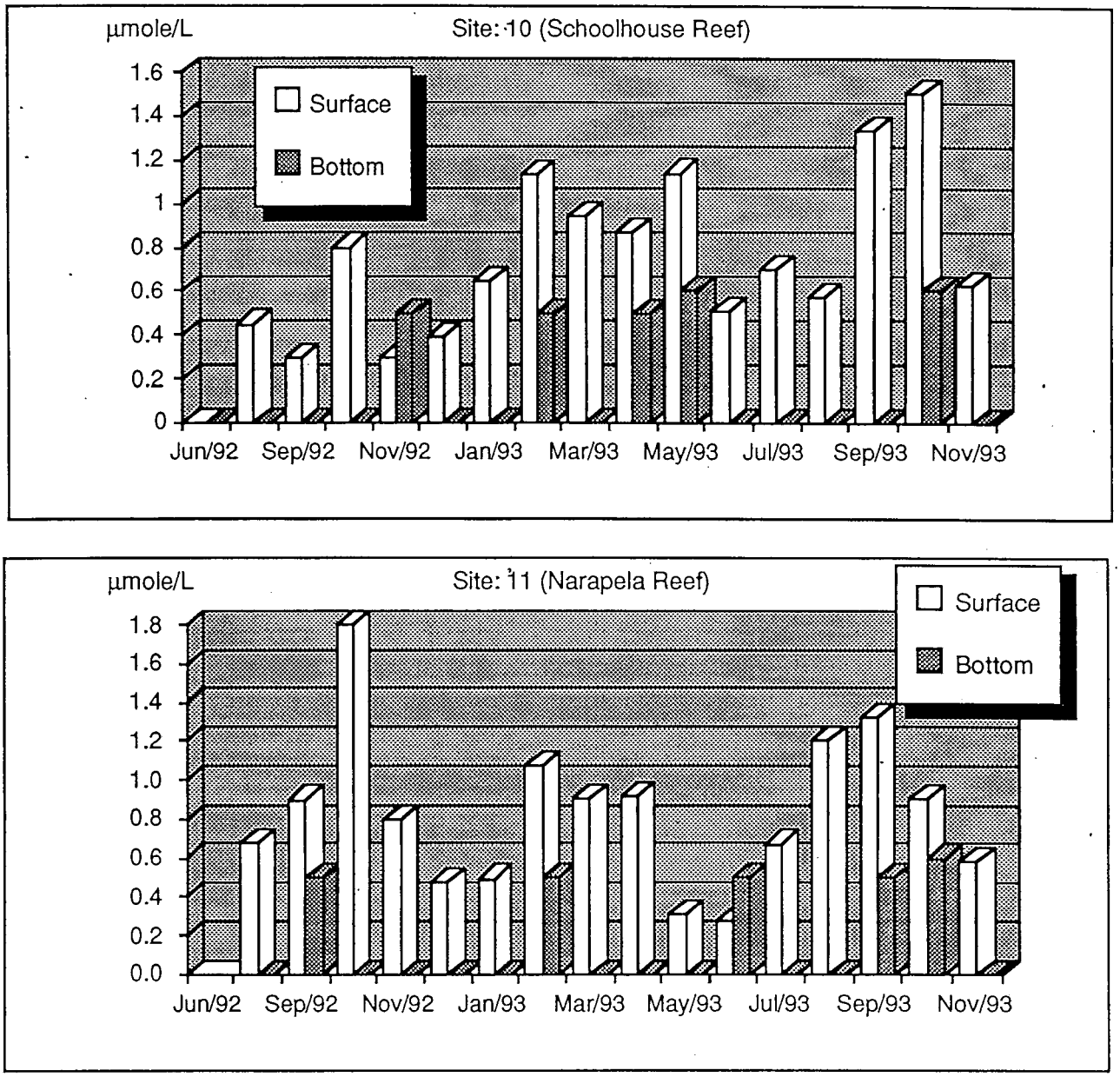
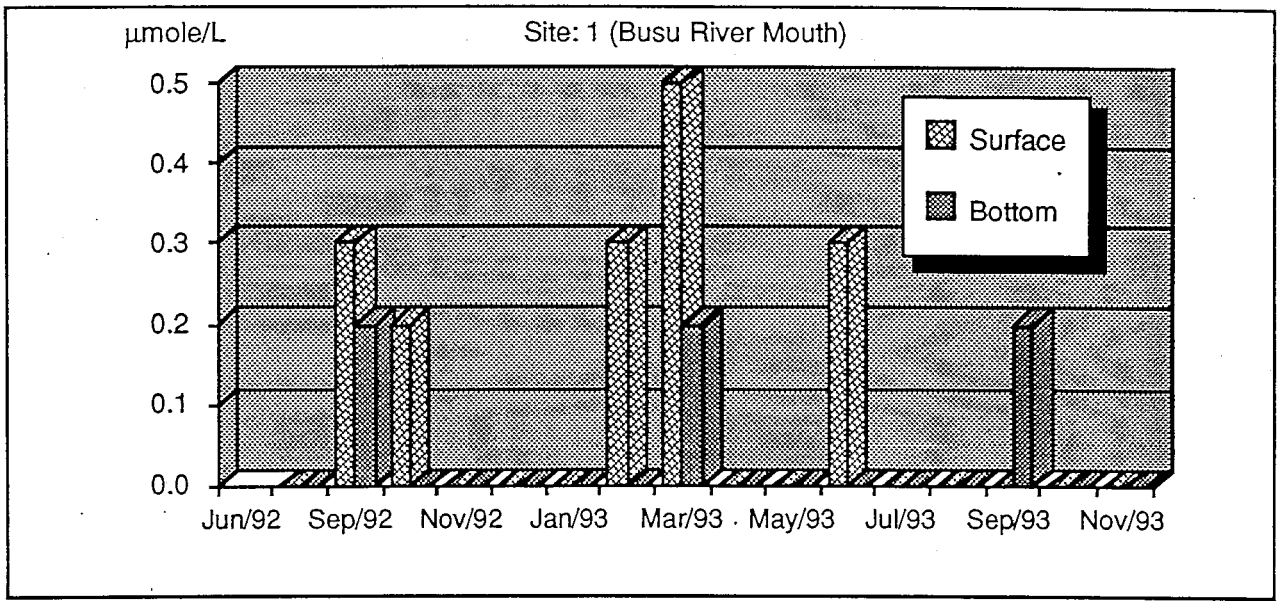
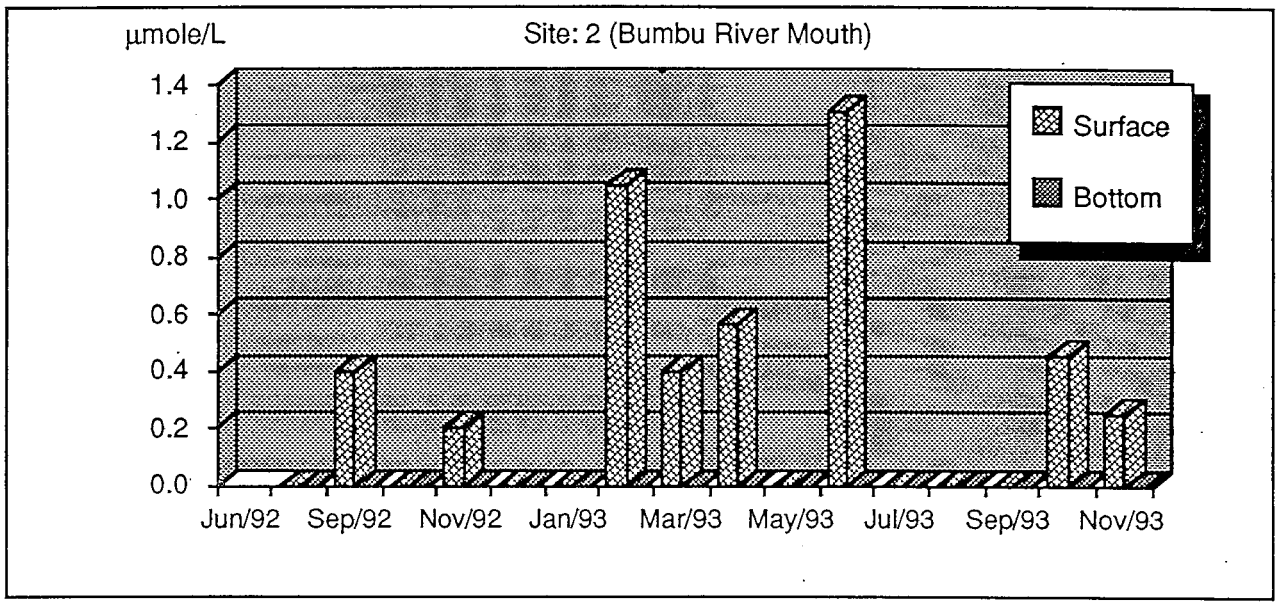


Figure 19: Total Phosphorus versus sample date for sites 10 and 11.





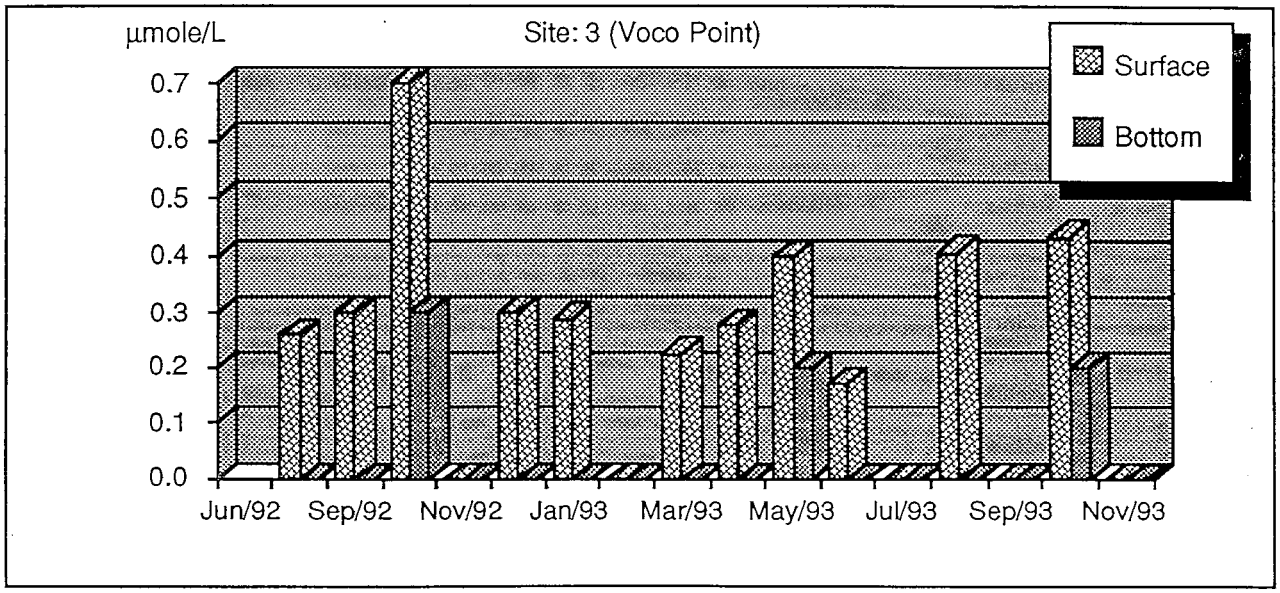
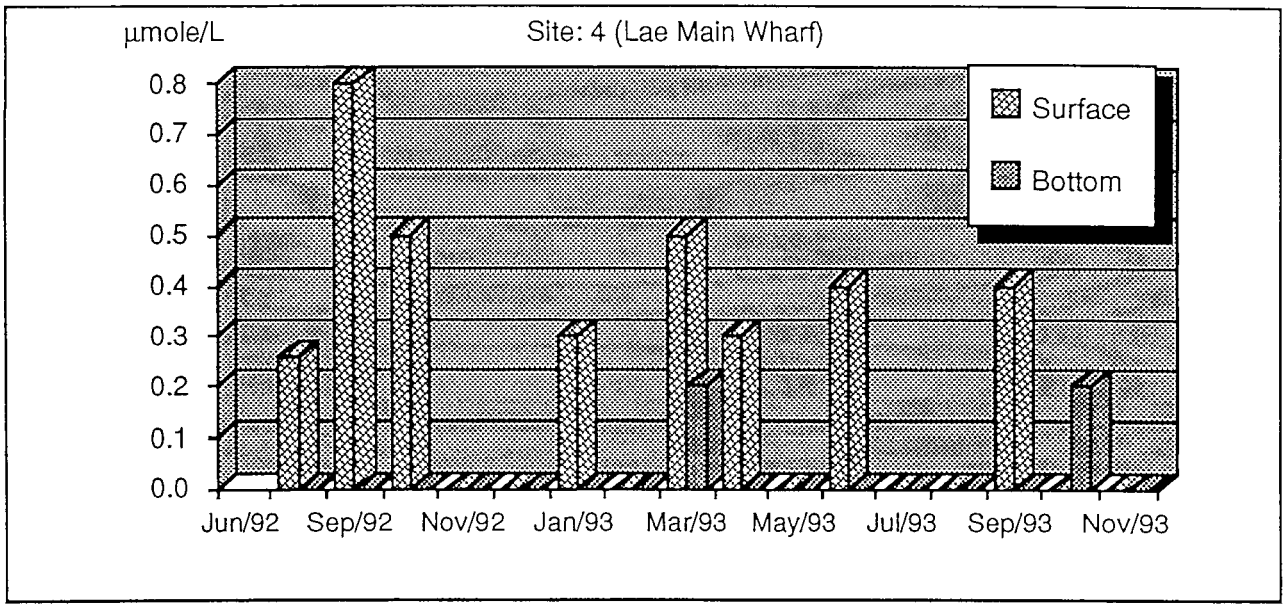
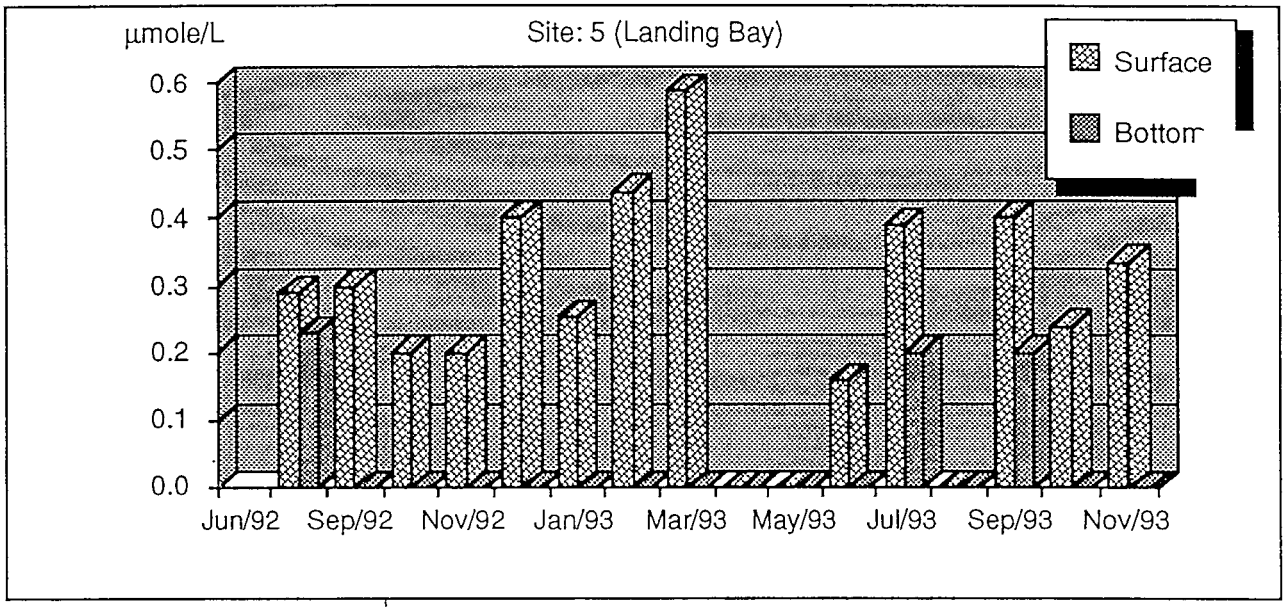


Figure 20: Dissolved Phosphorus versus sample date for sites 1 to 3.





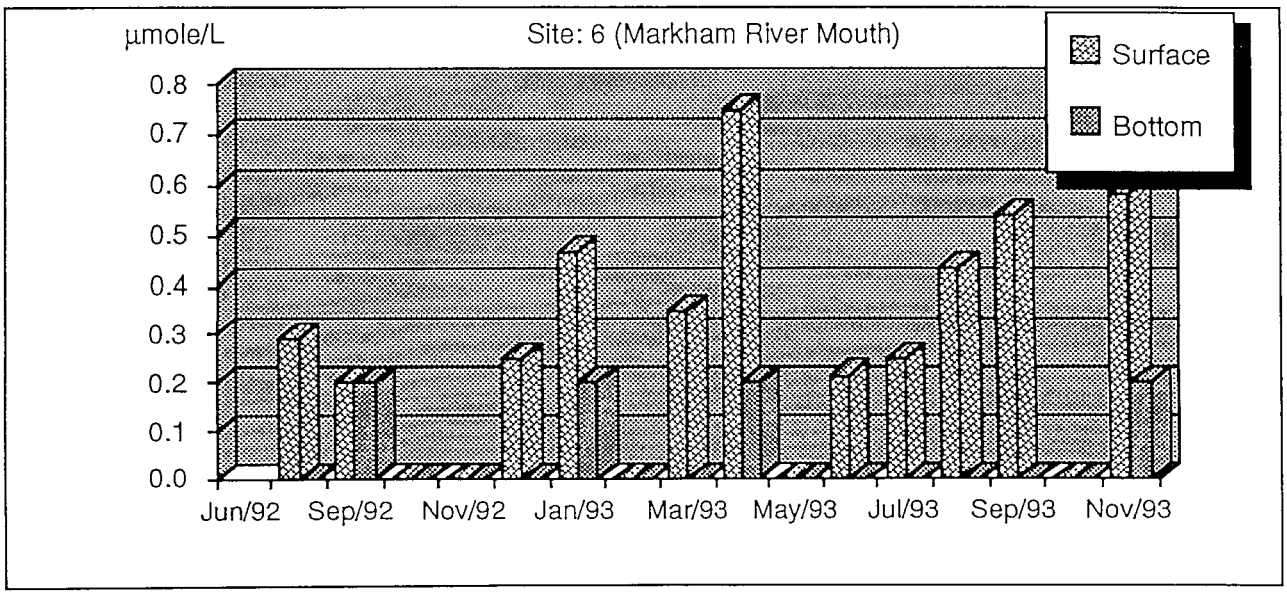
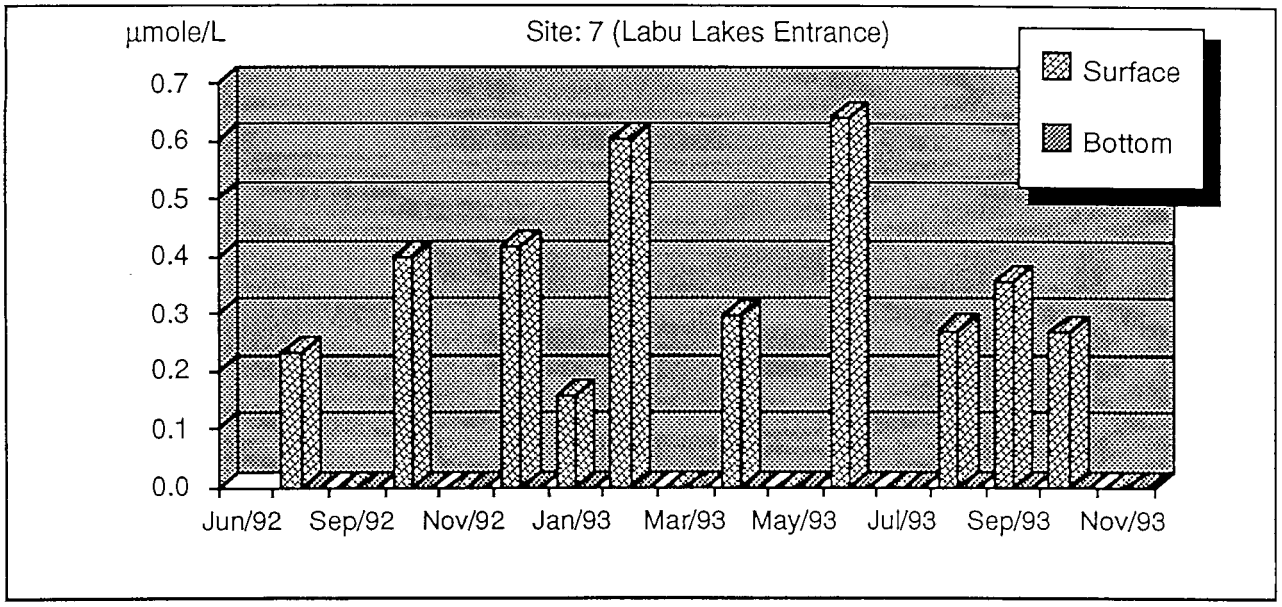
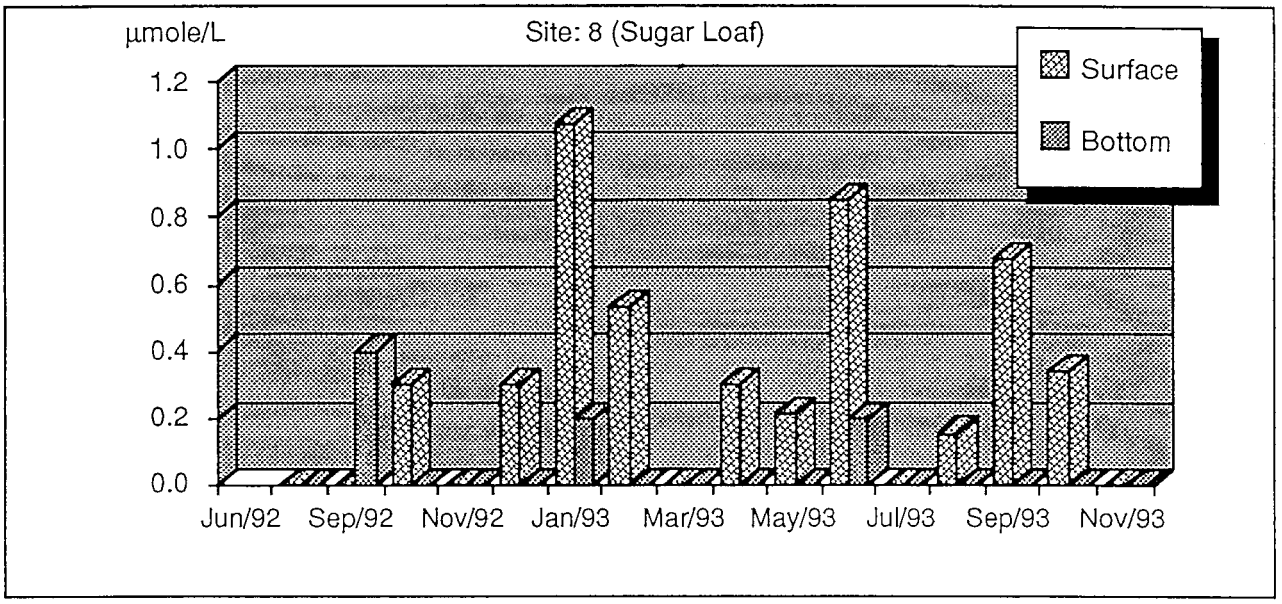


Figure 21: Dissolved Phosphorus versus sample date for sites 4 to 6.





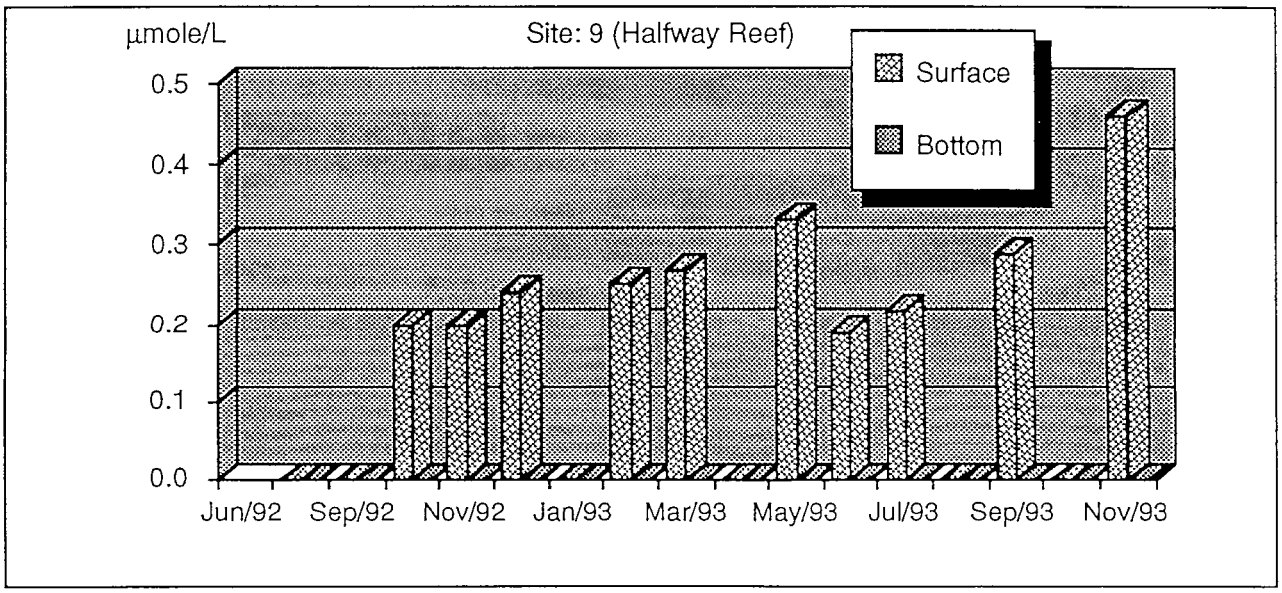


Figure 22: Dissolved Phosphorus versus sample date for sites 7 to 9.

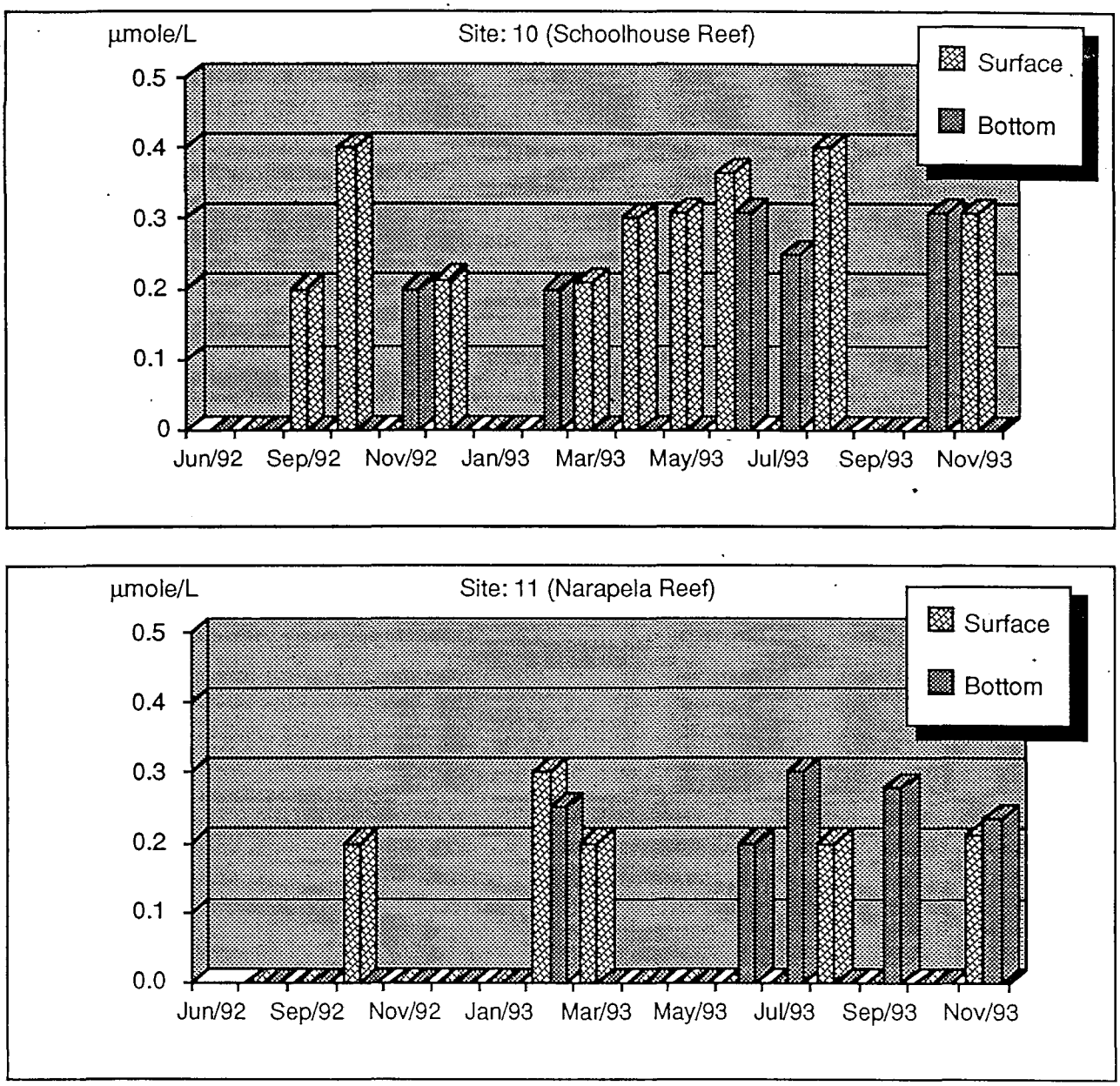
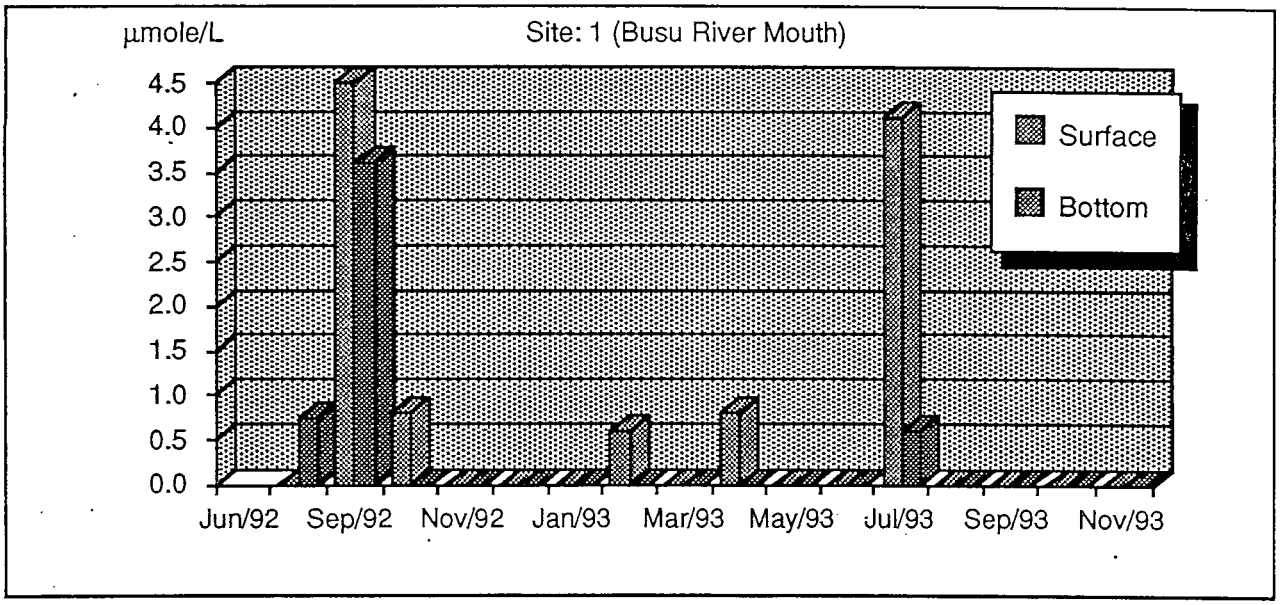
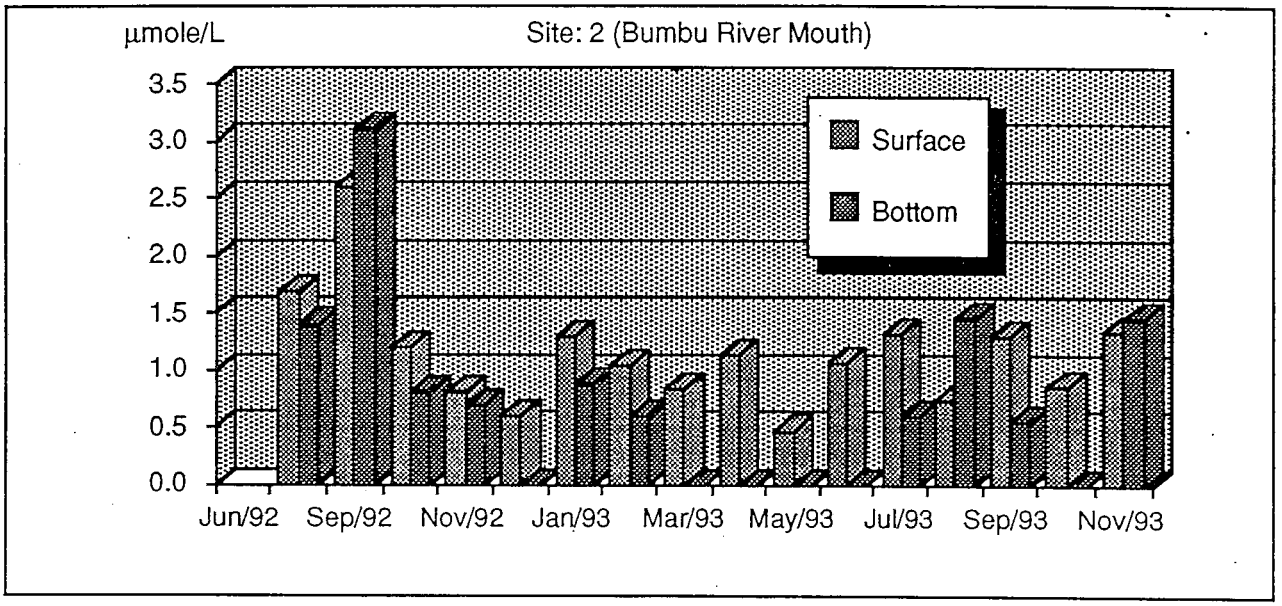


Figure 23: Dissolved Phosphorus versus sample date for sites 10 and 11.





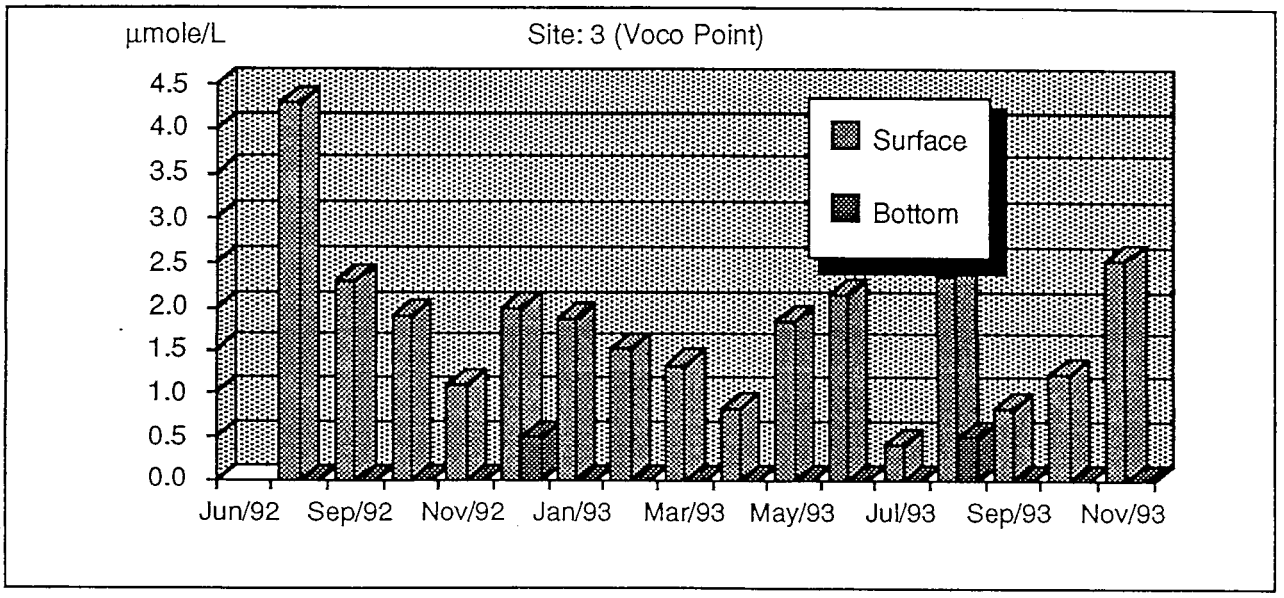
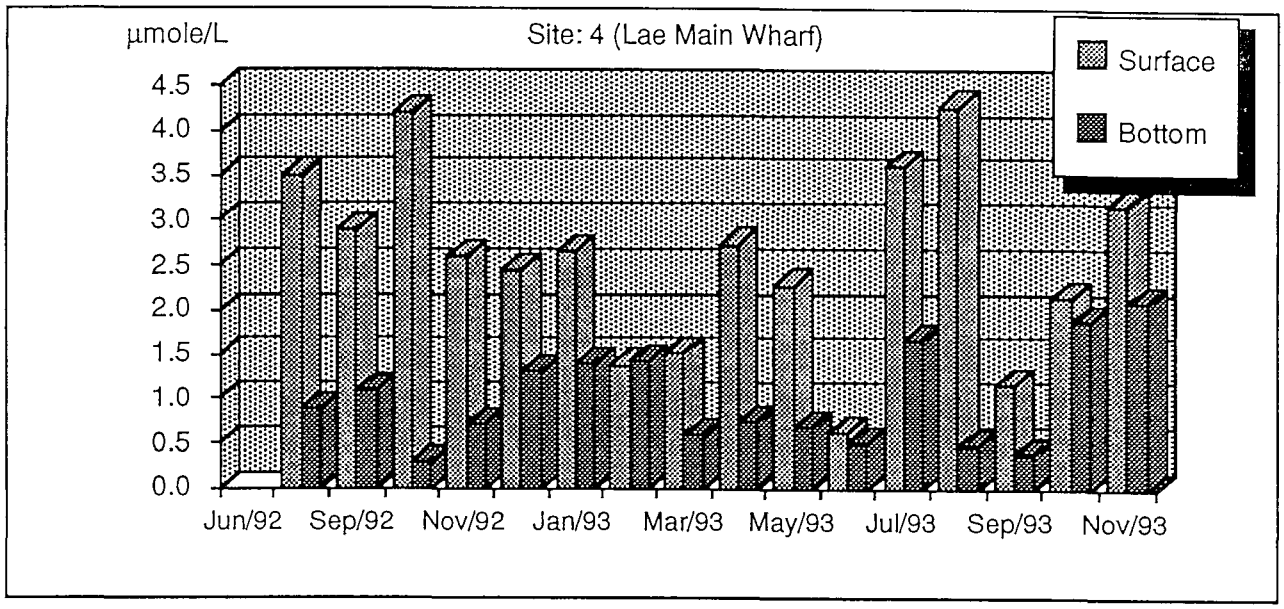
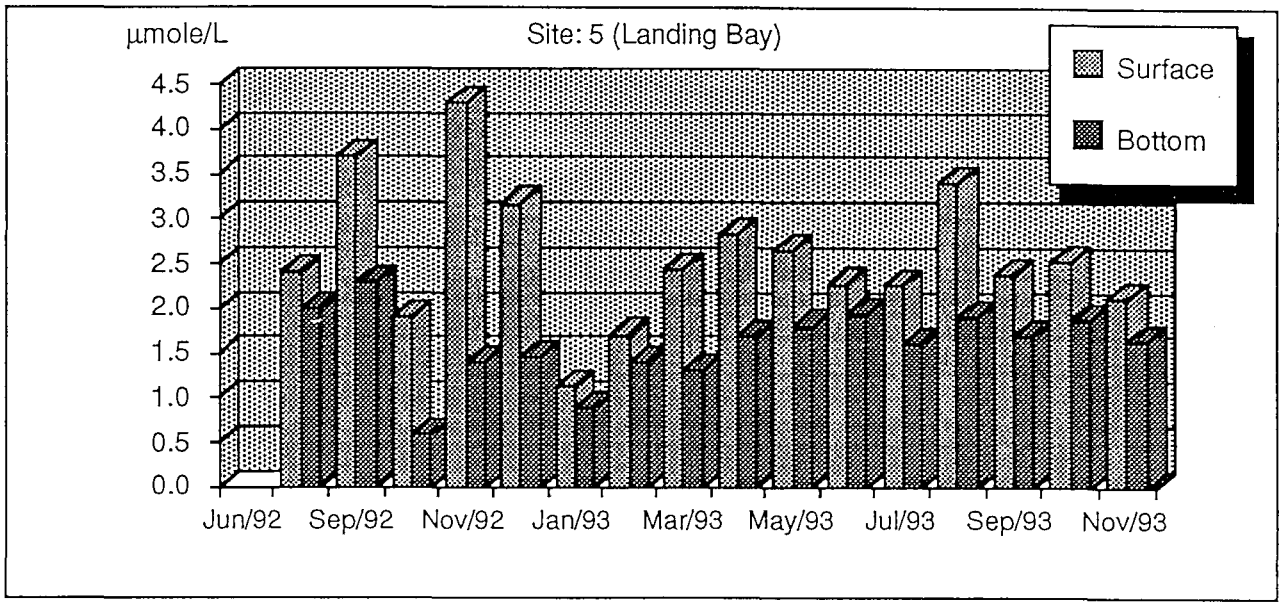


Figure 24: Dissolved Nitrate versus sample date for sites 1 to 3.





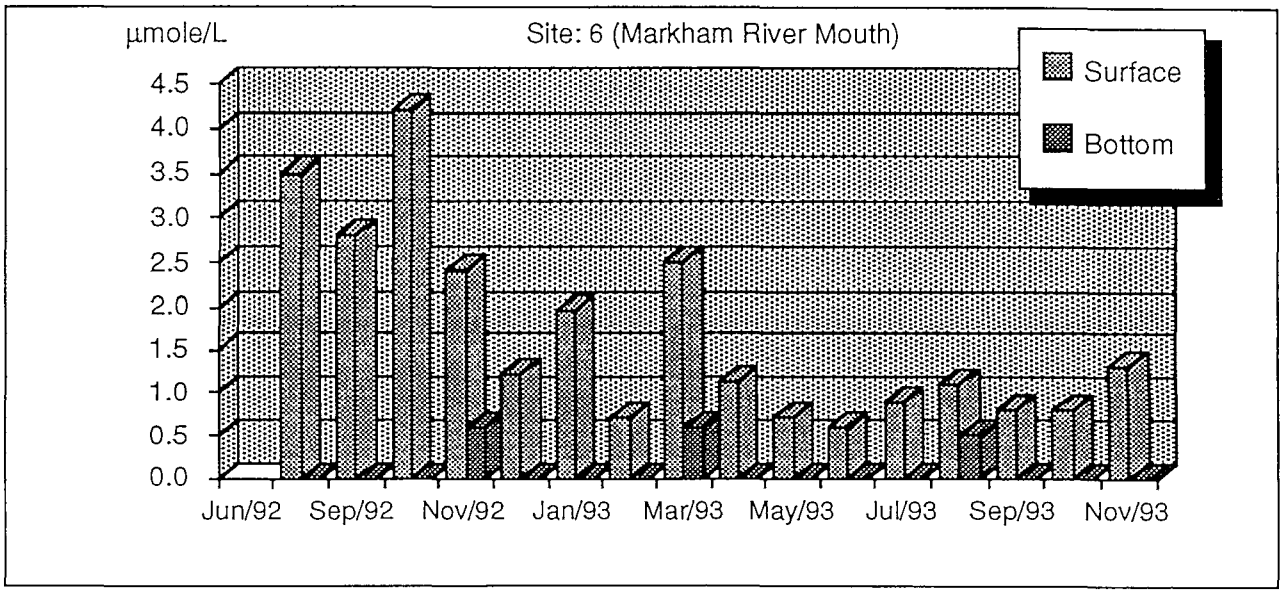
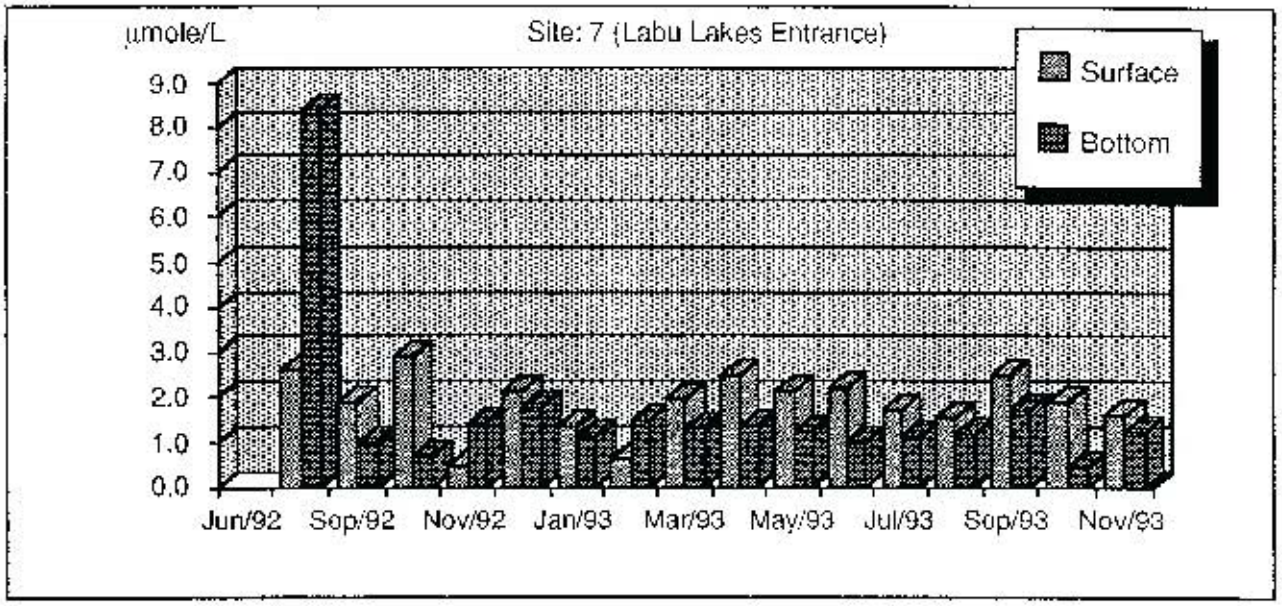
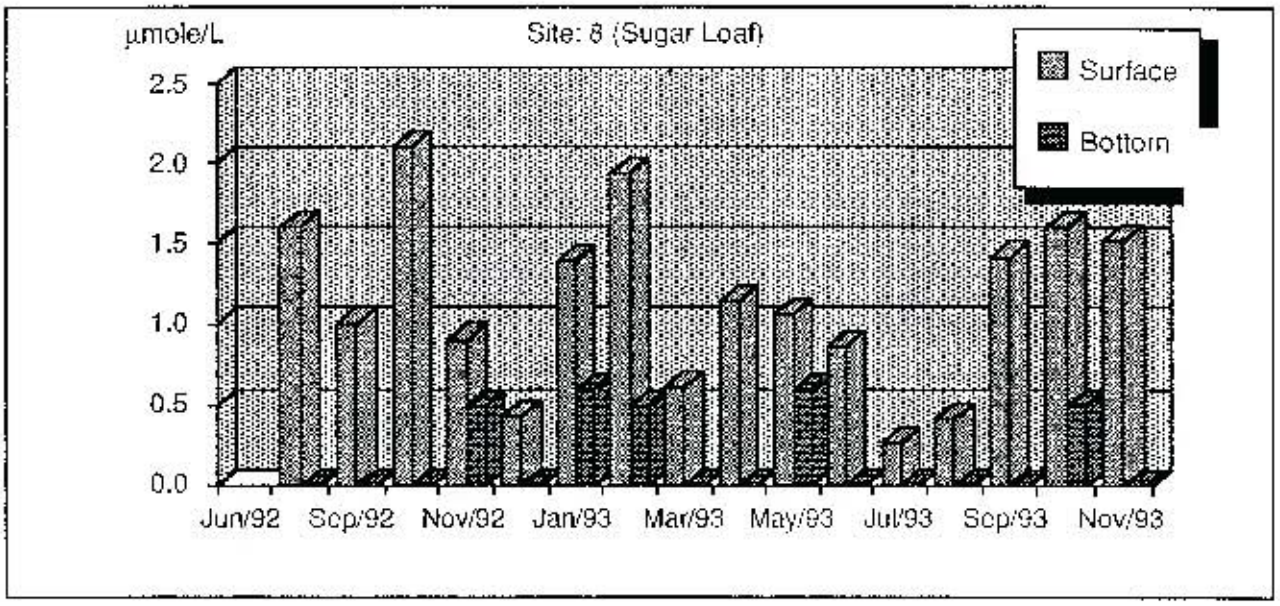


Figure 25: Dissolved Nitrate versus sample date for sites 4 to 6.





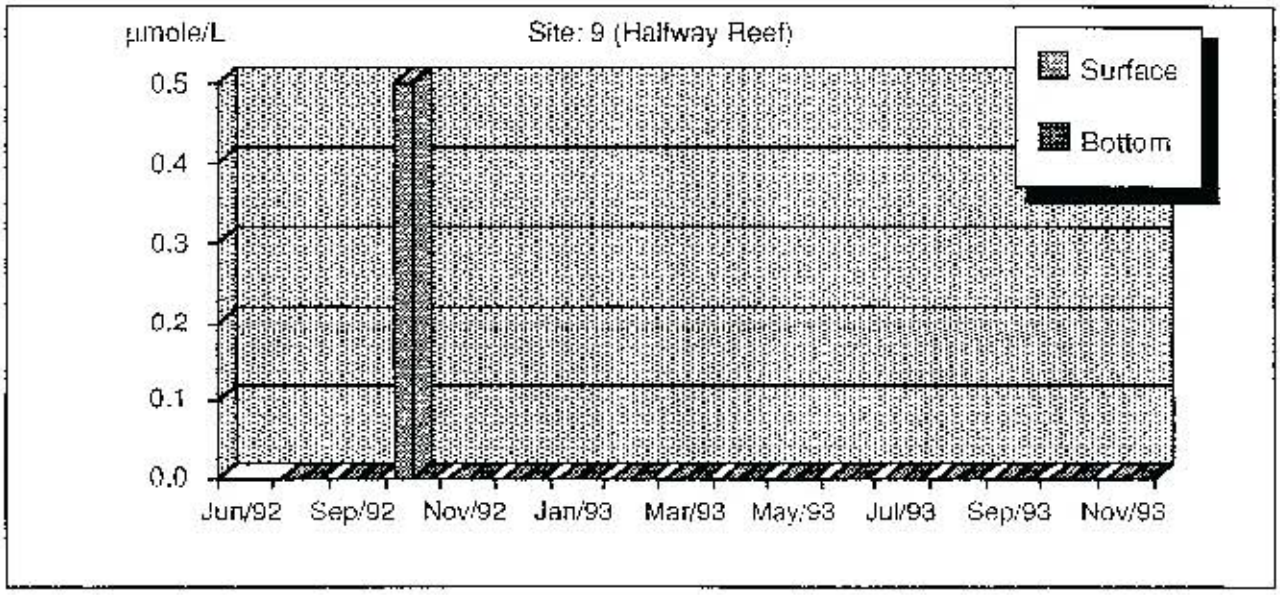


Figure 26: Dissolved Nitrate versus sample date for sites 7 to 9.

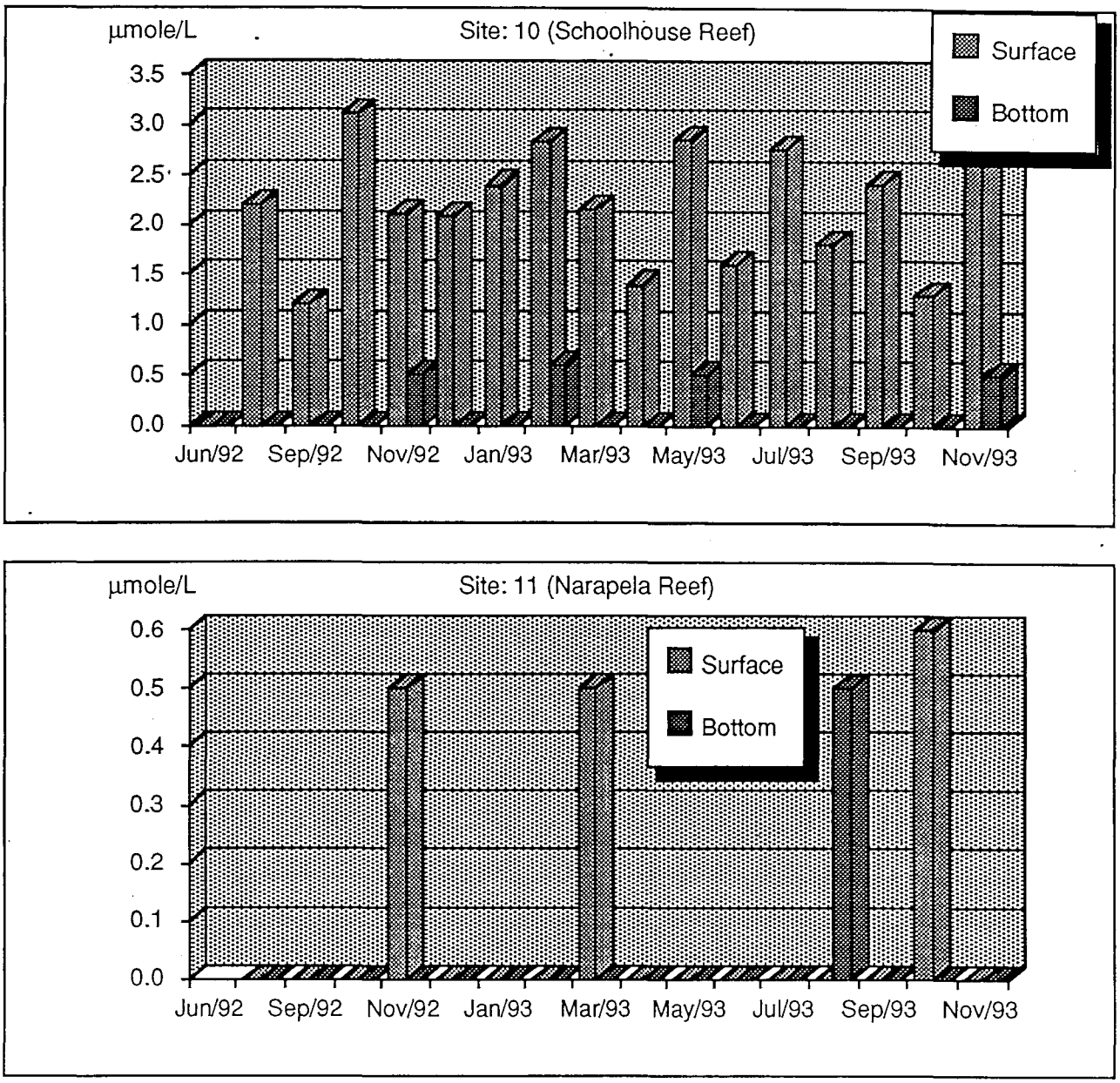
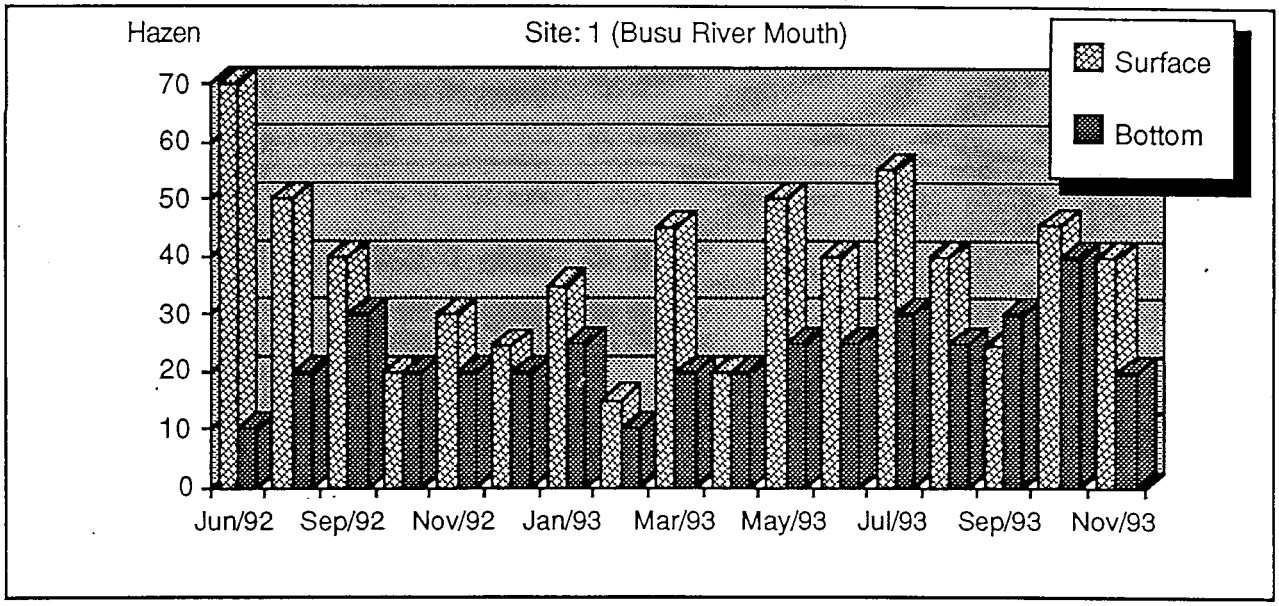
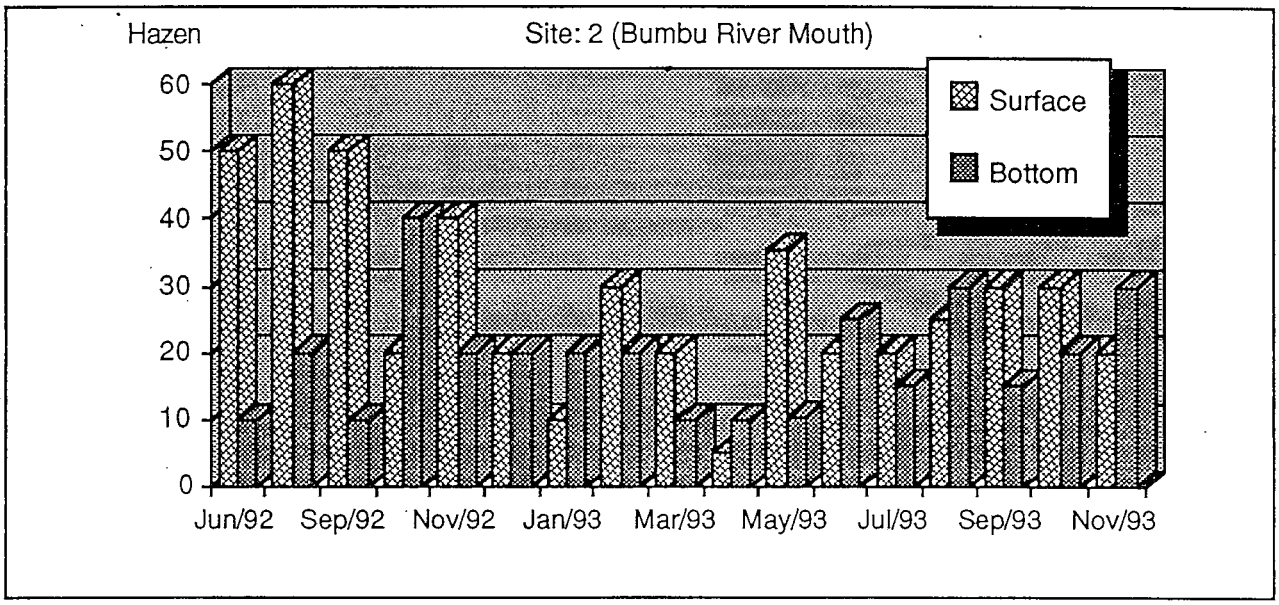


Figure 27: Dissolved Nitrate versus sample date for sites 10 and 11.





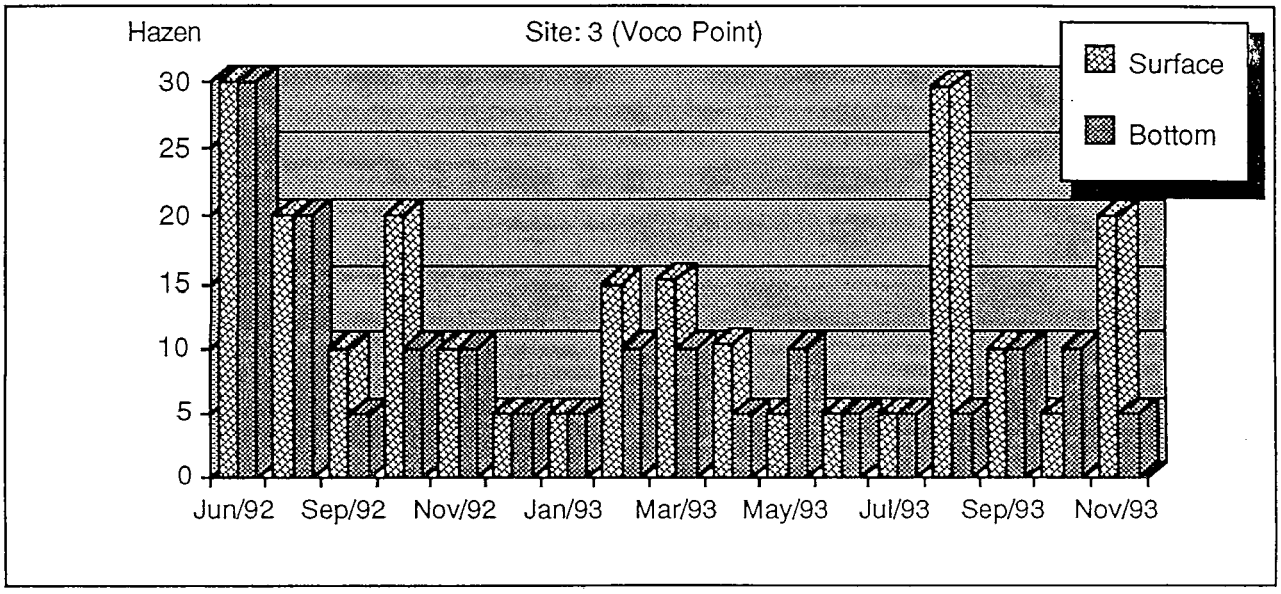
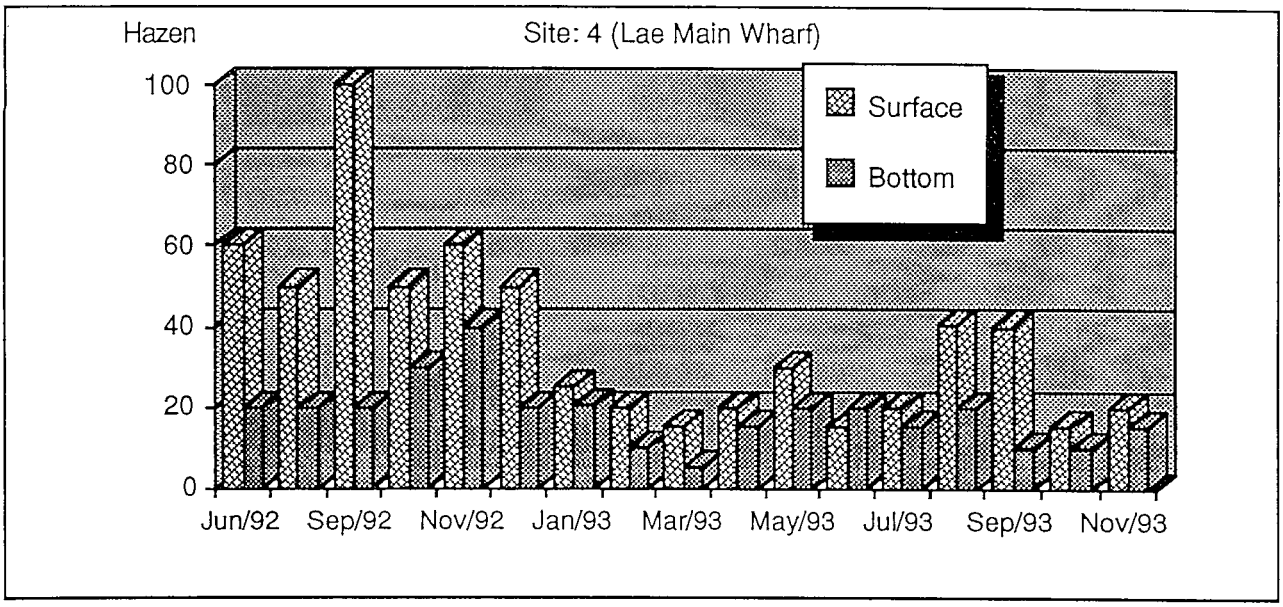
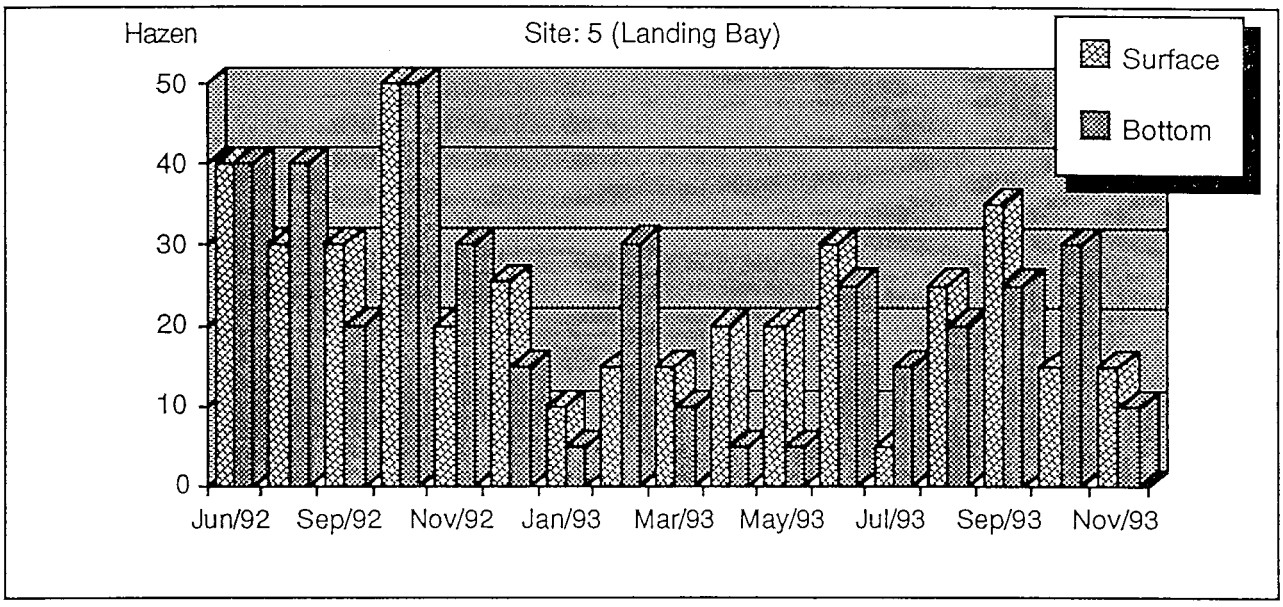


Figure 28: Colour versus sample date for sites 1 to 3.





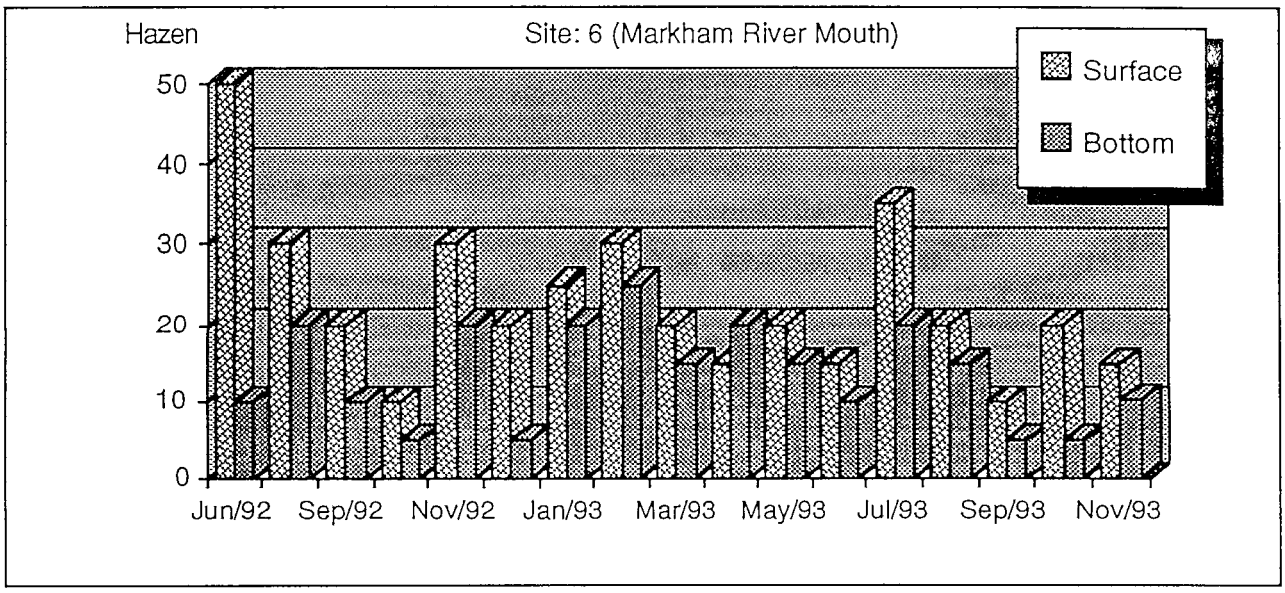
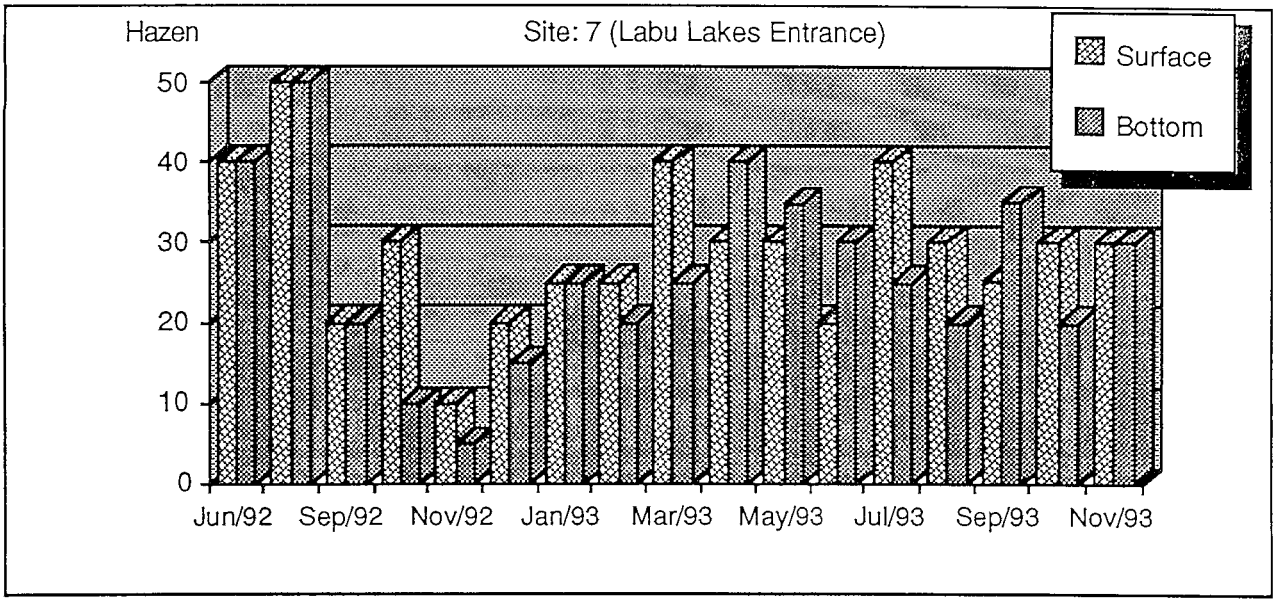
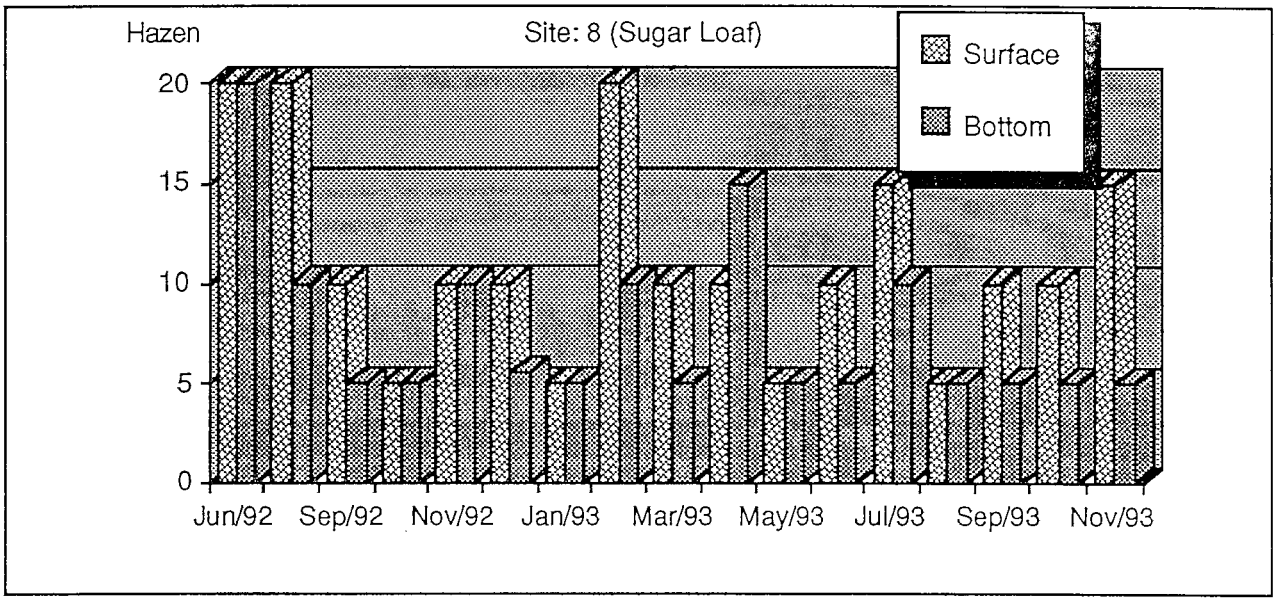


Figure 29: Colour versus sample date for sites 4 to 6.





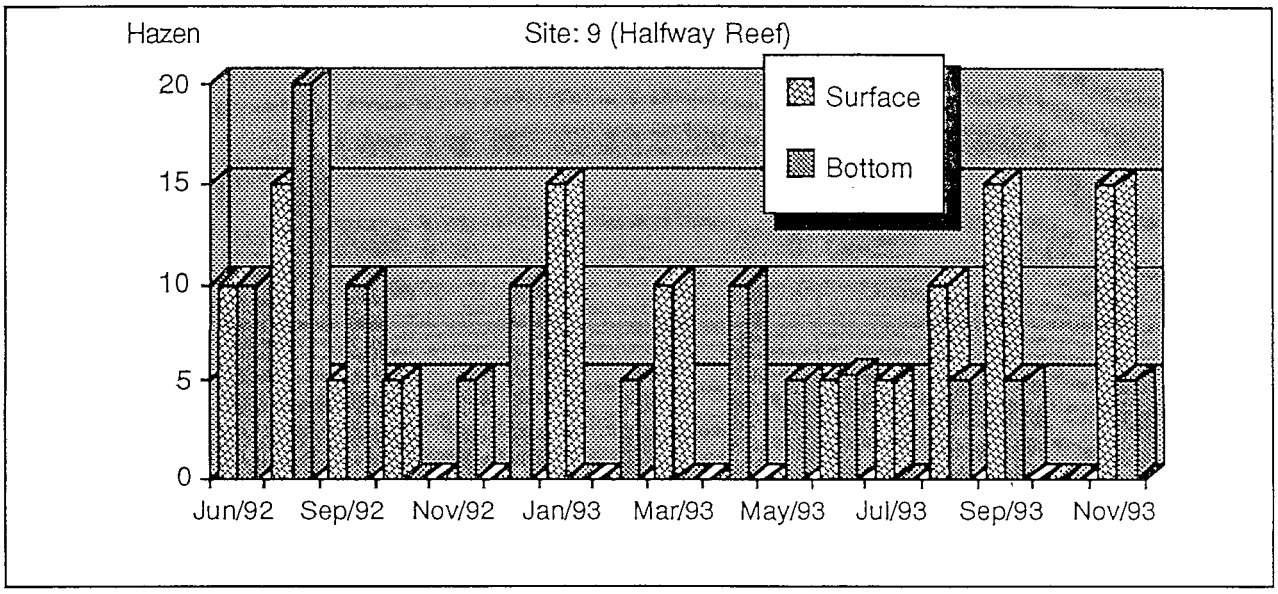


Figure 30: Colour versus sample date for sites 7 to 9.

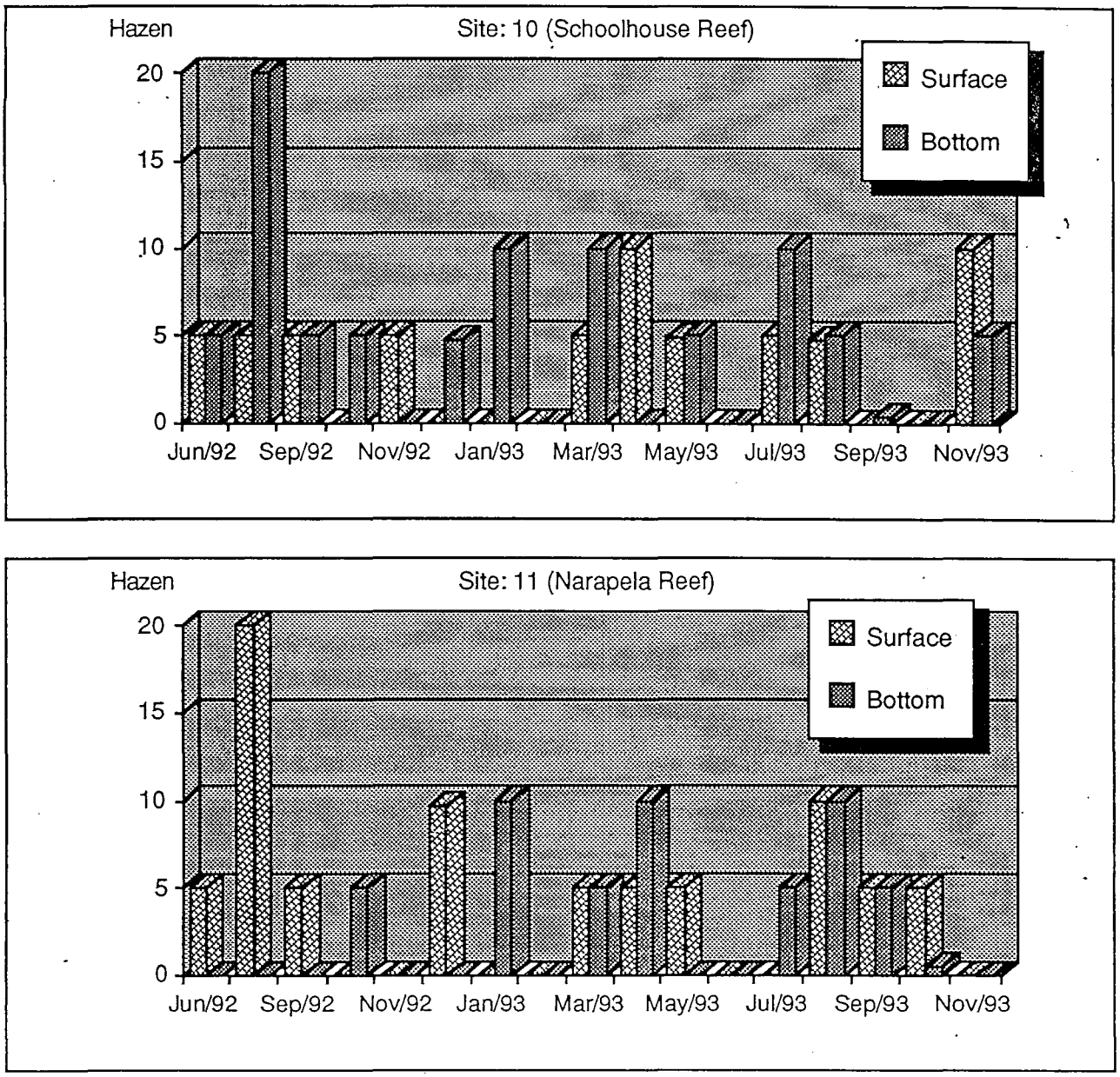
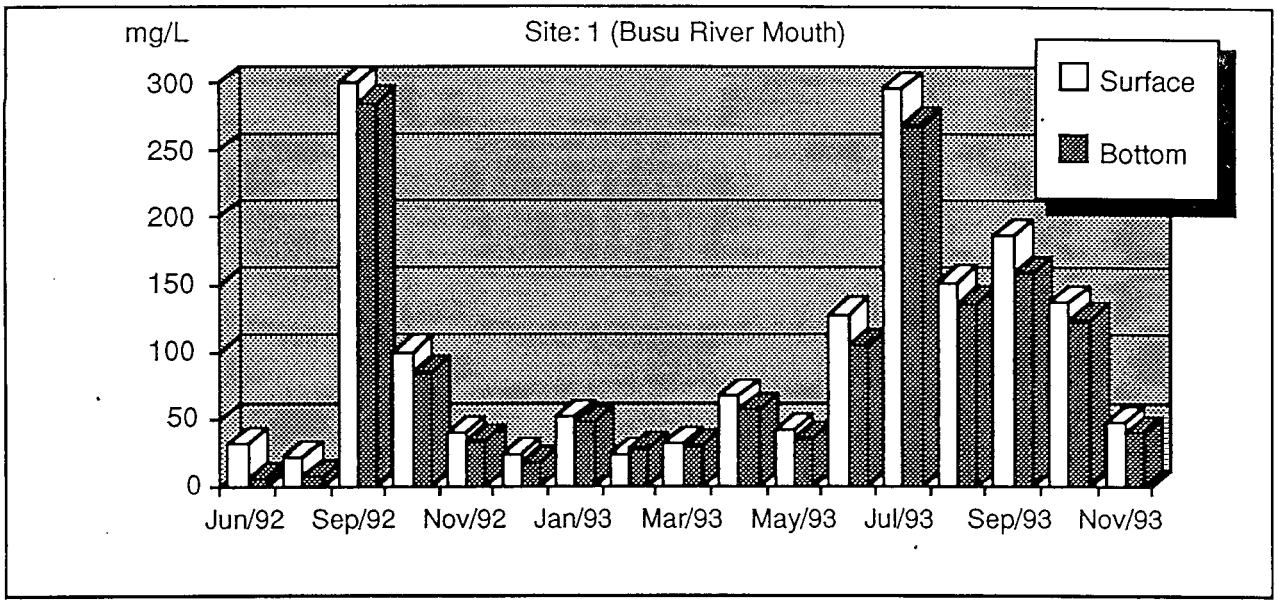
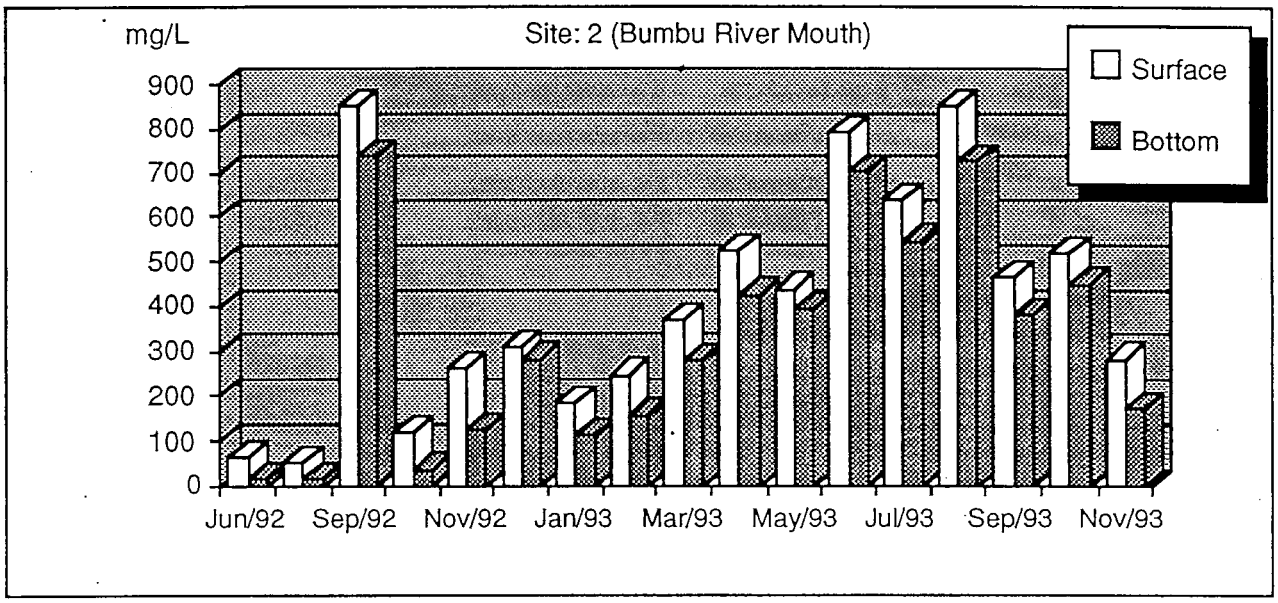


Figure 31: Colour versus sample date for sites 10 and 11.





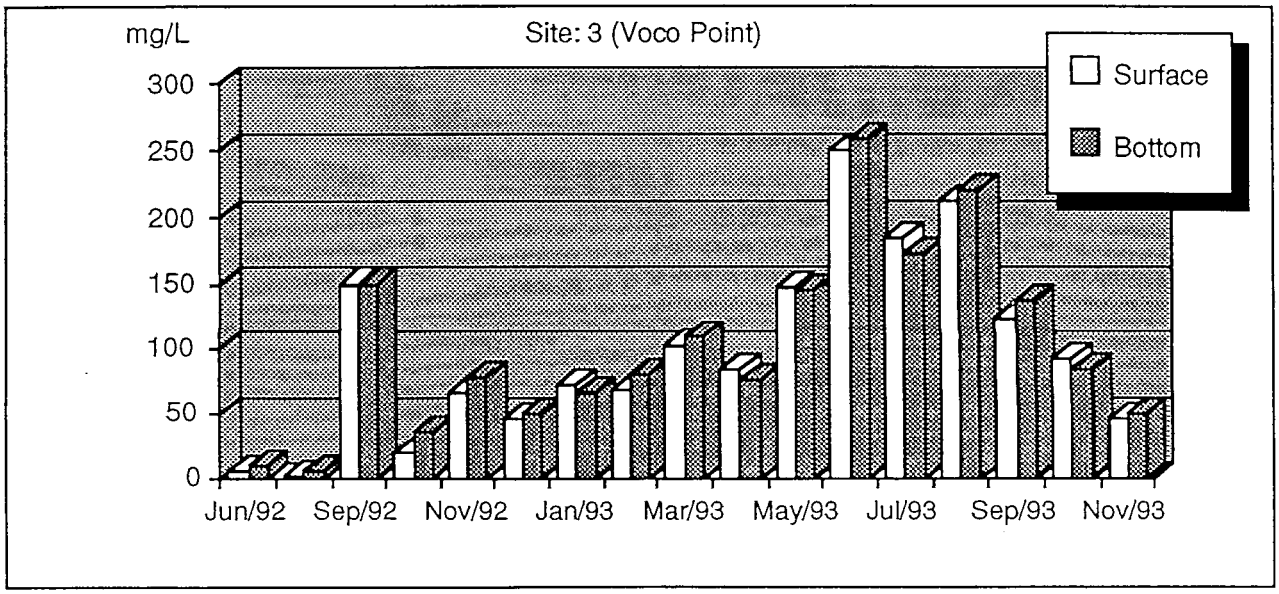
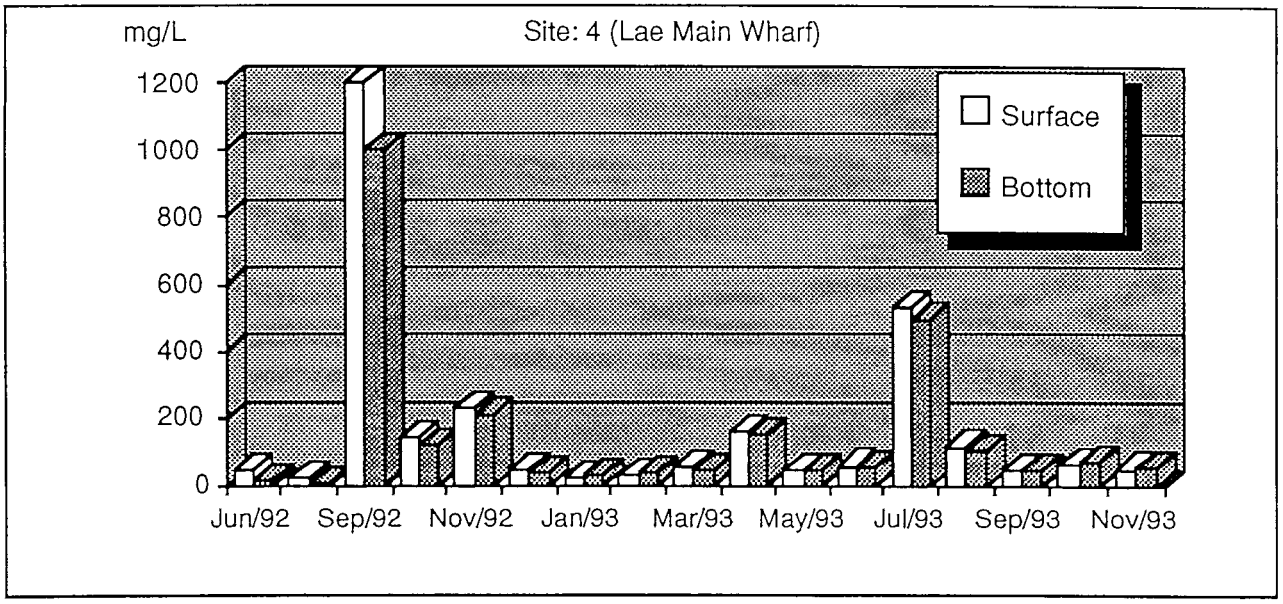
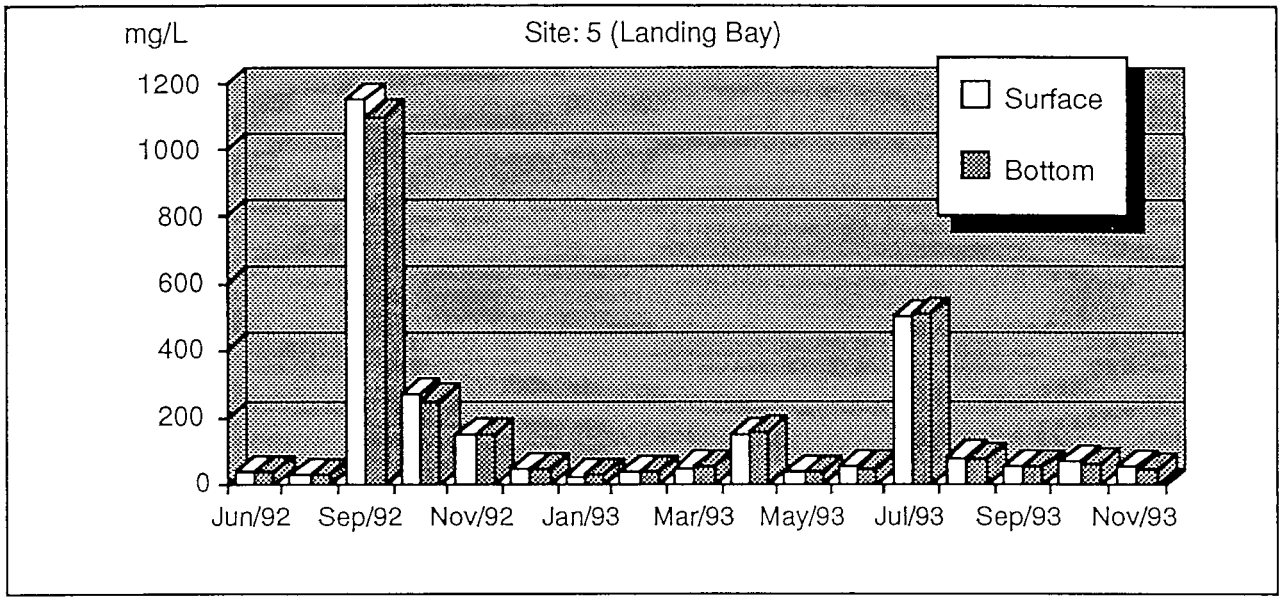


Figure 32: Total Suspended Solids versus sample date for sites 1 to 3.





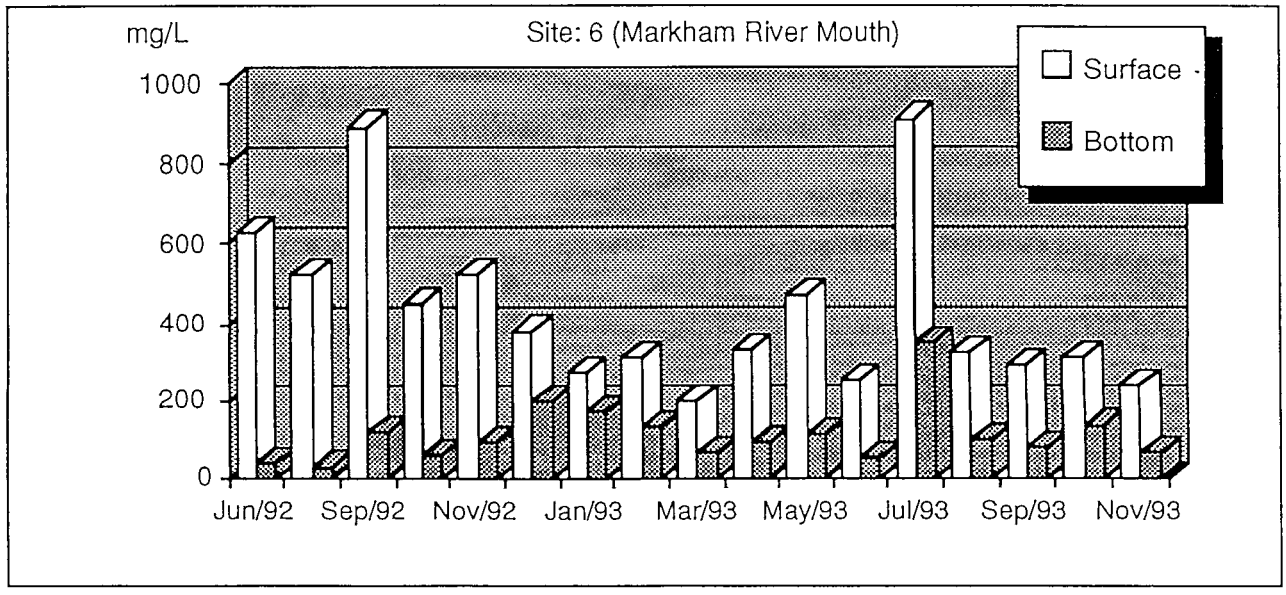
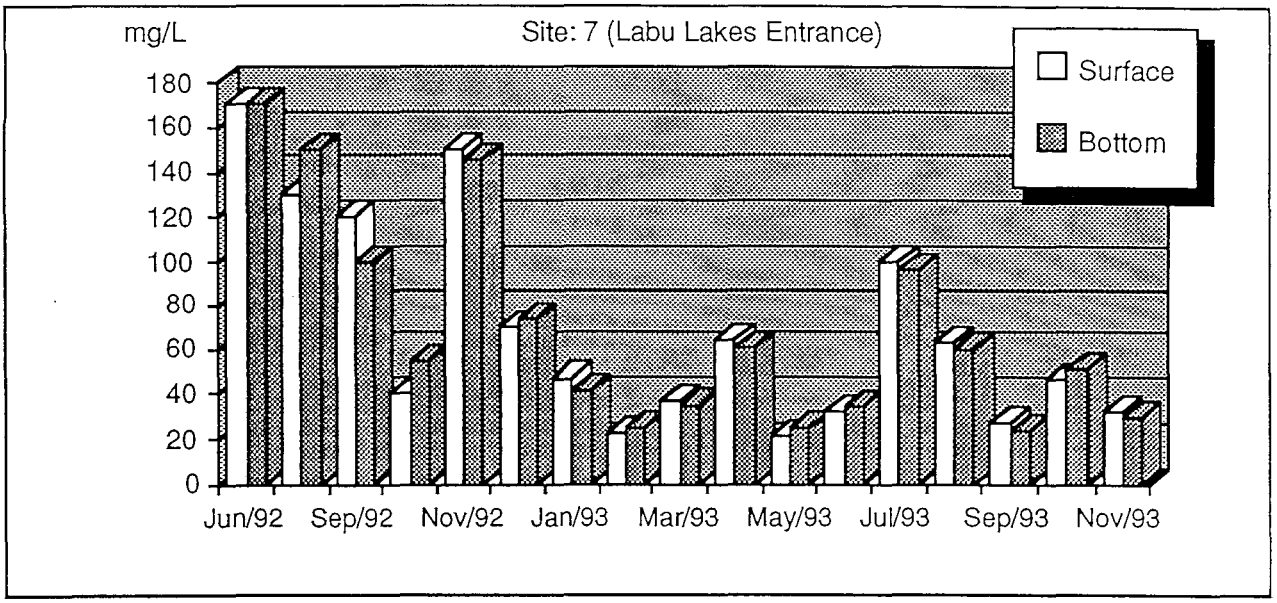
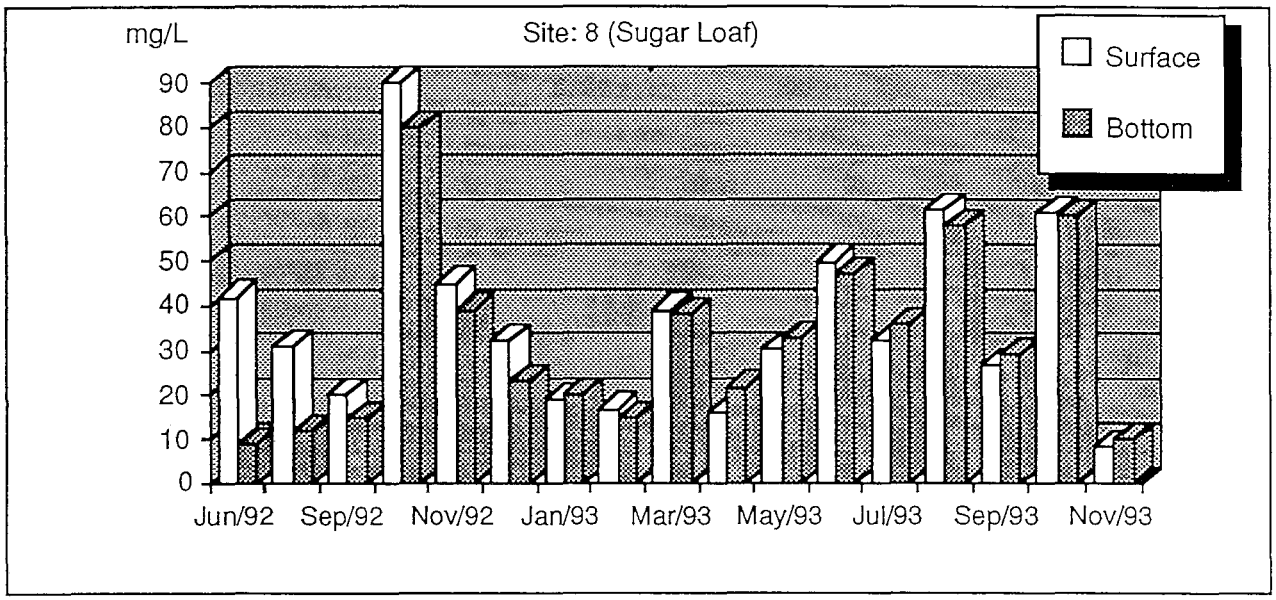


Figure 33: Total Suspended Solids versus sample date for sites 4 to 6.





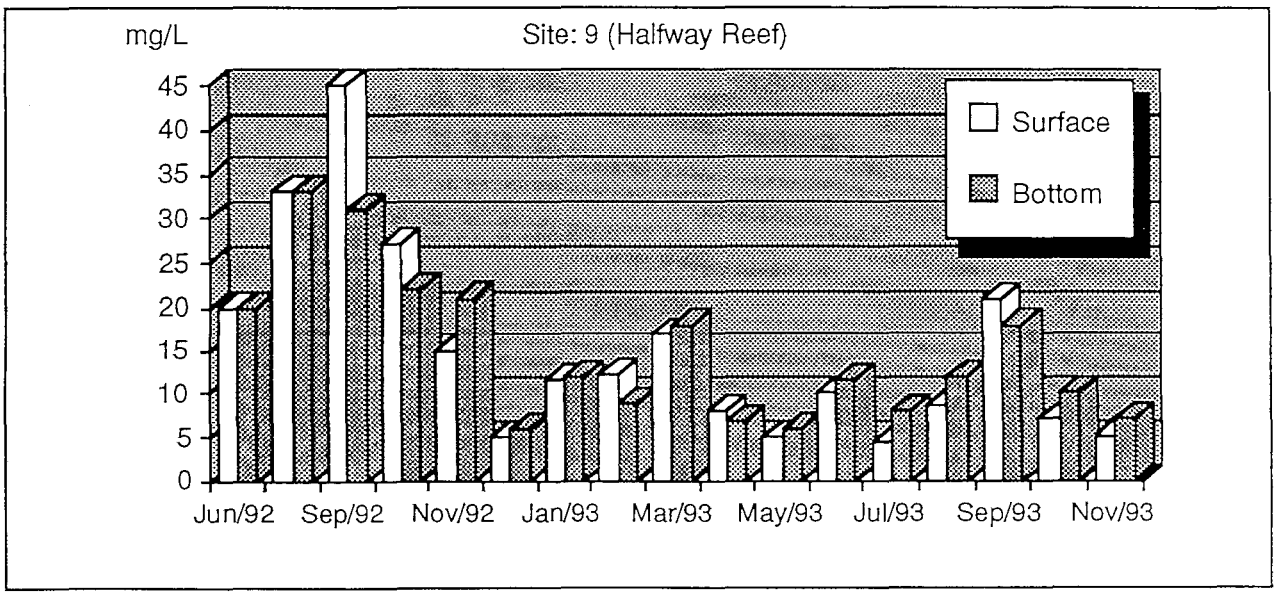


Figure 34: Total Suspended Solids versus sample date for sites 7 to 9.

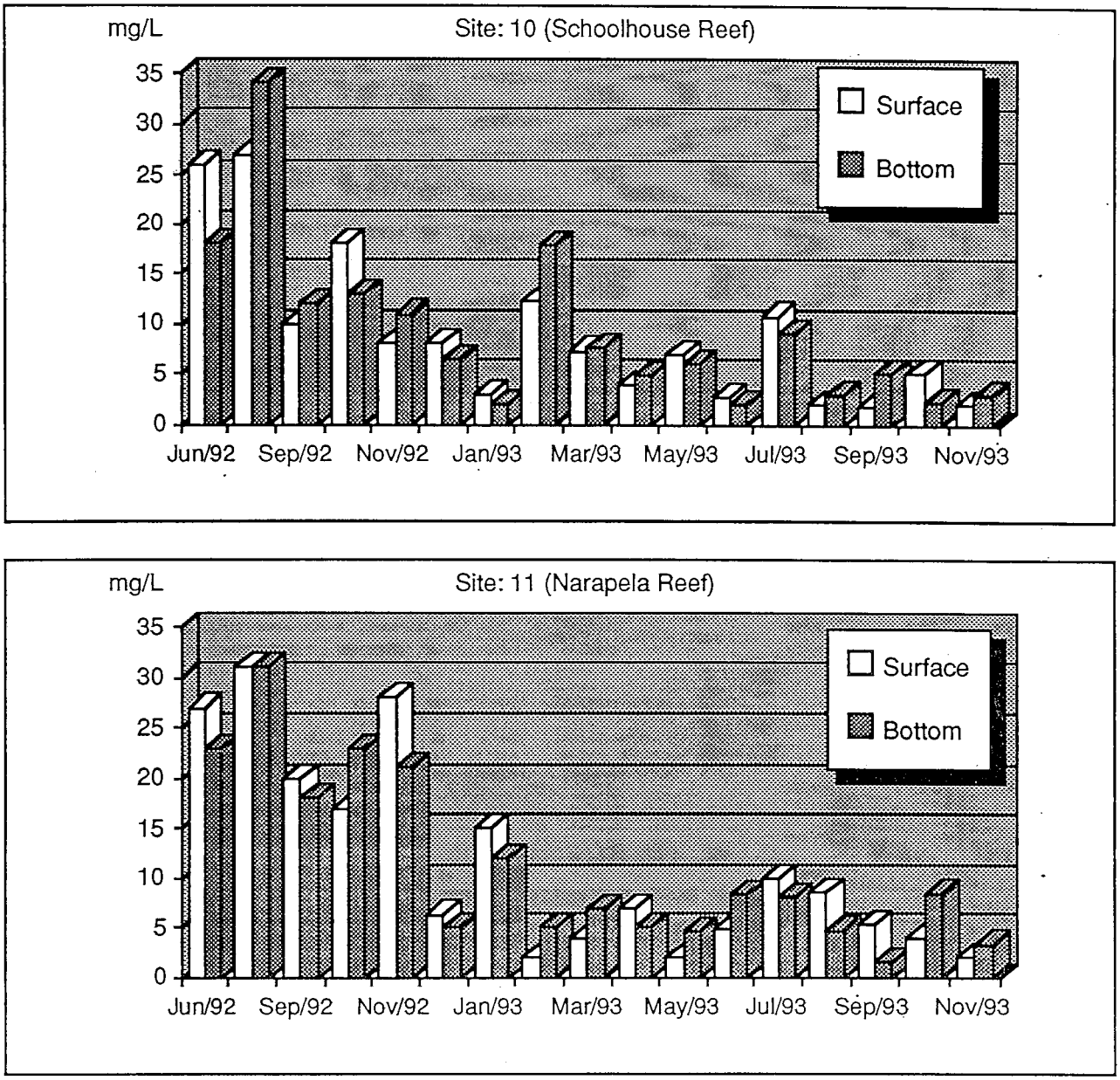
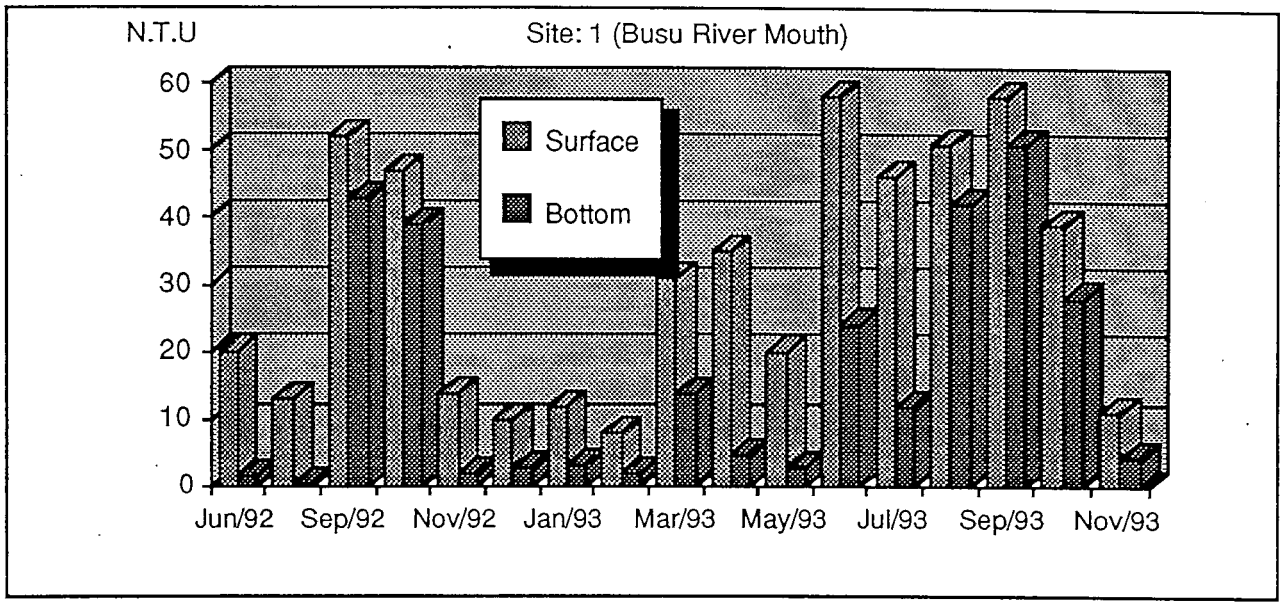
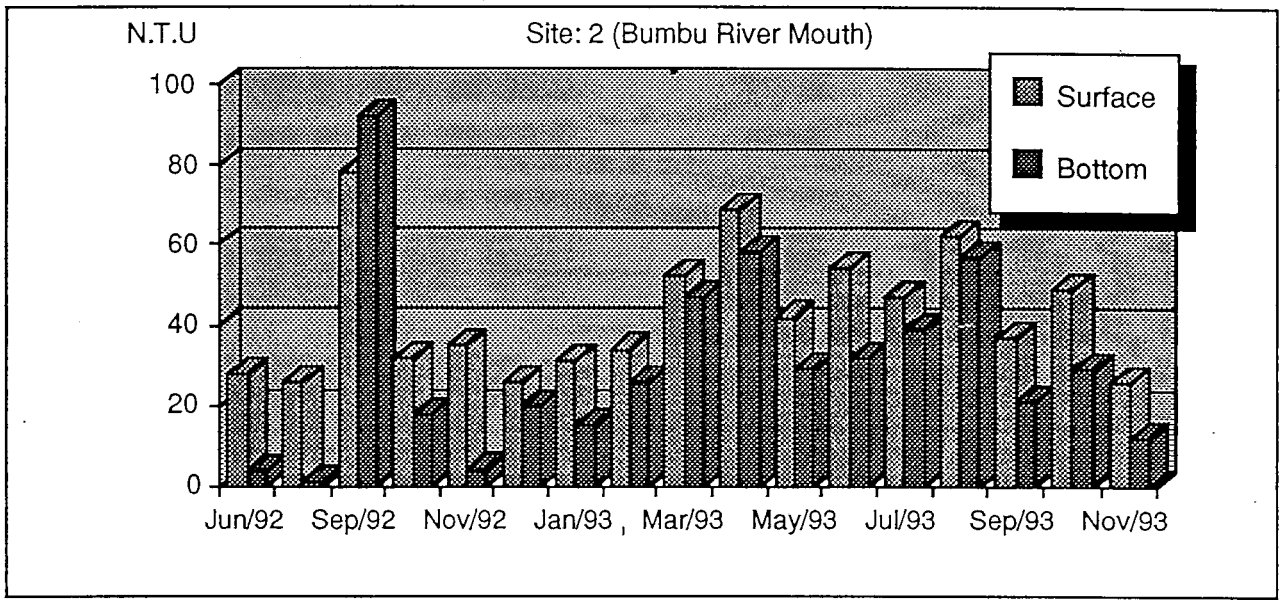


Figure 35: Total Suspended Solids versus sample date for sites 10 and 11.





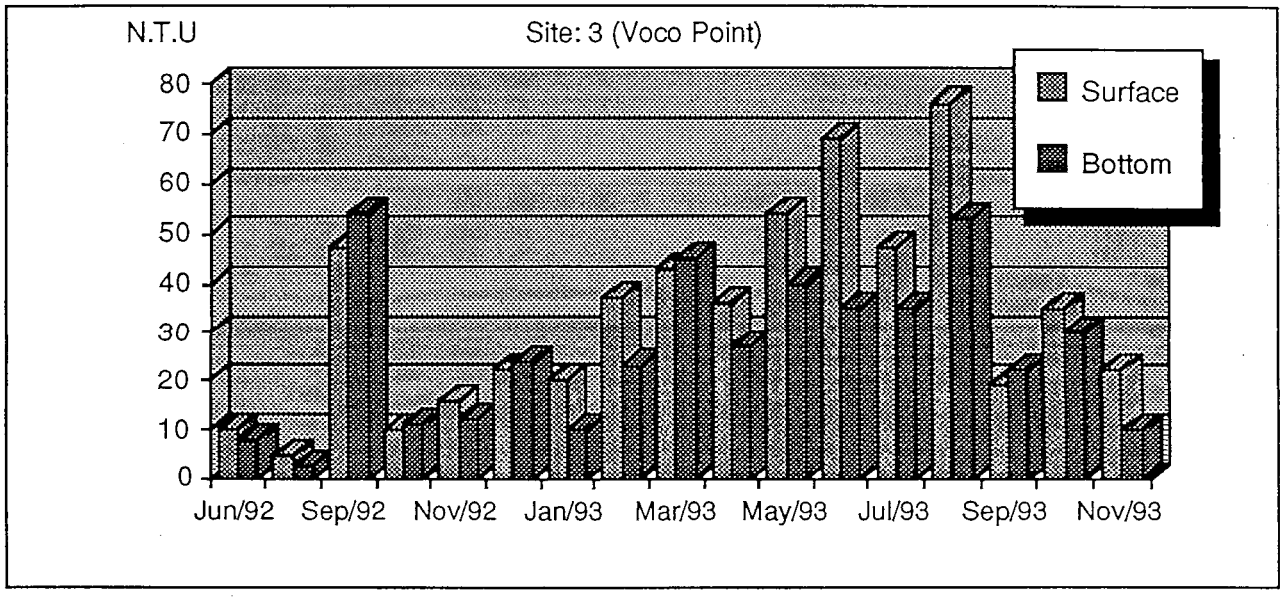
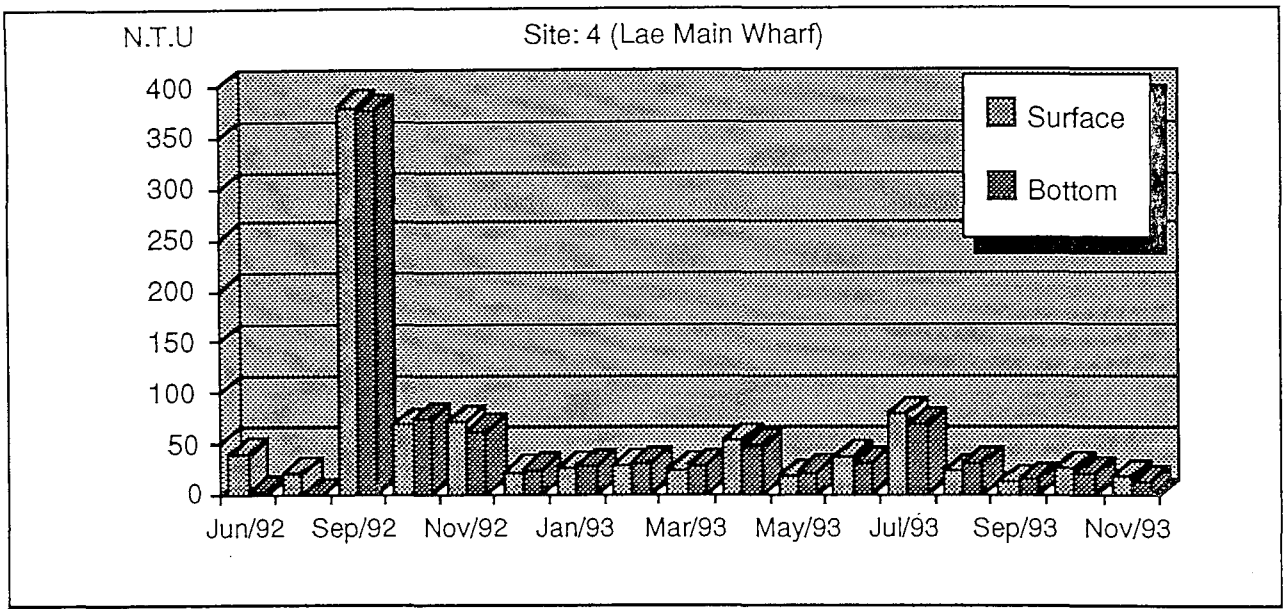
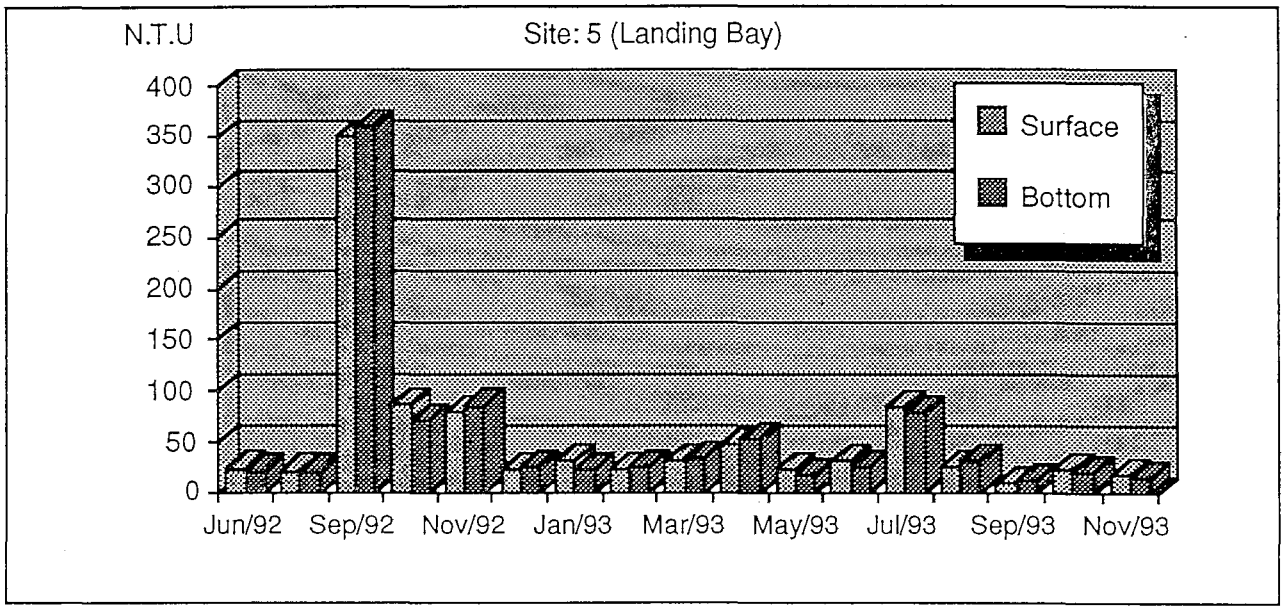


Figure 36: Turbidity versus sample date for sites 1 to 3.





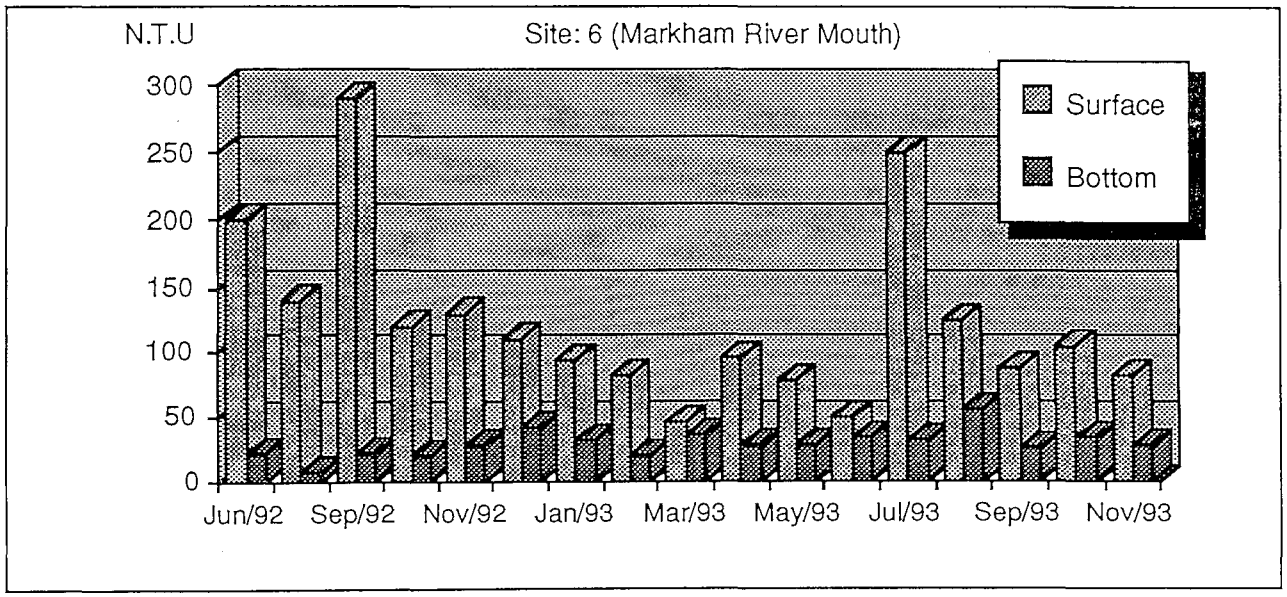
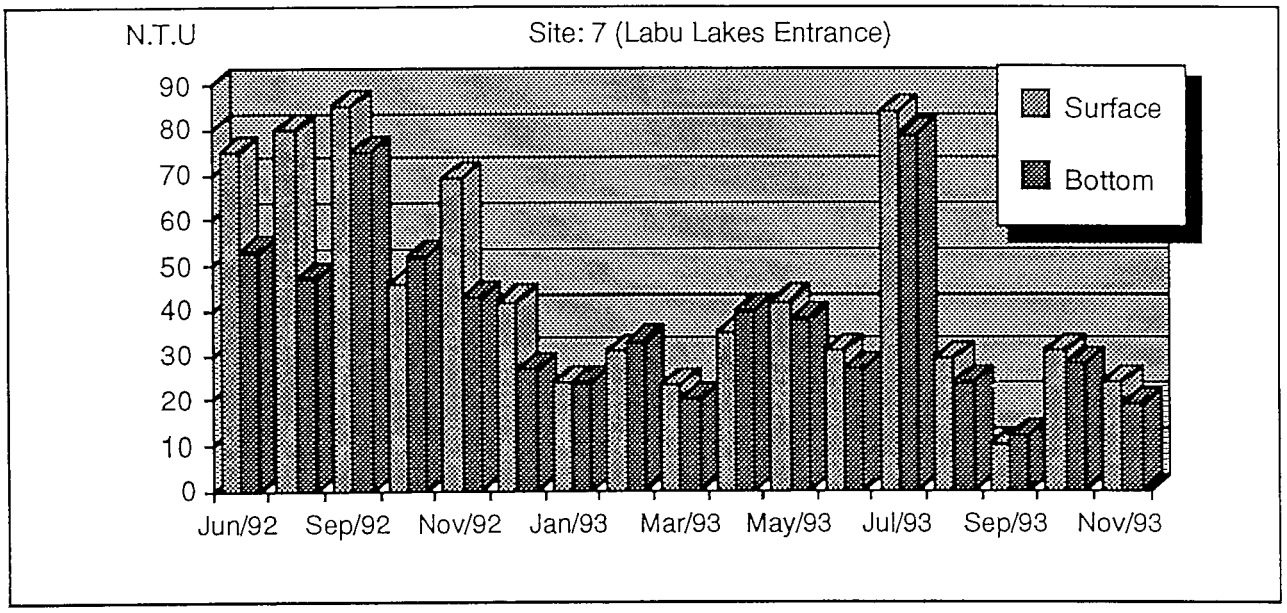
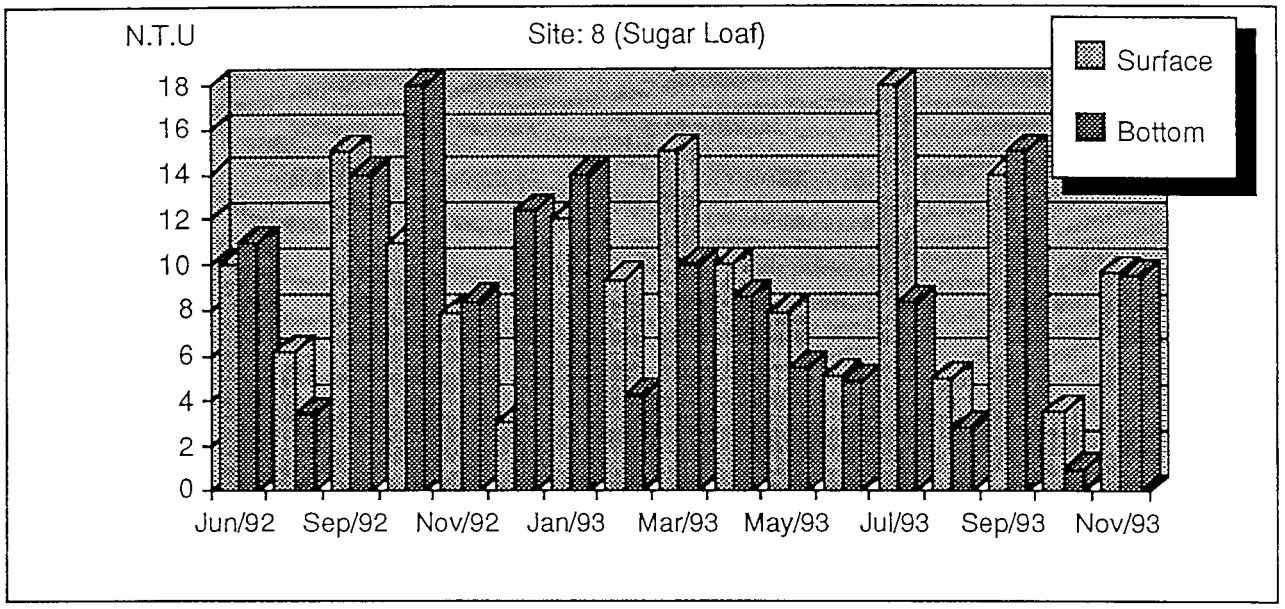


Figure 37: Turbidity versus sample date for sites 4 to 6.





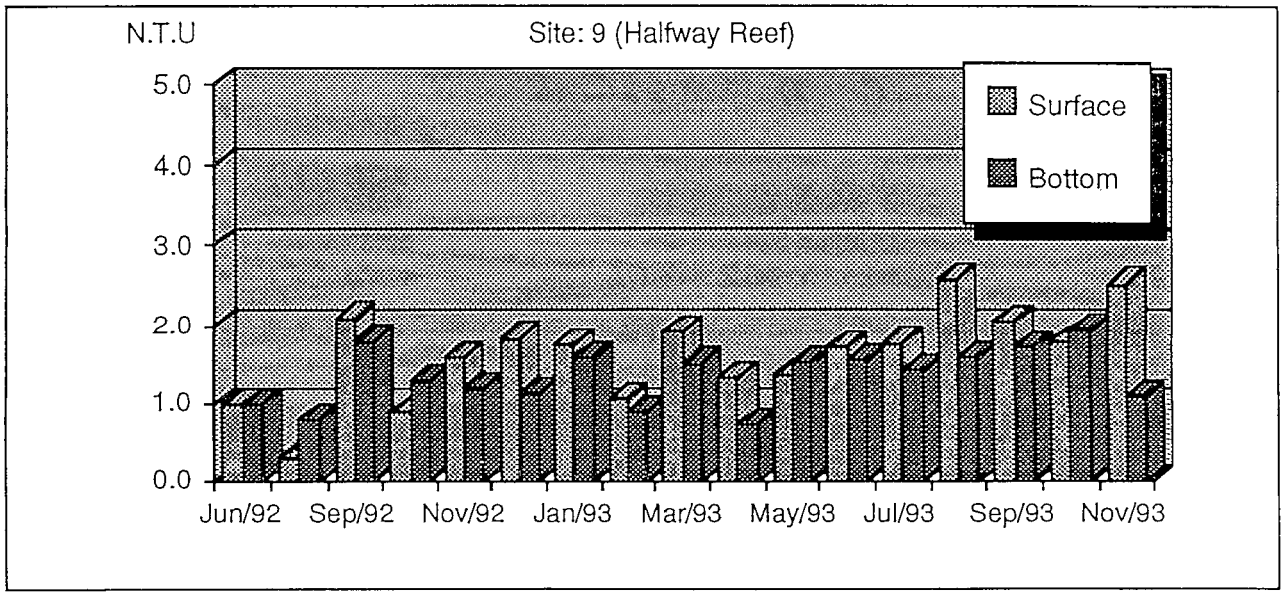


Figure 38: Turbidity versus sample date for sites 7 to 9.

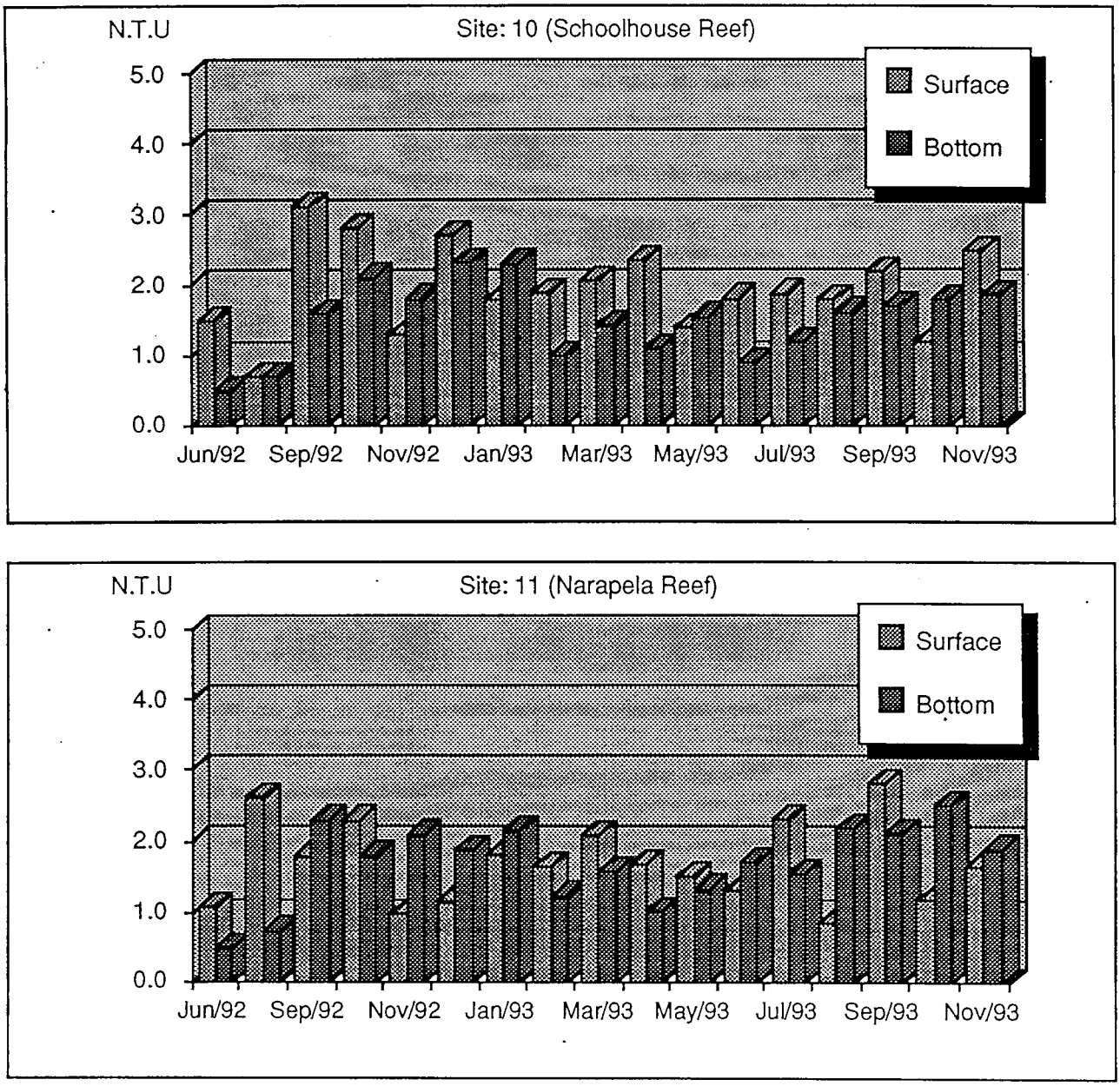


Figure 39: Turbidity versus sample date for sites 10 and 11.

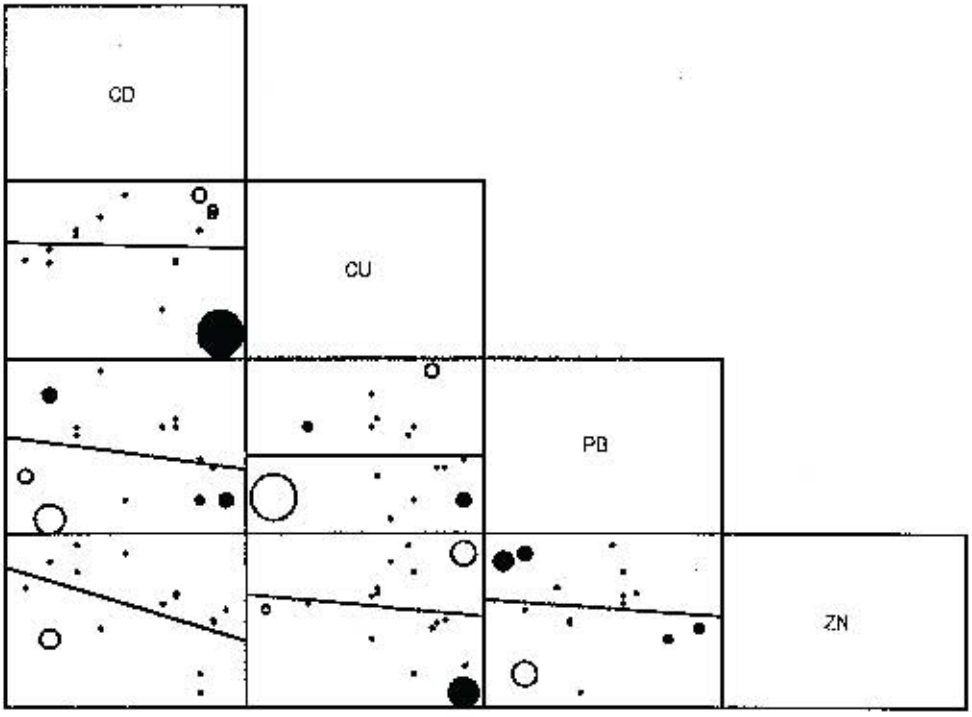


Figure 40: Scatterplot matrix for sediment metal results from site 1.

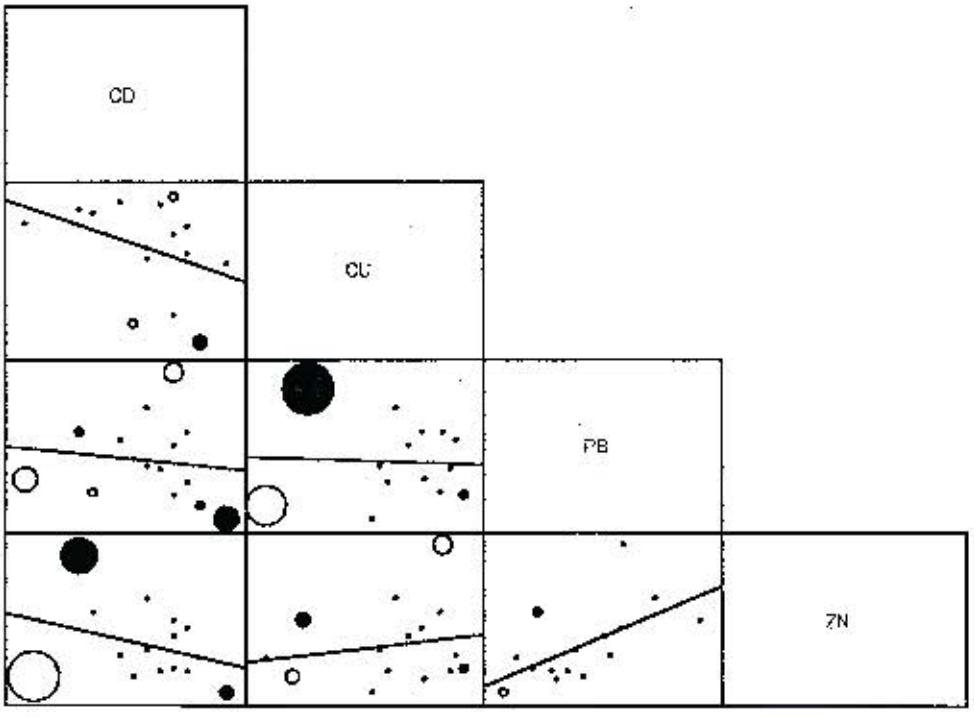


Figure 41: Scatterplot matrix for sediment metal results from site 2.

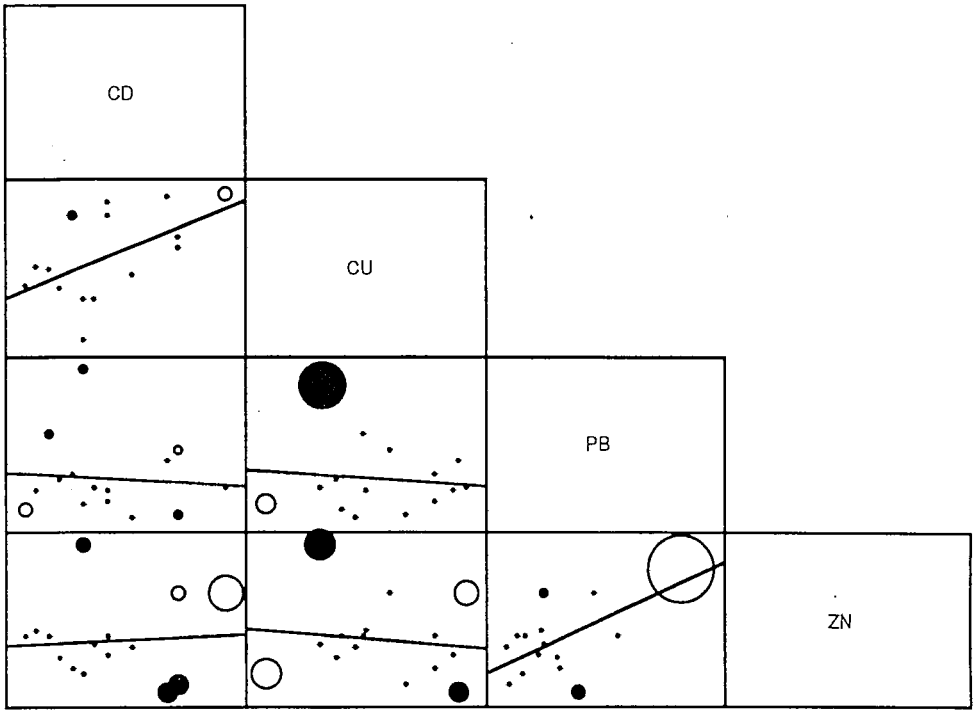


Figure 42: Scatterplot matrix for sediment metal results from site 3.

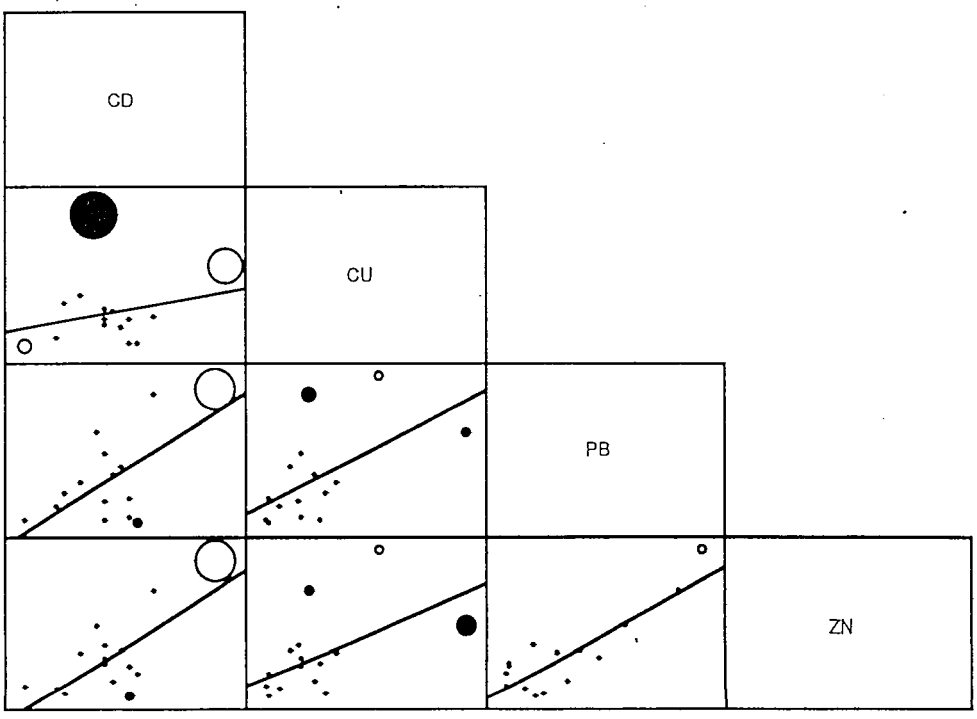


Figure 43: Scatterplot matrix for sediment metal results from site 4.

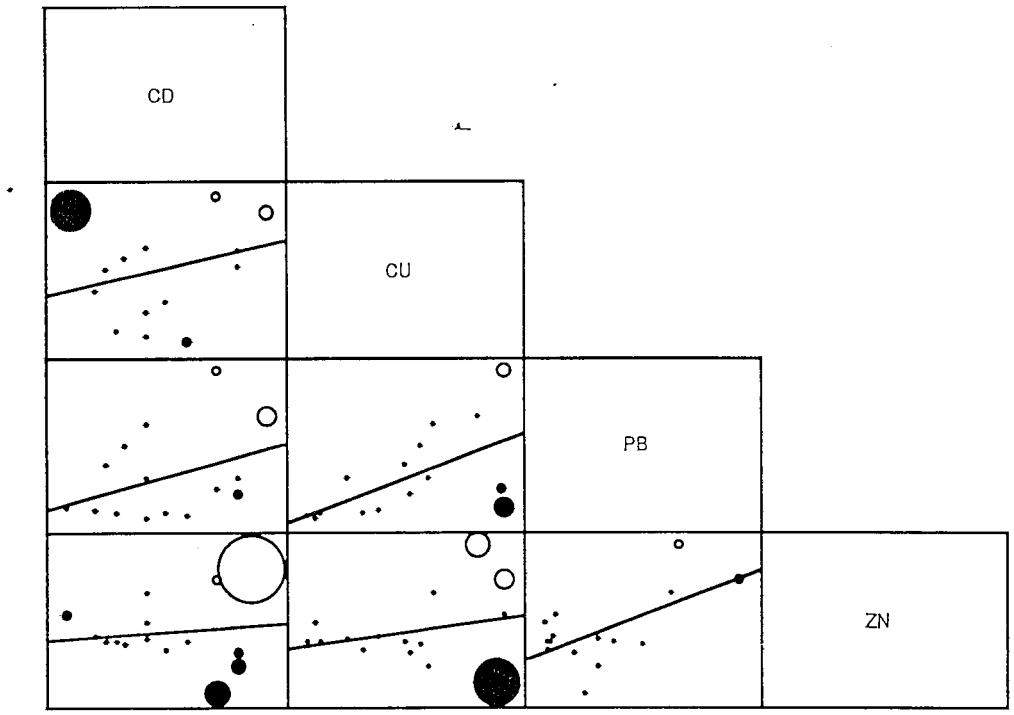


Figure 44: Scatterplot matrix for sediment metal results from site 5.

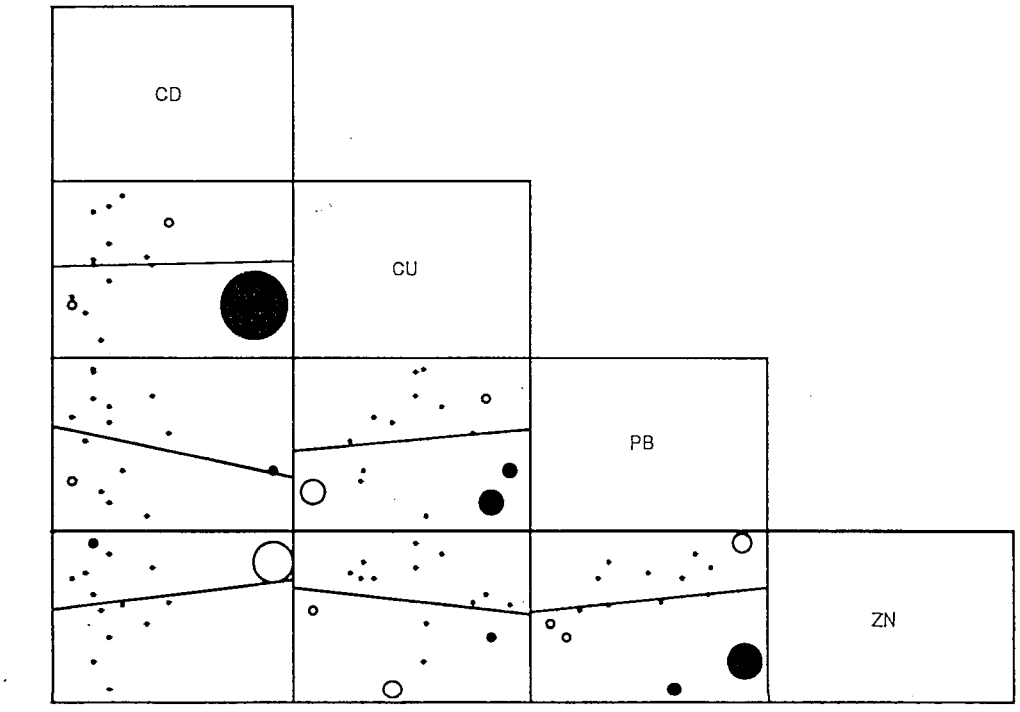


Figure 45: Scatterplot matrix for sediment metal results from site 6.

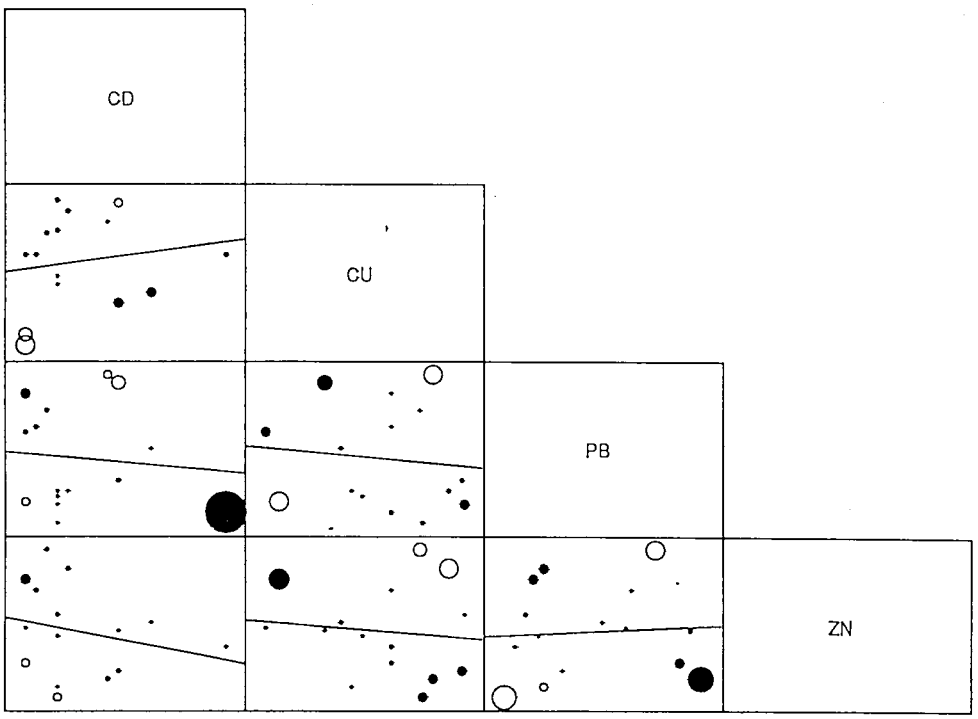


Figure 46: Scatterplot matrix for sediment metal results from site 7.

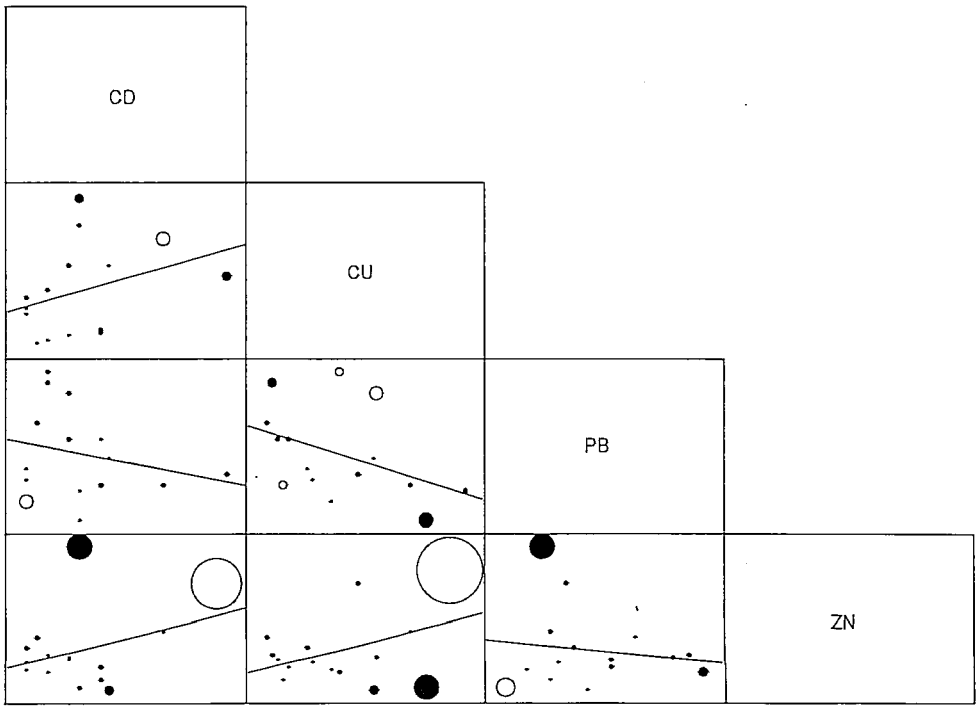


Figure 47: Scatterplot matrix for sediment metal results from site 8.

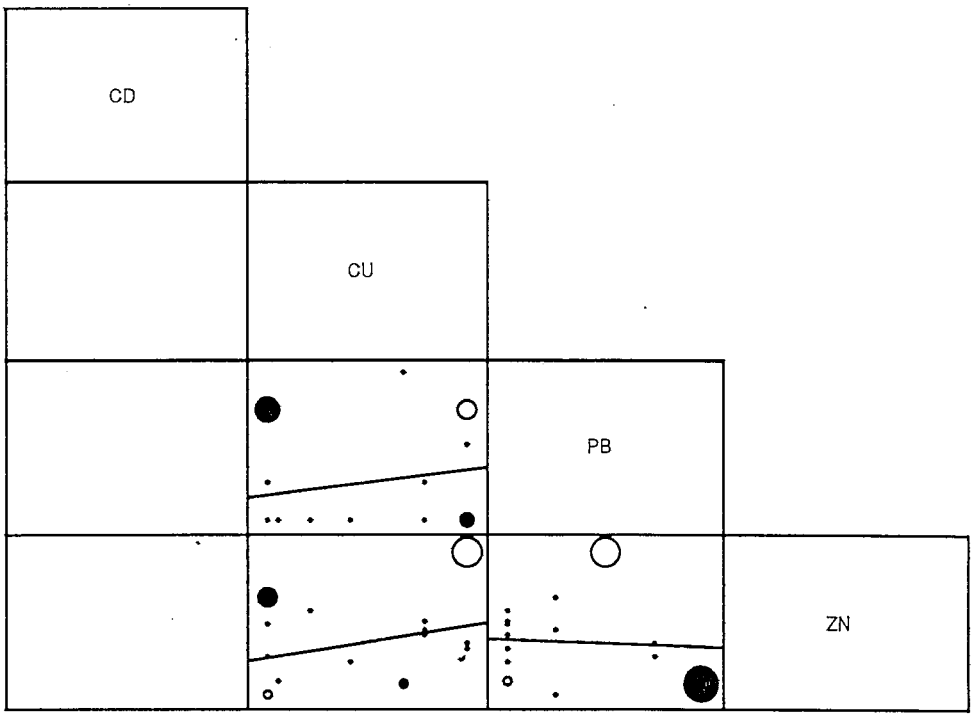


Figure 48: Scatterplot matrix for sediment metal results from site 9.

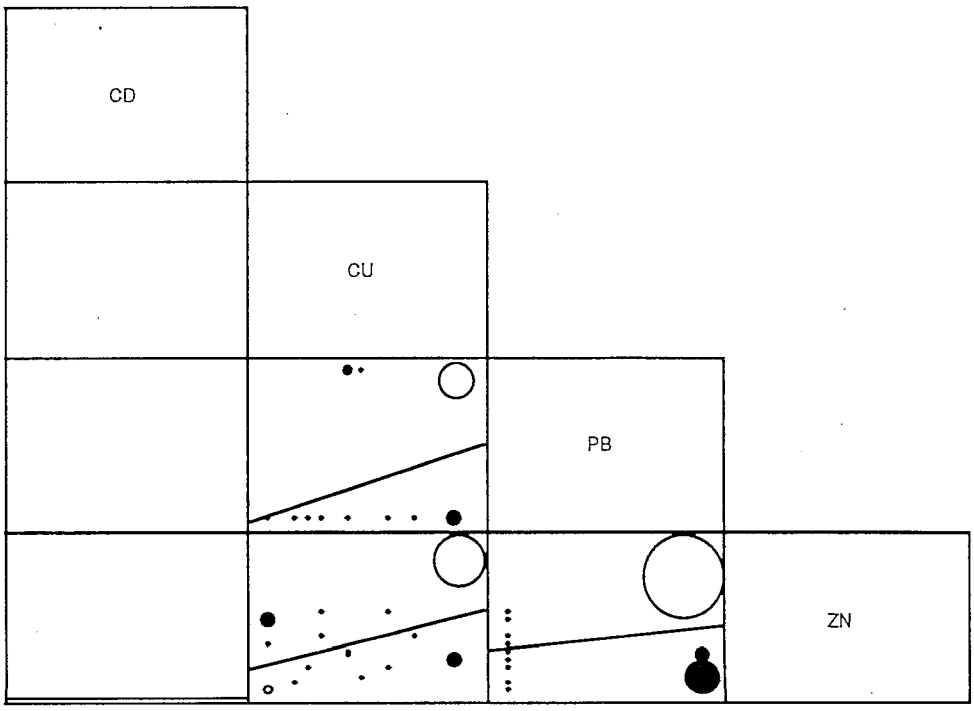
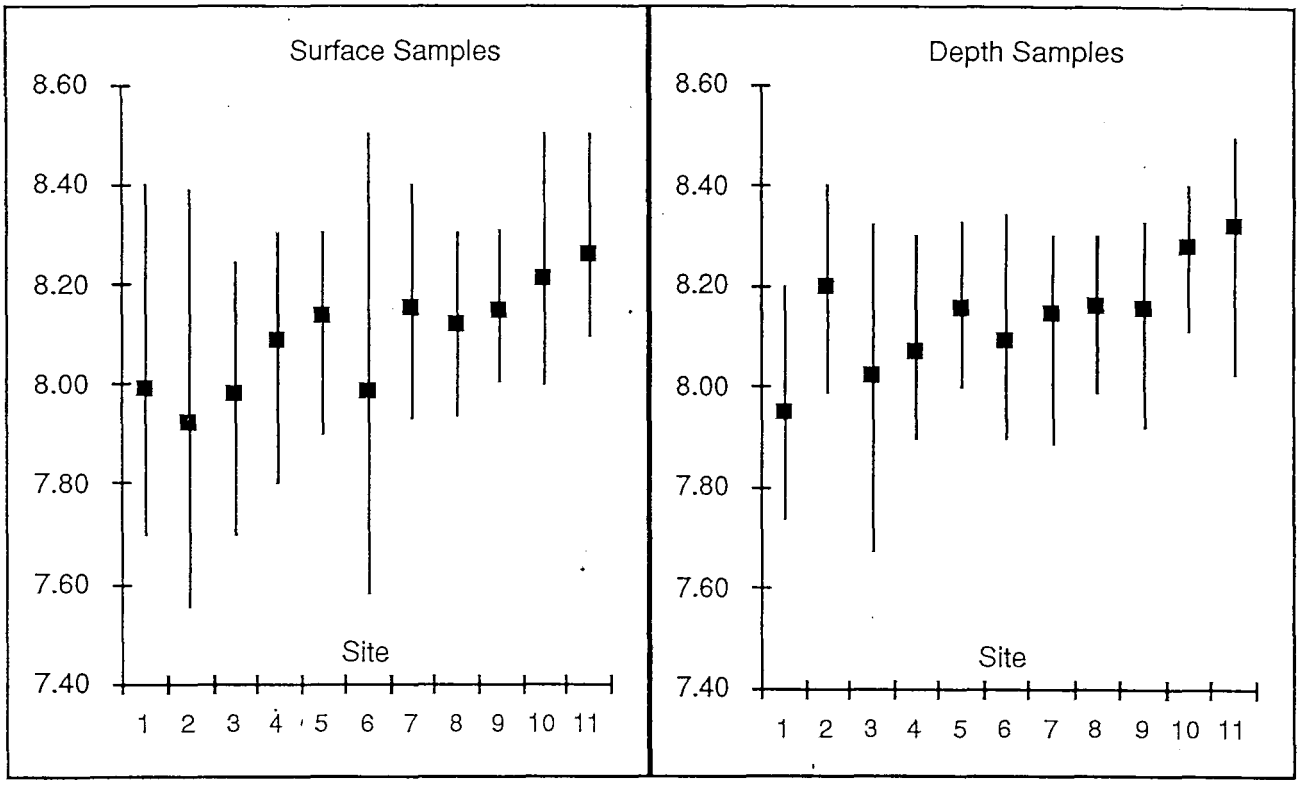


Figure 49: Scatterplot matrix for sediment metal results from site 10.



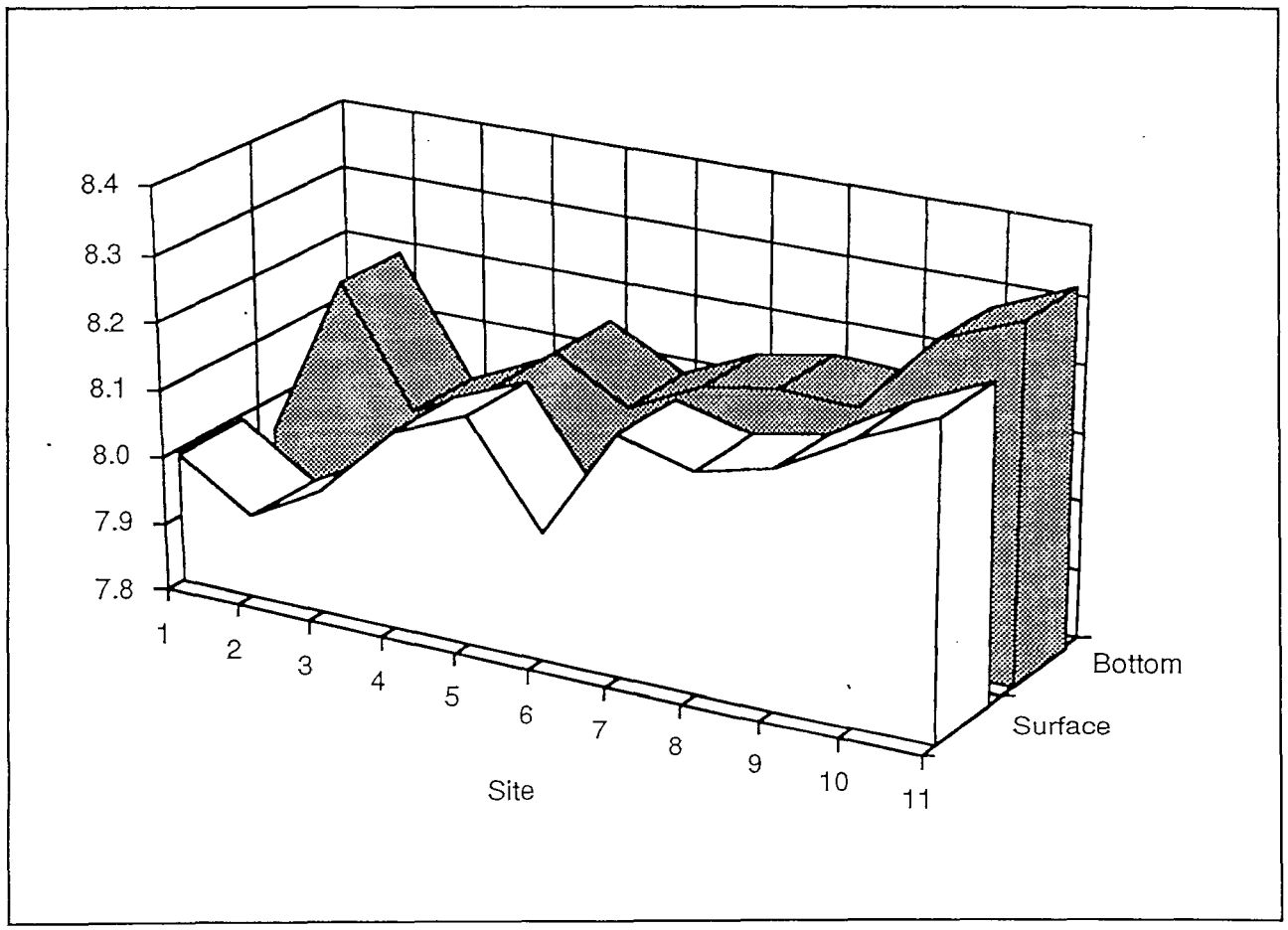
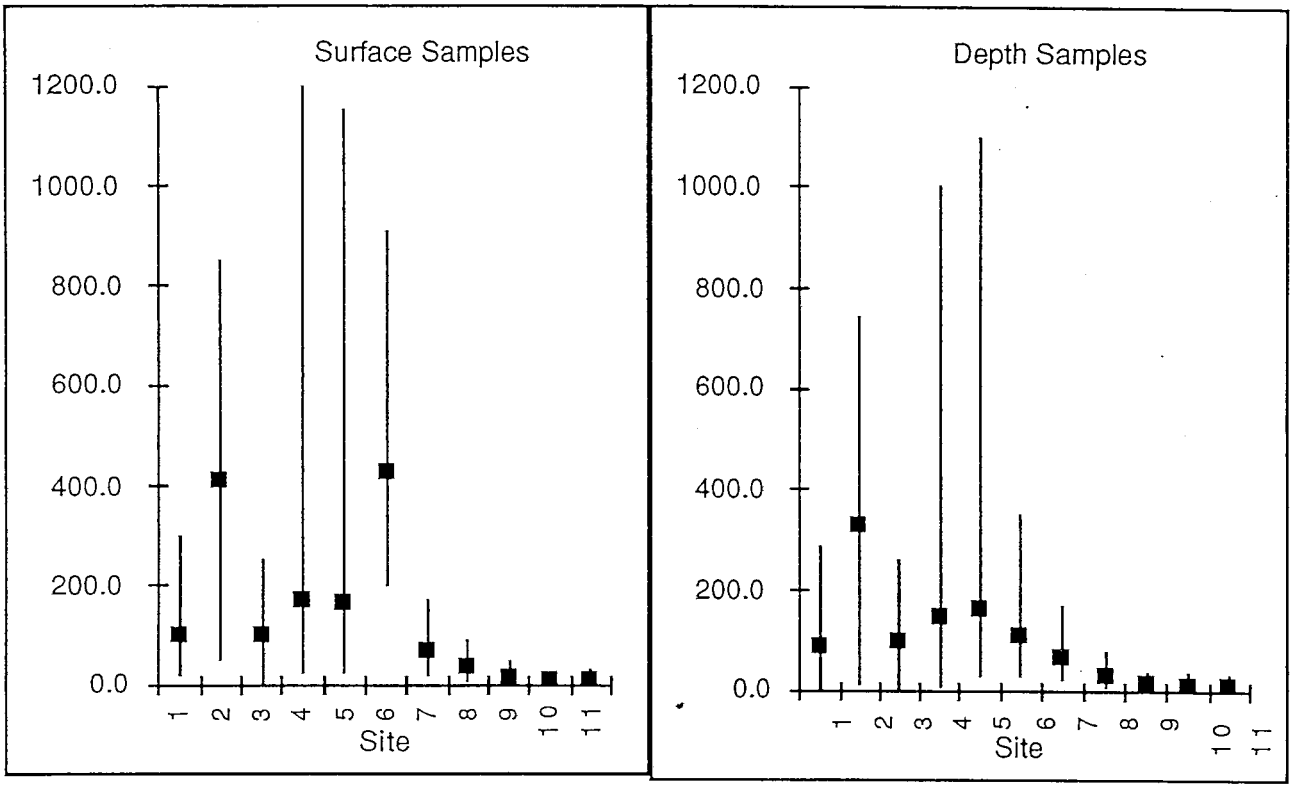


Figure 50: Average and range of pH by site.



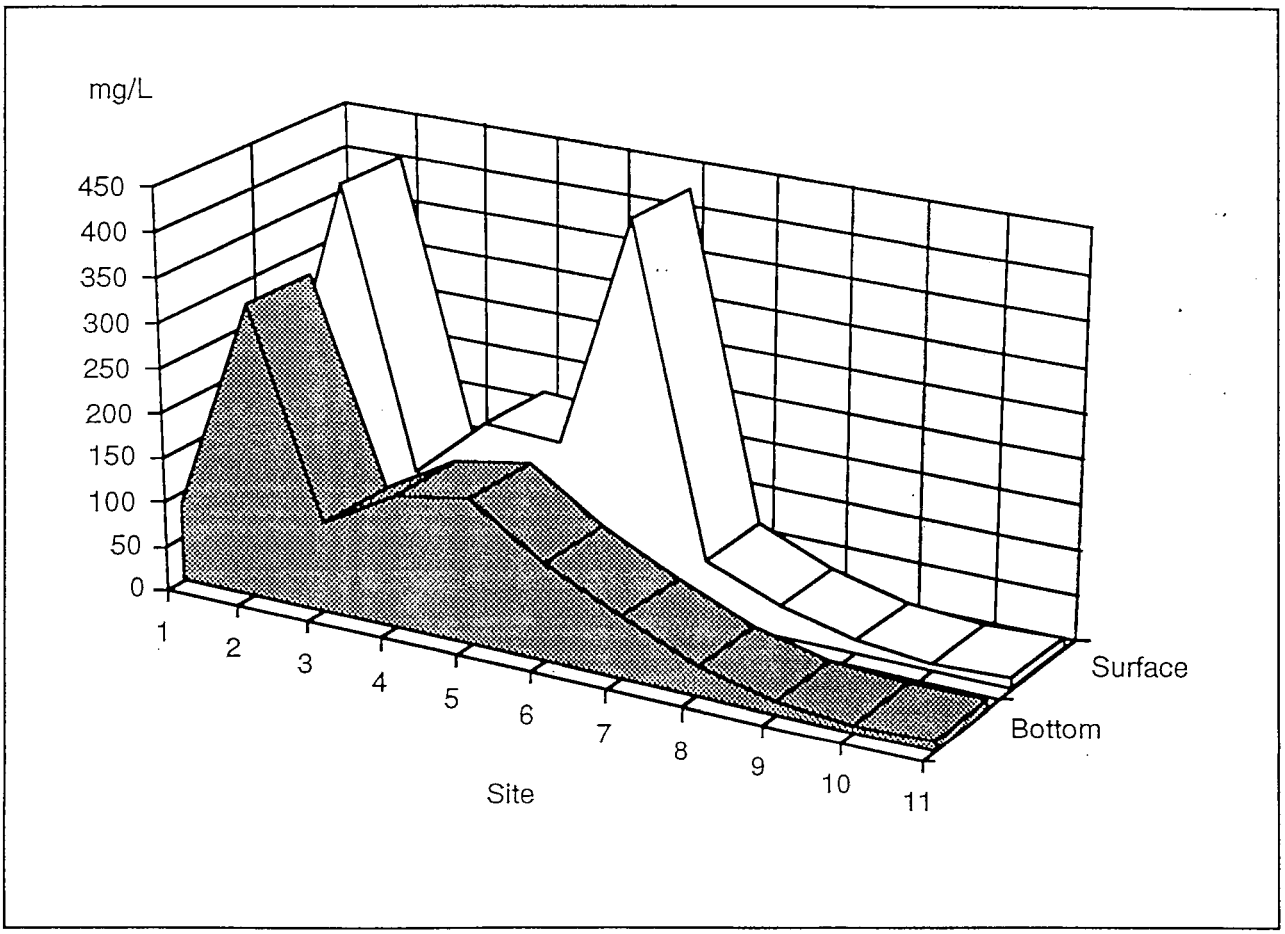
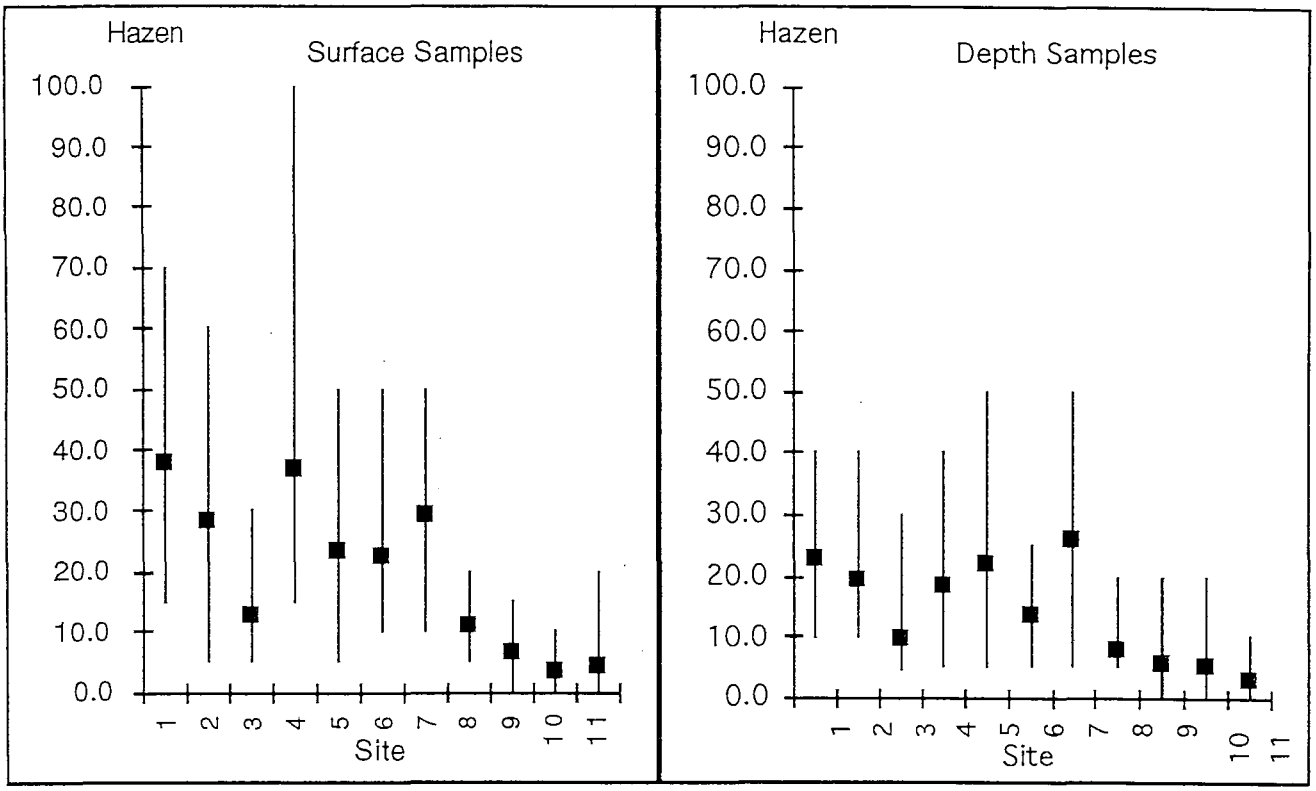


Figure 51: Average and range of Total Suspended Solids by site.



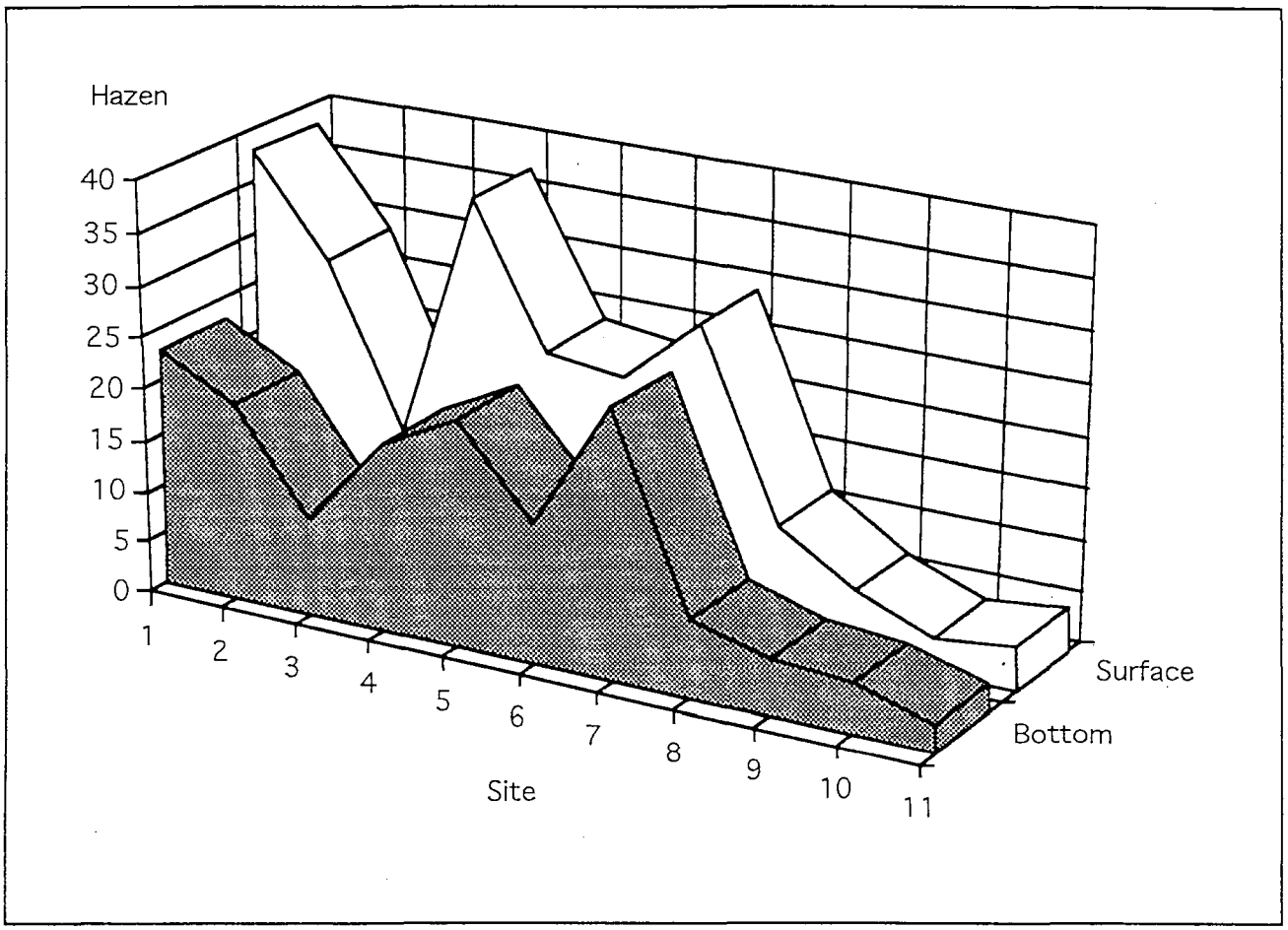
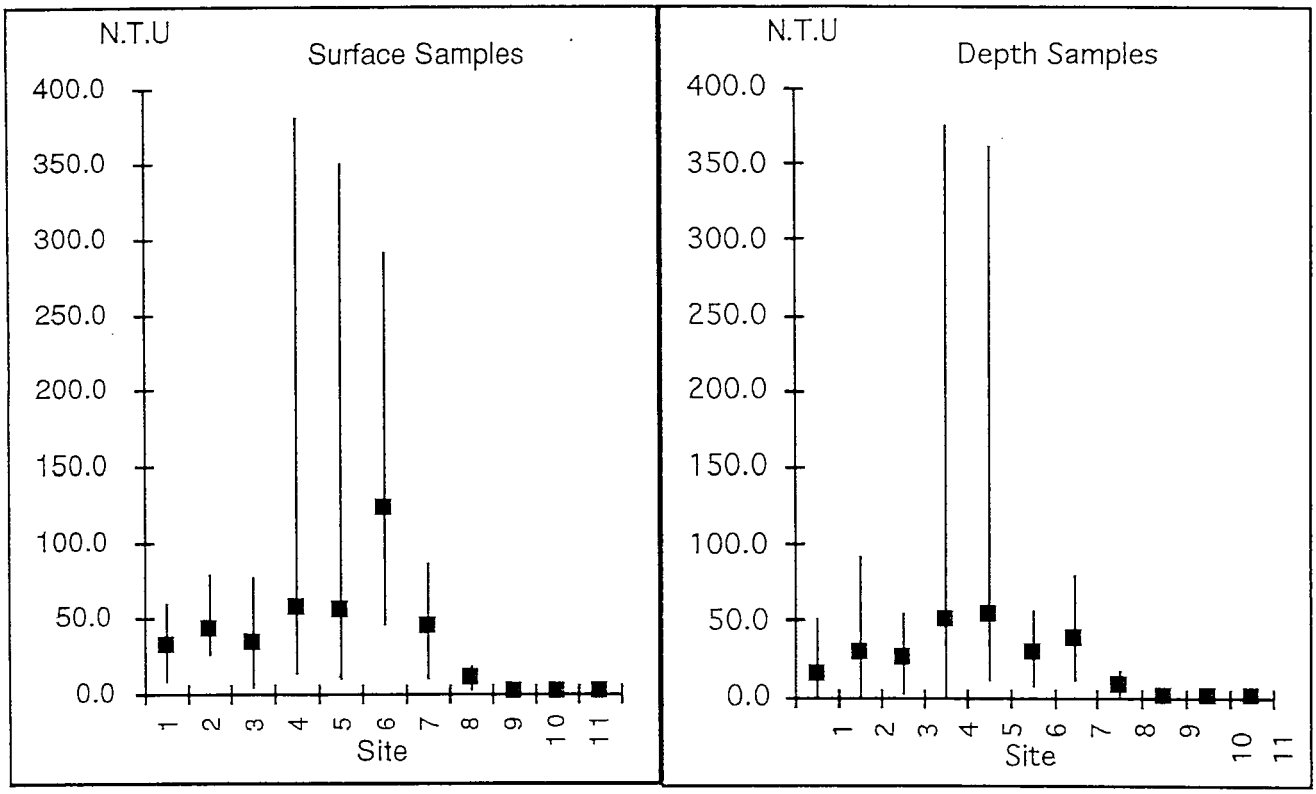


Figure 52: Average and range of Colour by site.



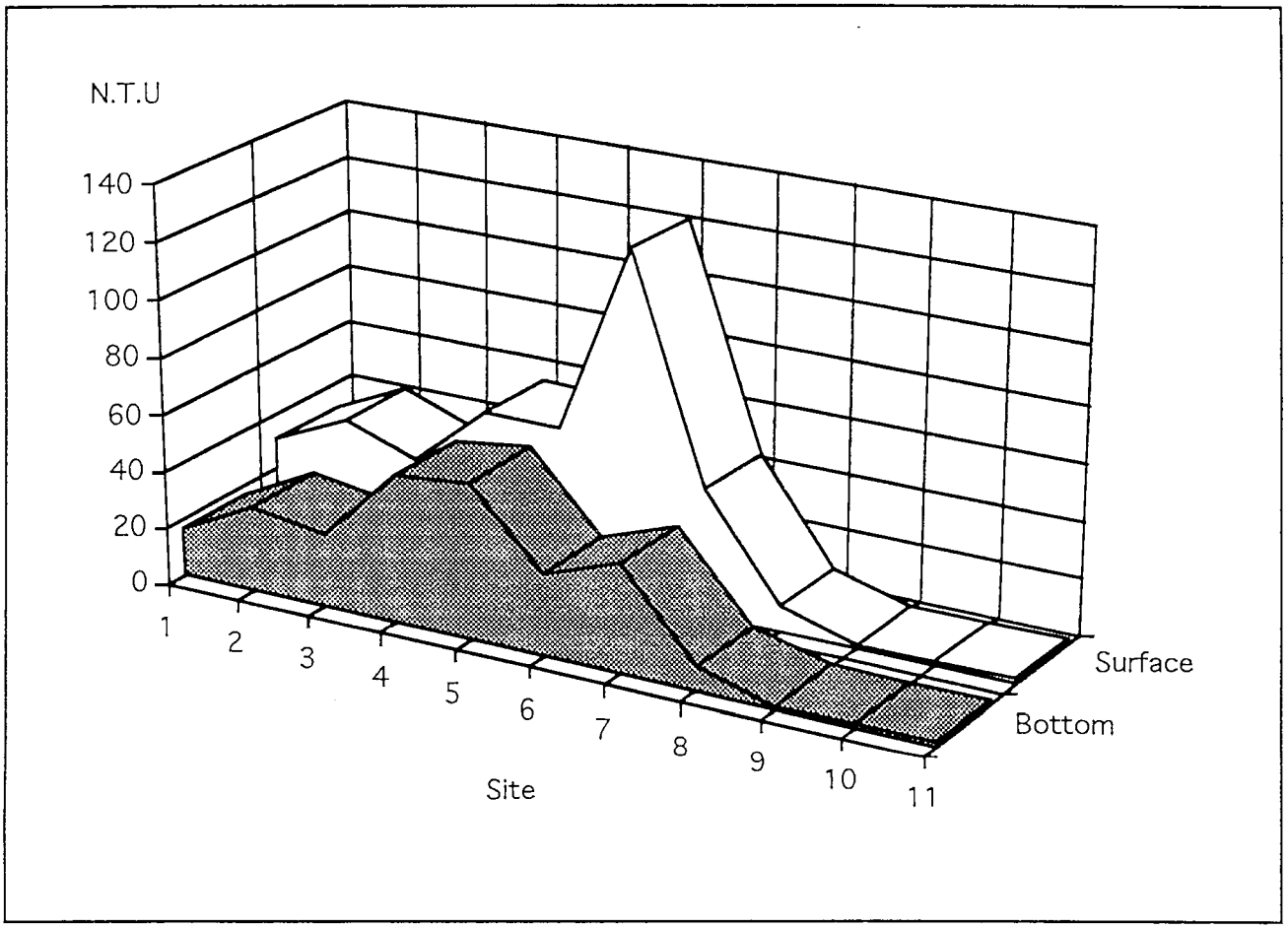
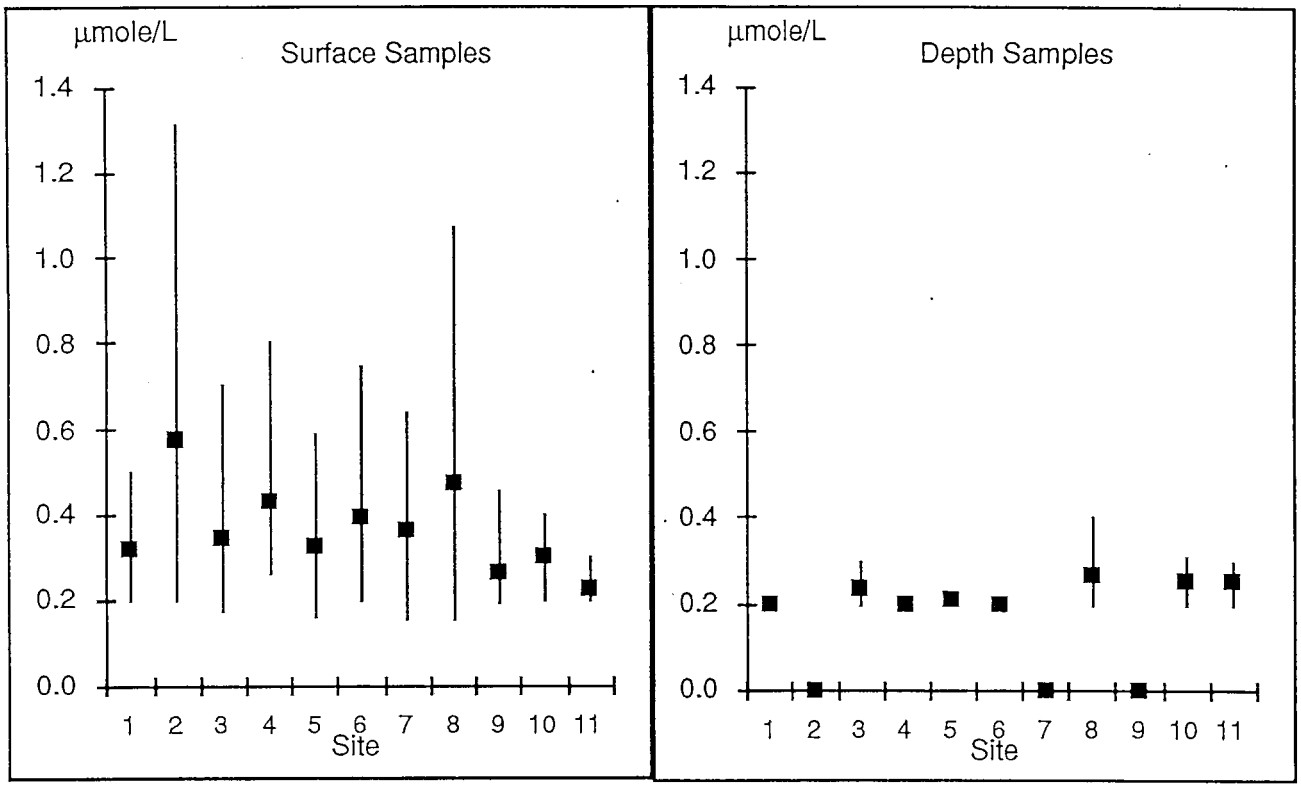


Figure 53: Average and range of Turbidity by site.



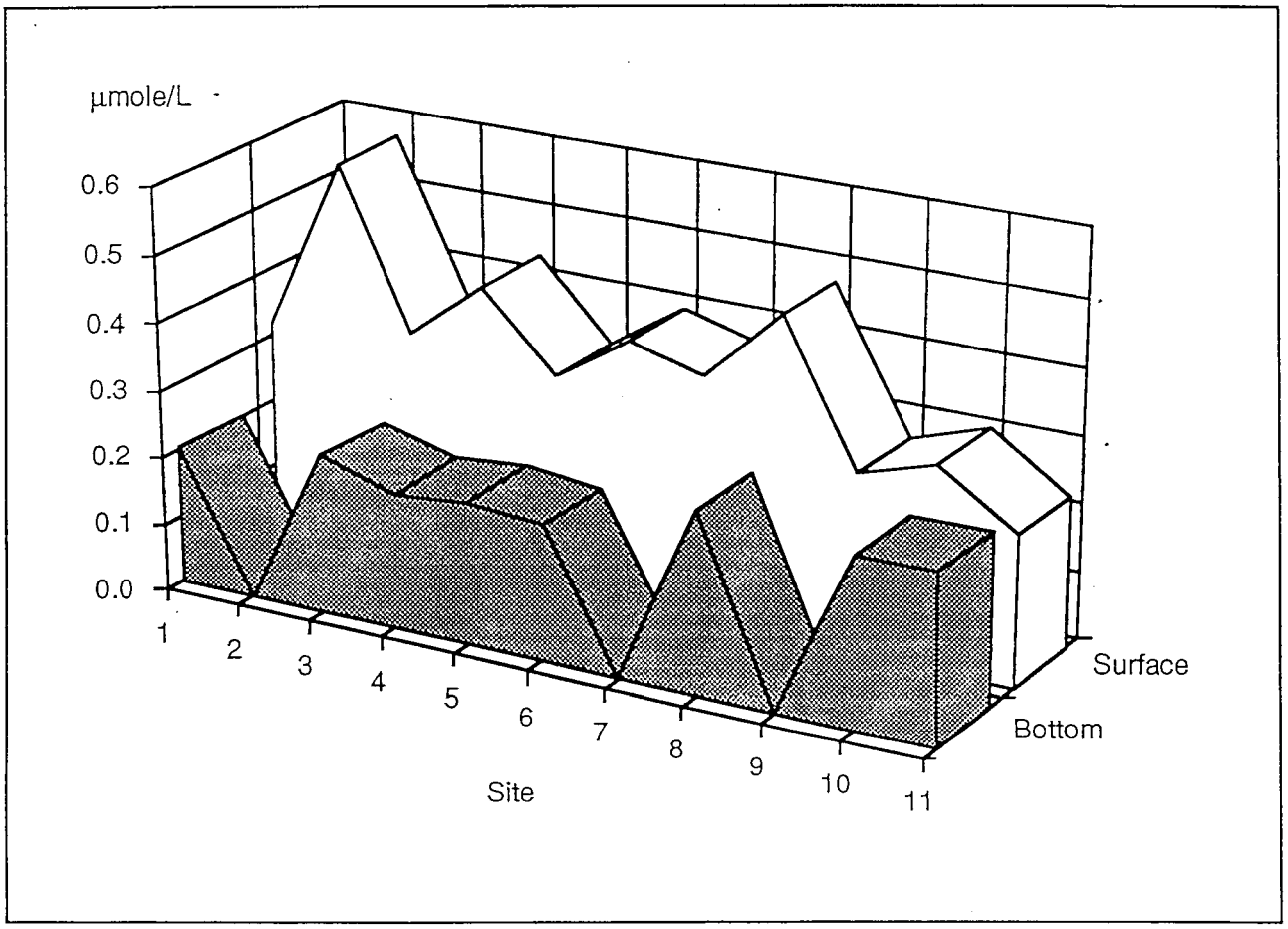
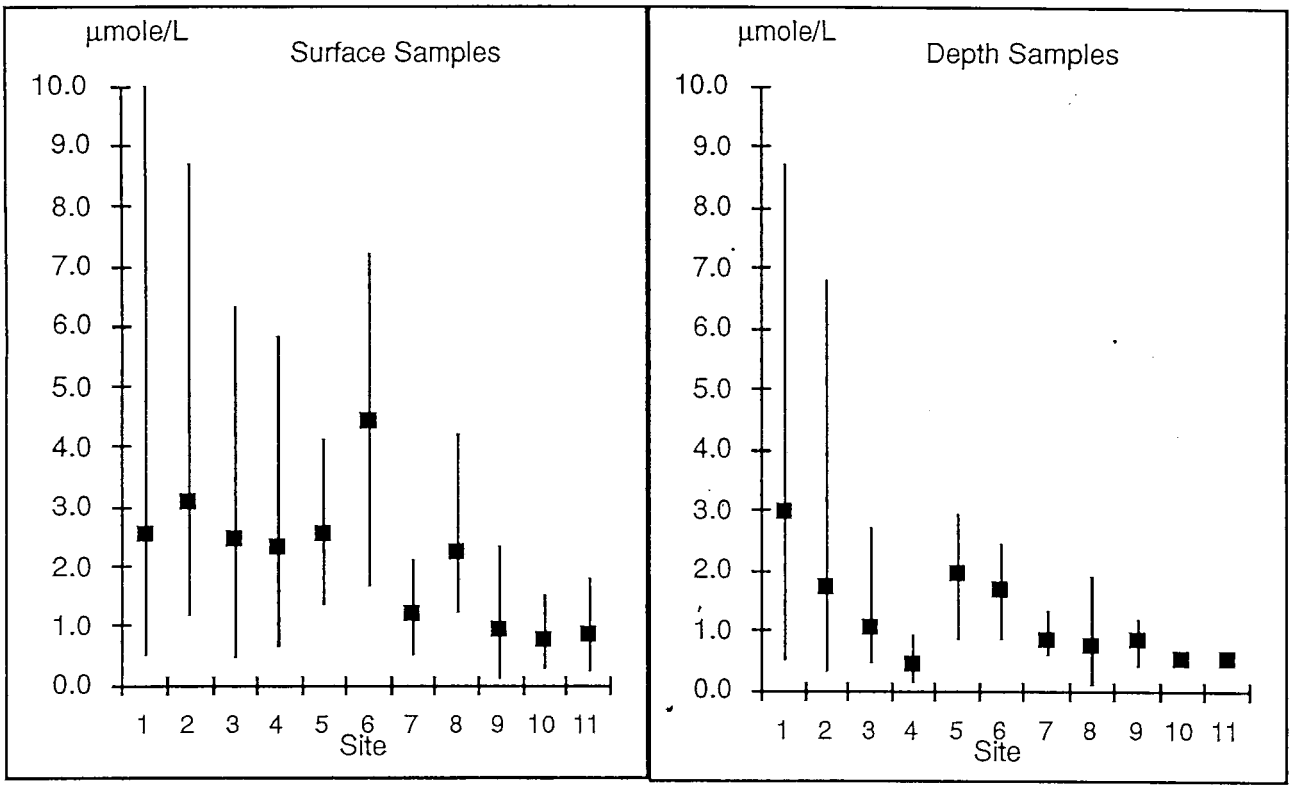


Figure 54: Average and range of Dissolved Phosphorus by site.



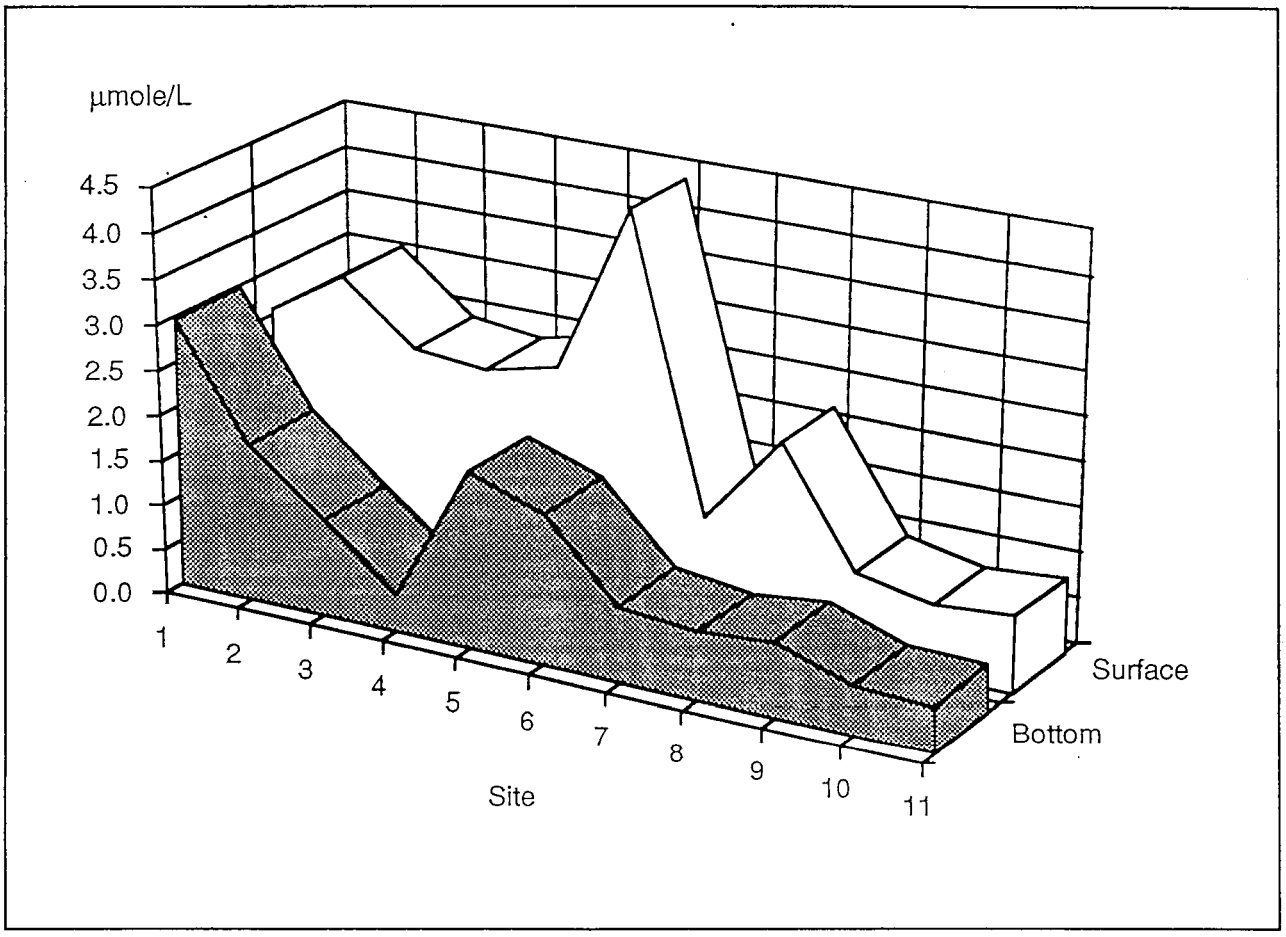
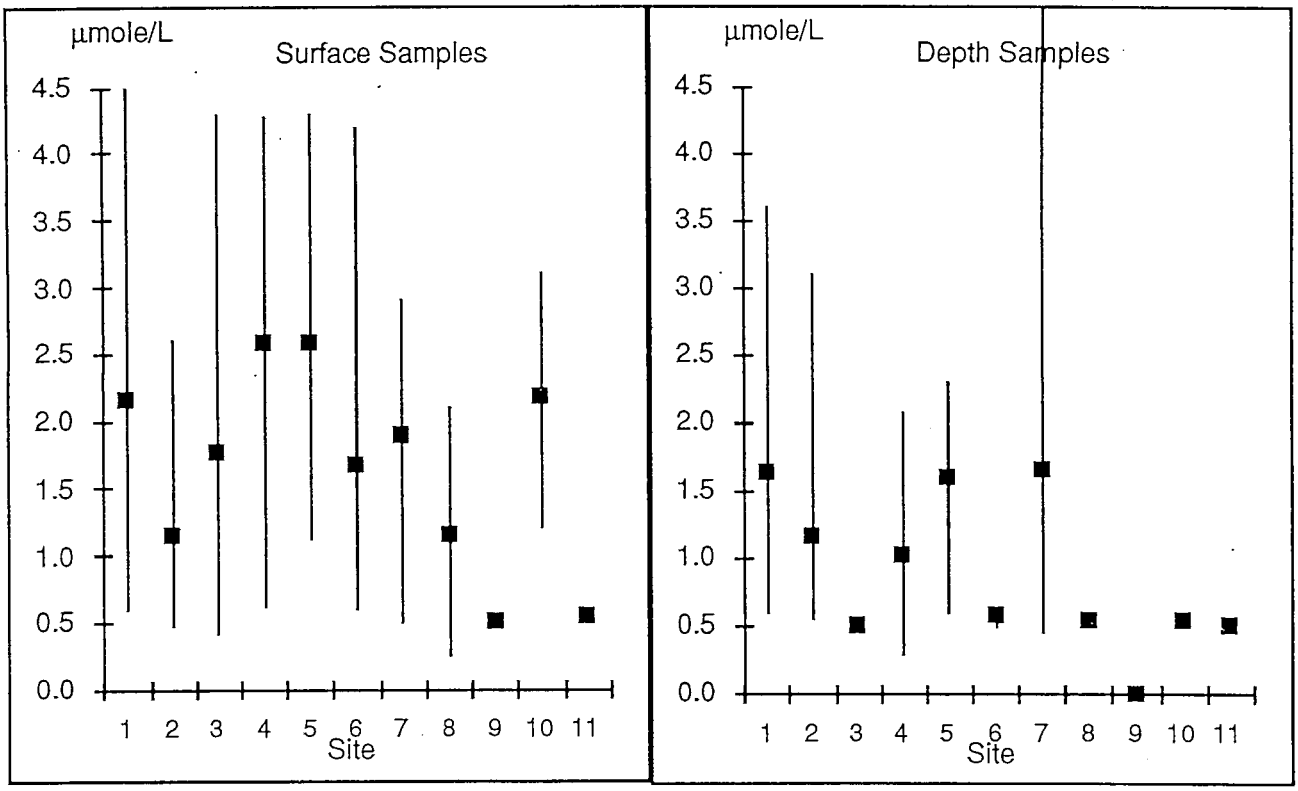


Figure 55: Average and range of Total Phosphorus by site.



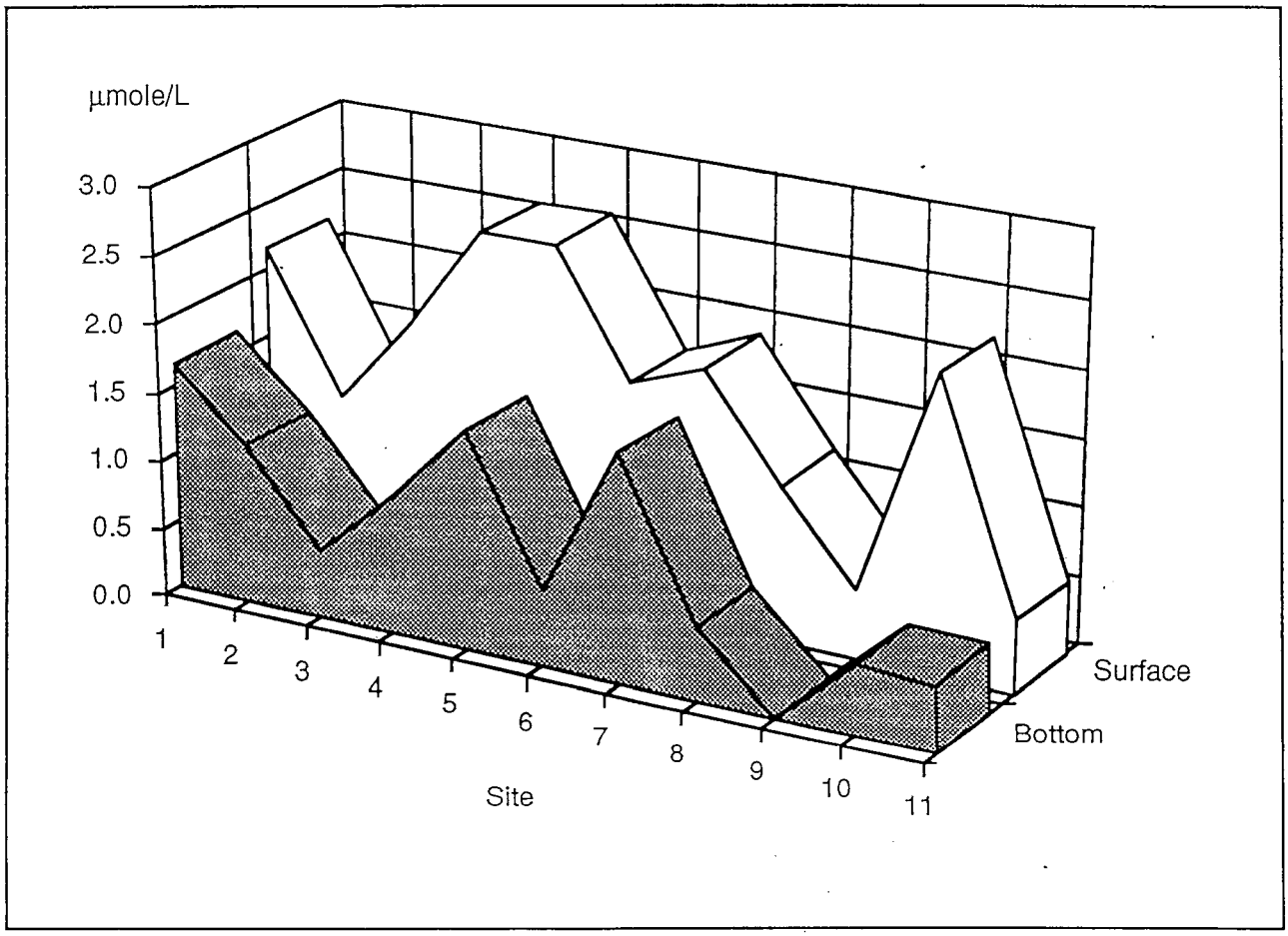


Figure 56: Average and range of Nitrate by site.

Figure 57: Total Coliform Results for Lae City Interim Authority Samples.

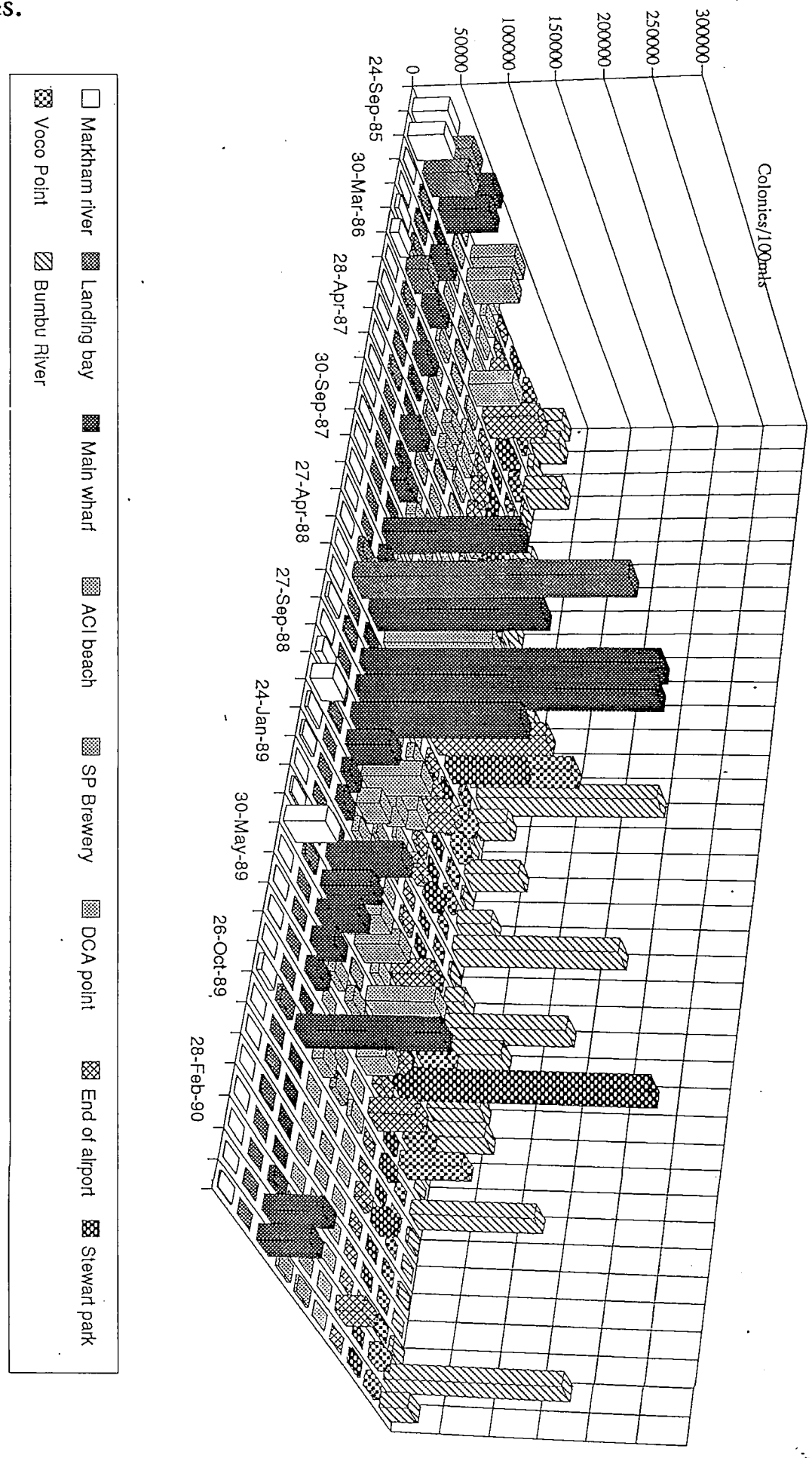


Figure 58: Faecal Coliform Results for Lae City Interim Authority Samples.

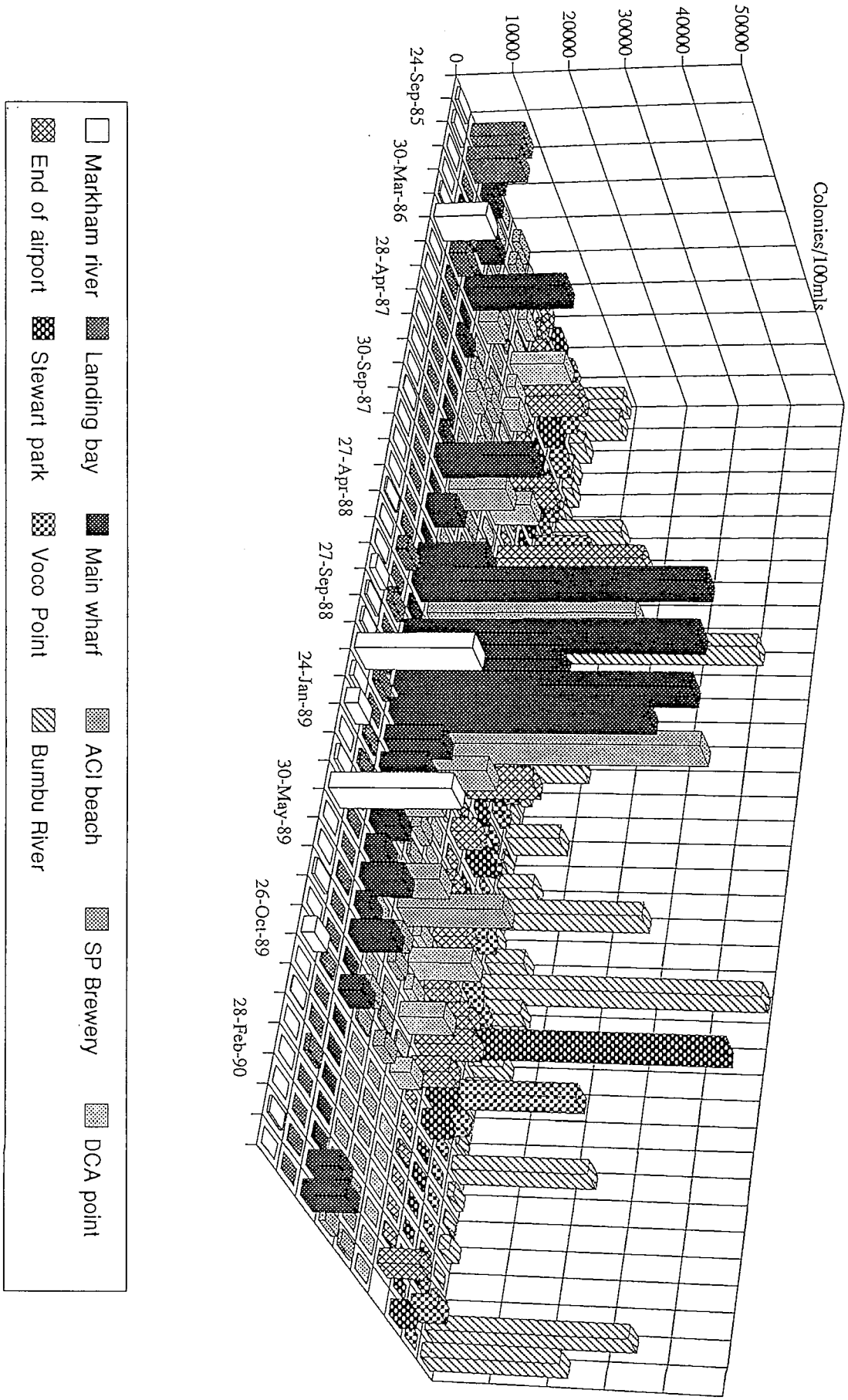


Figure 59: Salinity Depth Profile Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf

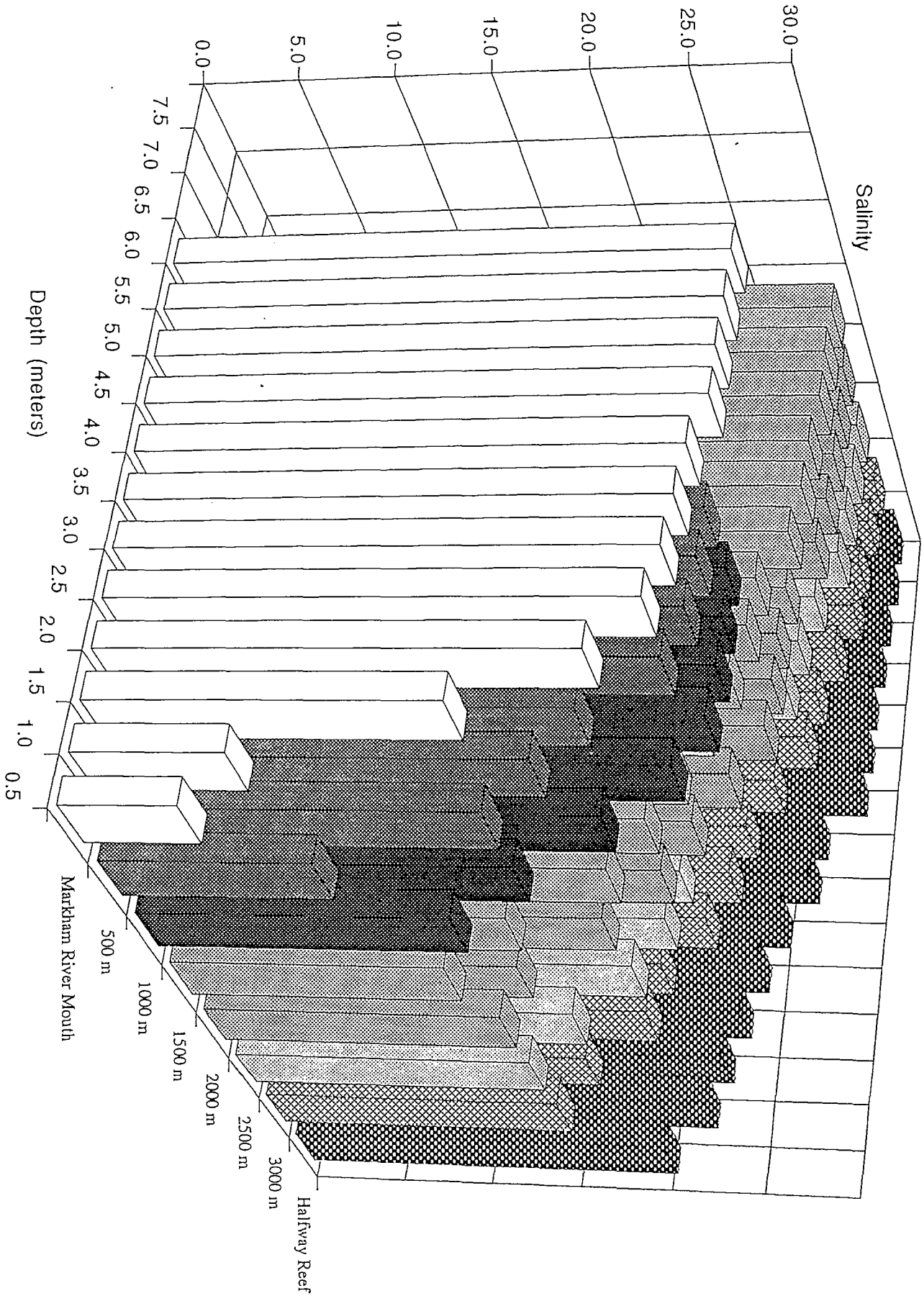


Figure 60: Dissolved Oxygen Depth Profile Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf

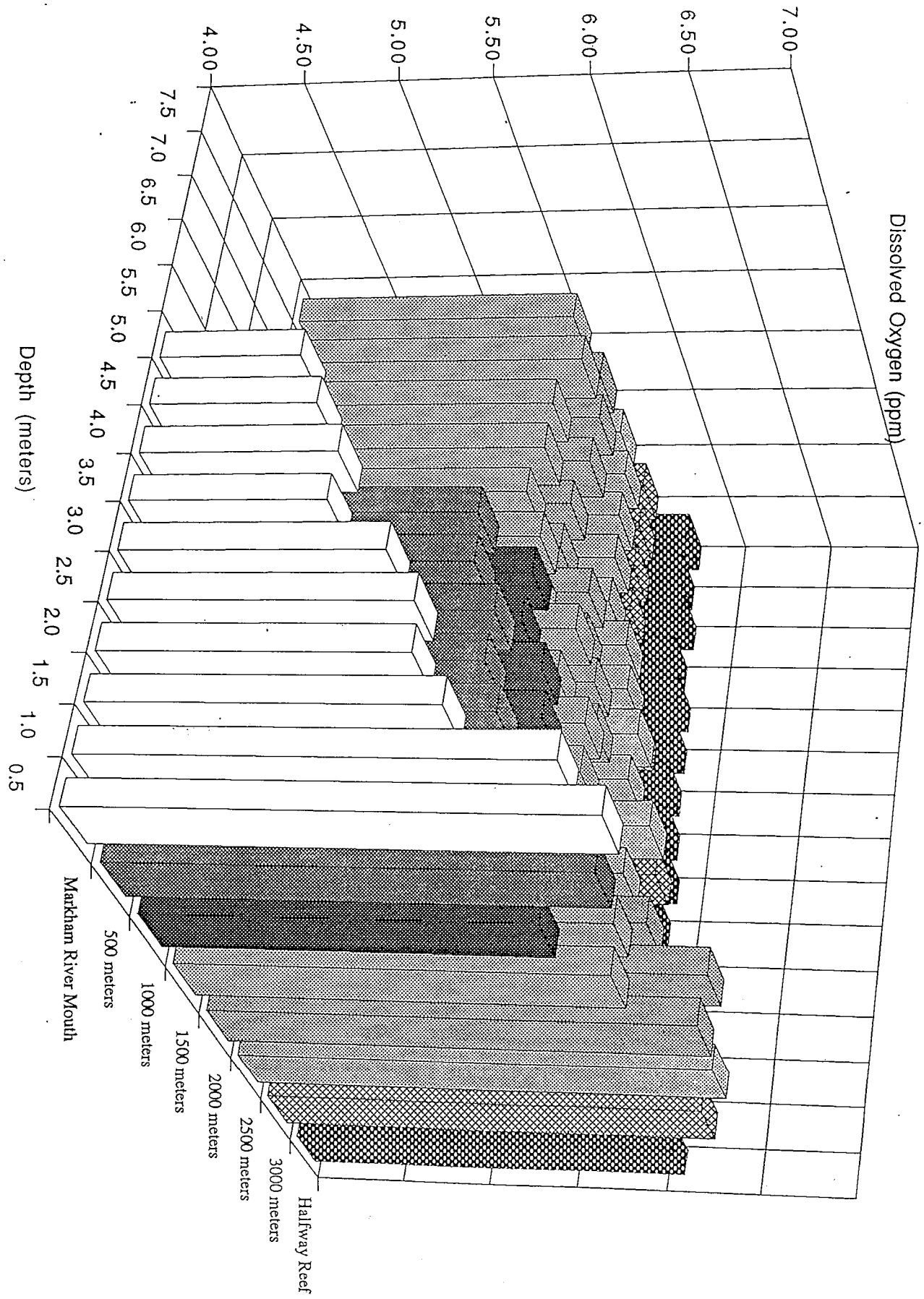


Figure 61: Temperature Depth Profile Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf

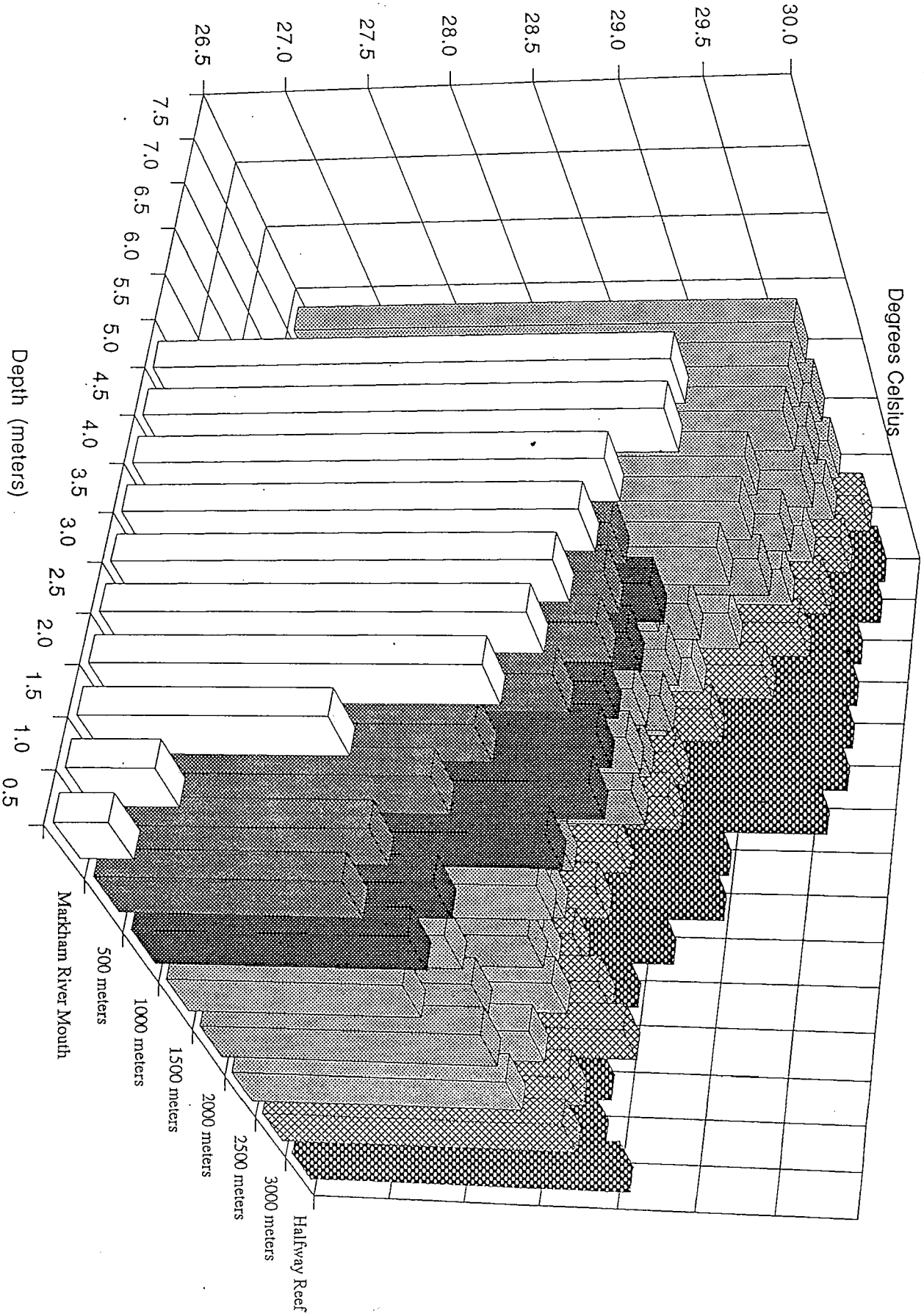


Figure 62: pH Results for Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf

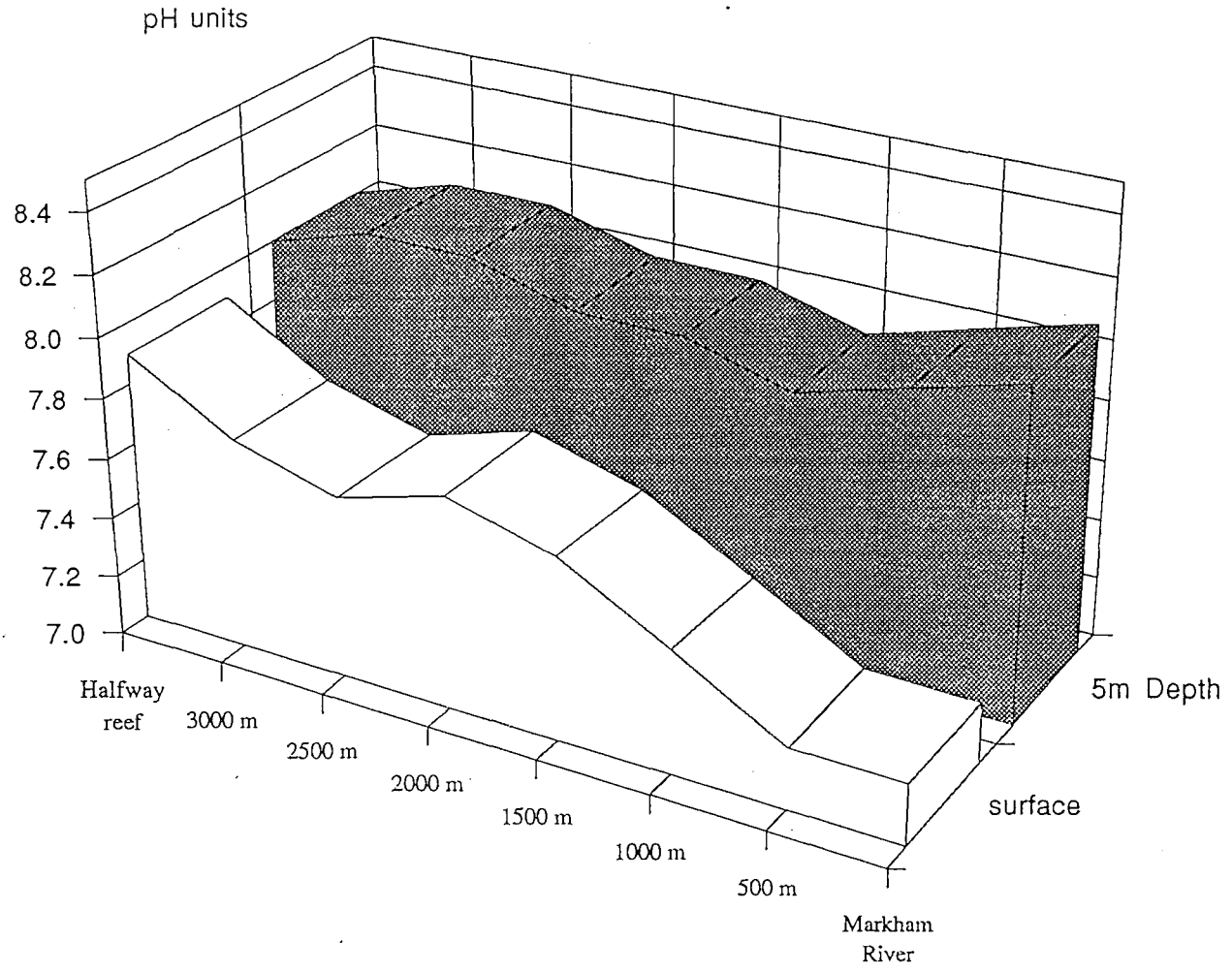


Figure 63: Colour Results for Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf

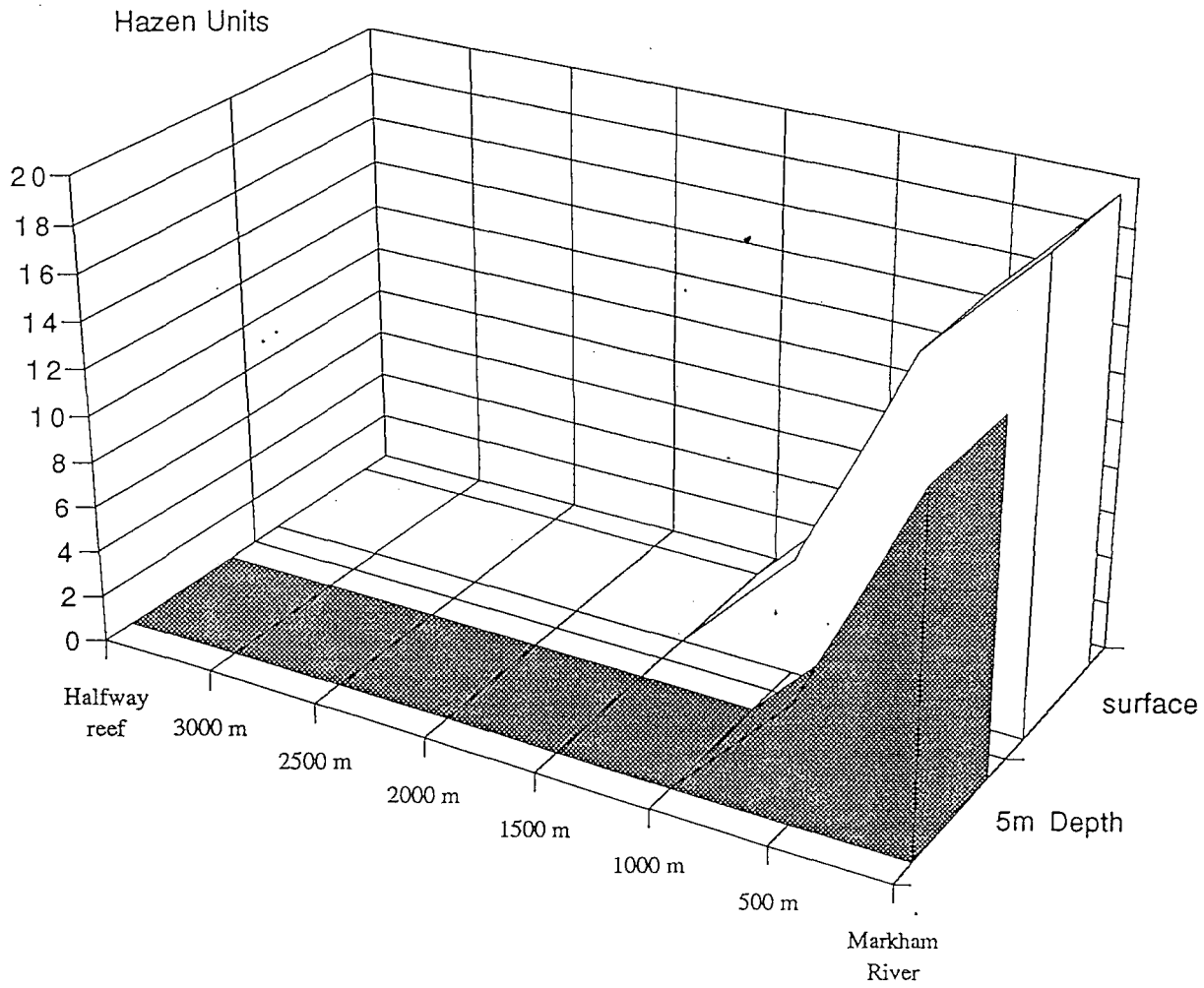


Figure 64: Total Suspended Solids Results for Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf

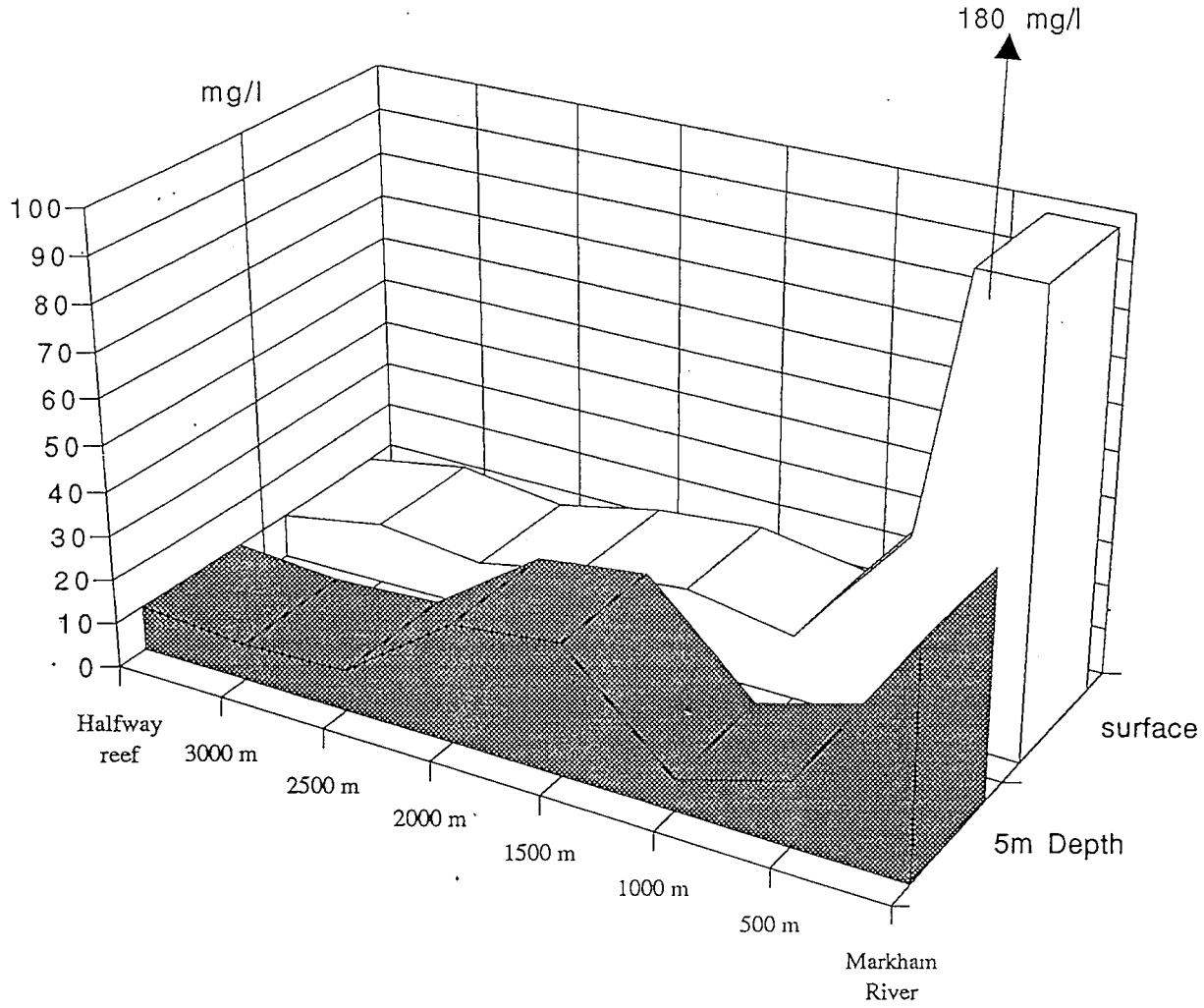
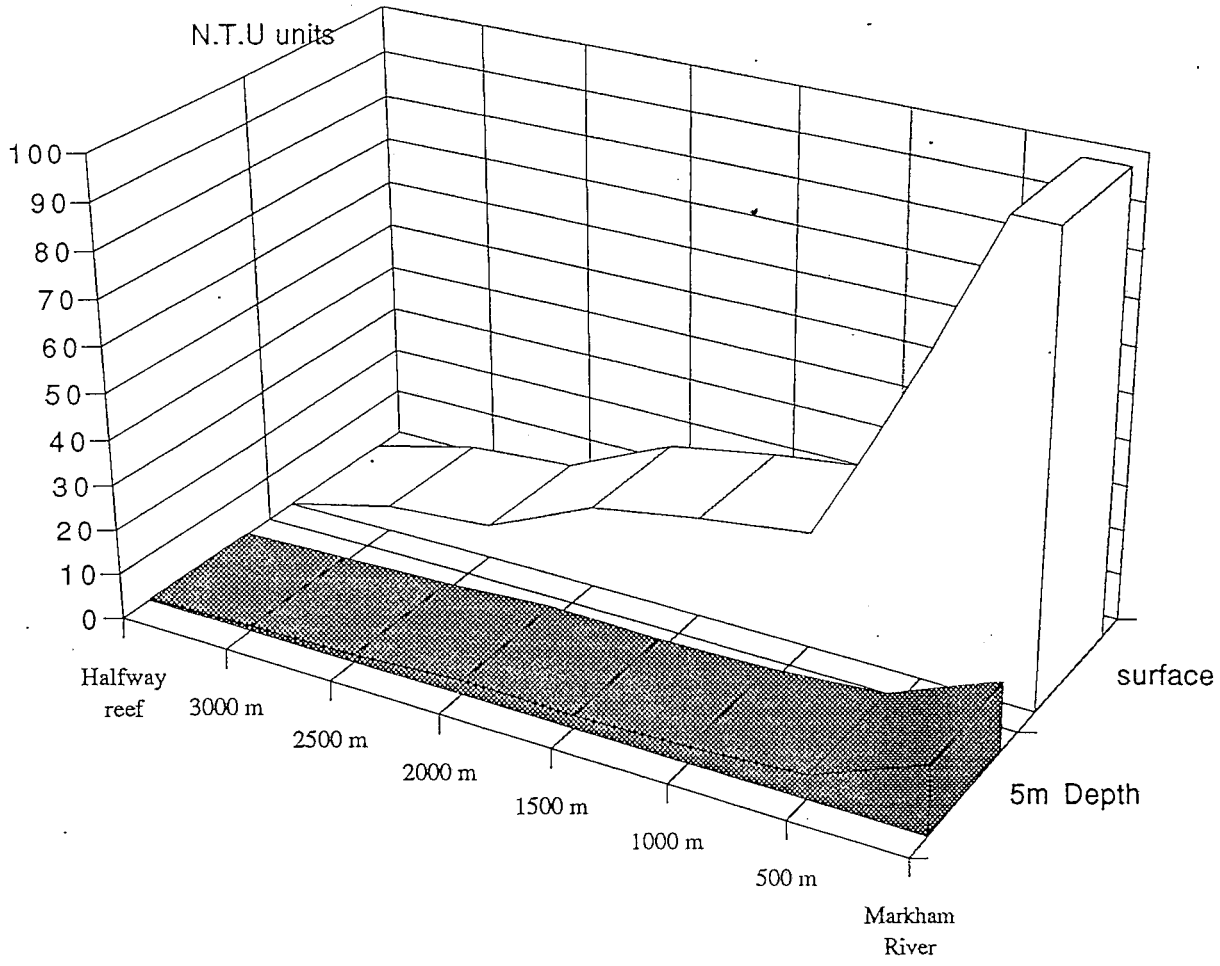


Figure 65: Turbidity Results for Transect from the Mouth of the Markham River to Halfway Reef in the Huon Gulf



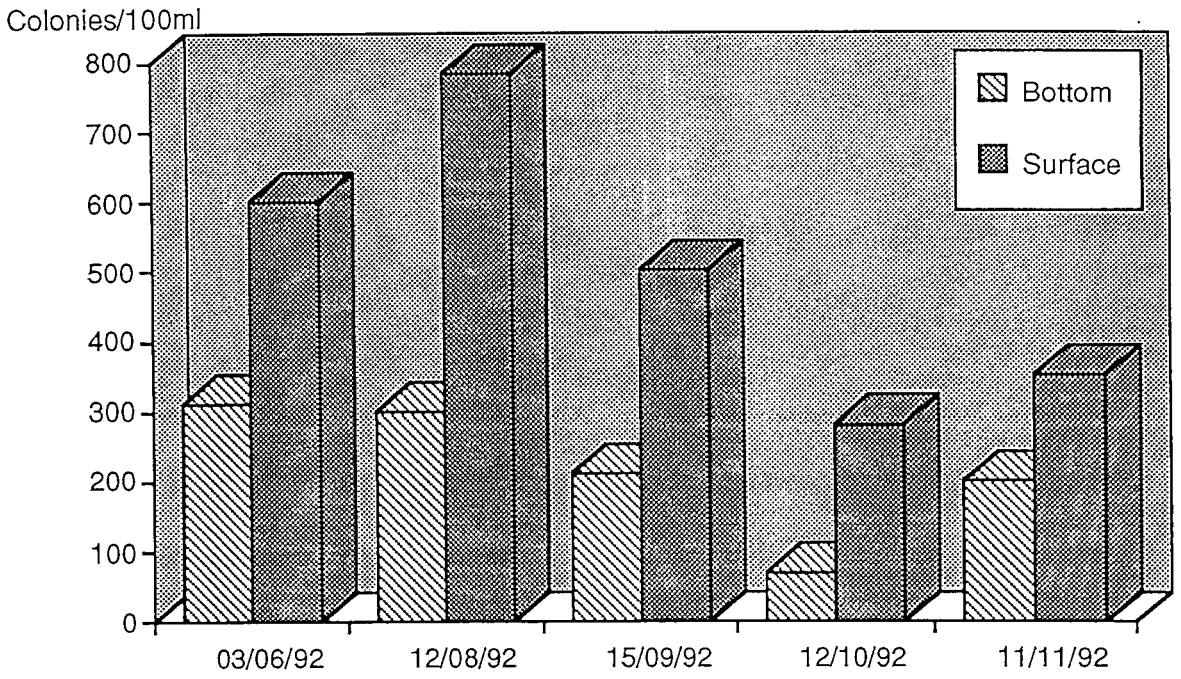


Figure 66: Total Coliform Results for Site 1, Busu River Mouth

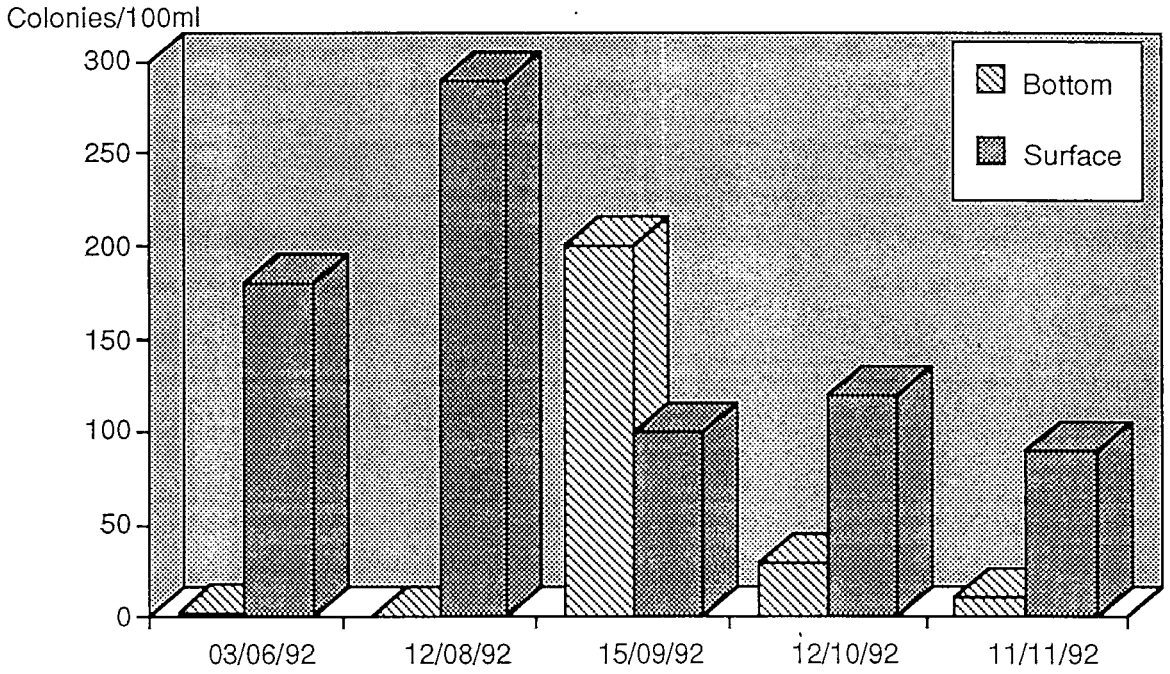


Figure 67: Faecal Coliform Results for Site 1, Busu River Mouth

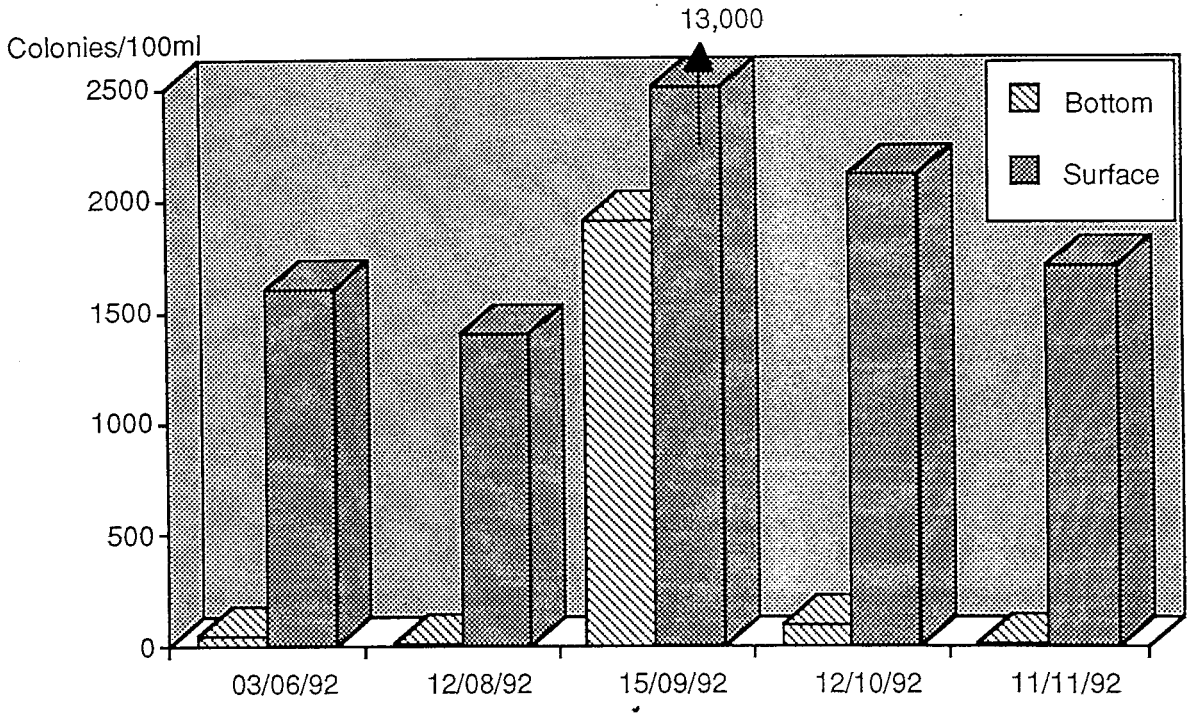


Figure 68: Total Coliform Results for Site 2, Bumbu River Mouth

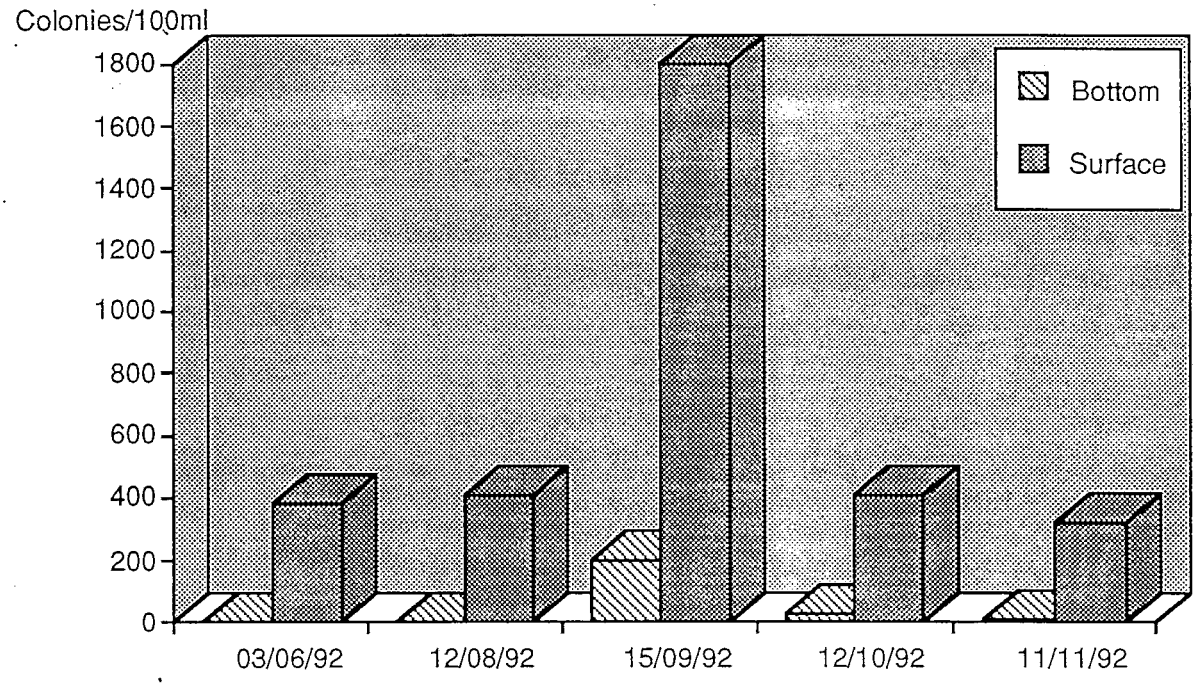


Figure 69: Faecal Coliform Results for Site 2, Bumbu River Mouth

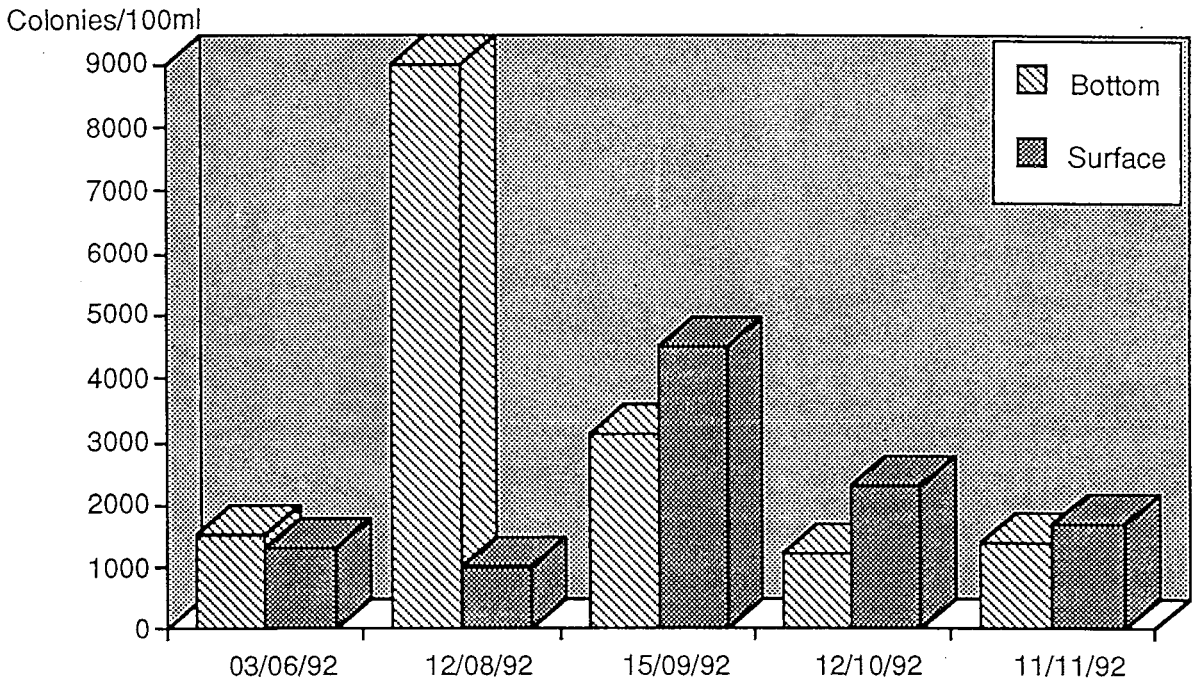


Figure 70: Total Coliform Results for Site 3, Voco Point

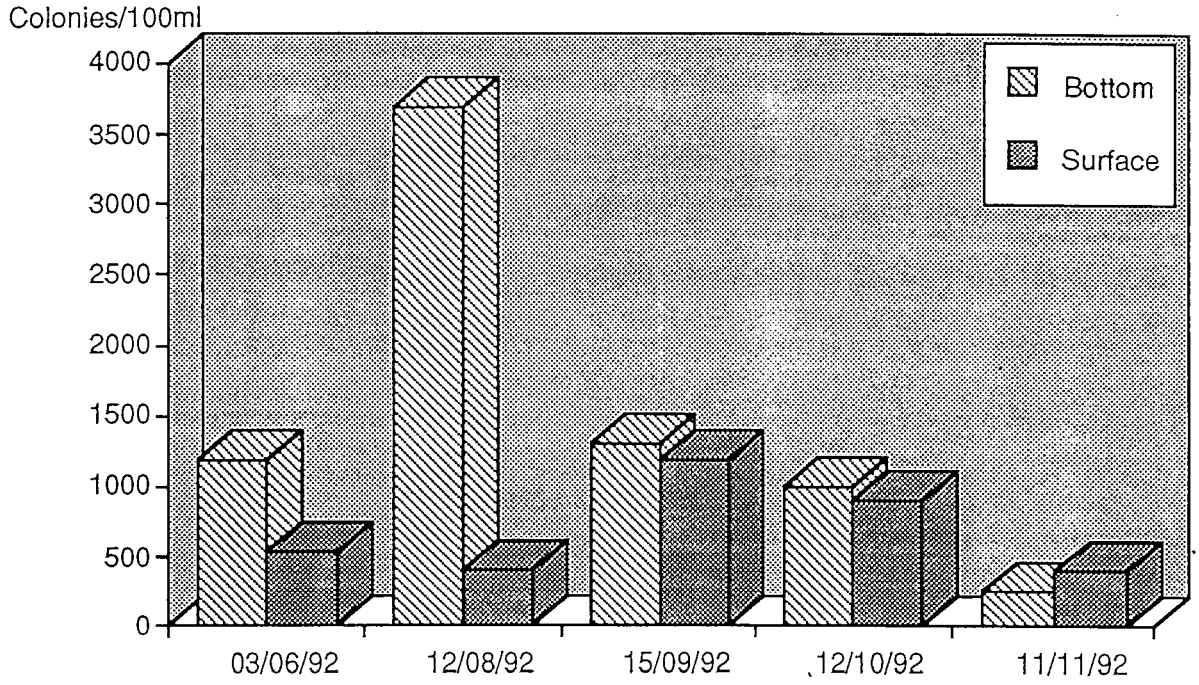


Figure 71: Faecal Coliform Results for Site 3, Voco Point

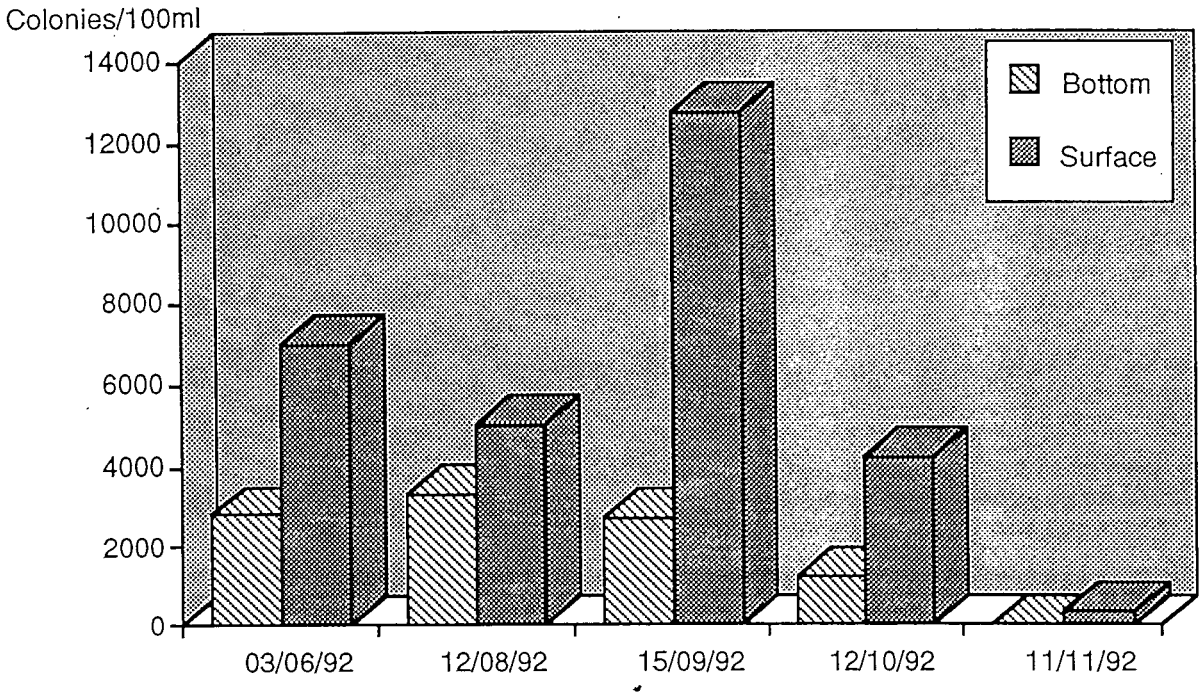


Figure 72: Total Coliform Results for Site 4, Main Wharf

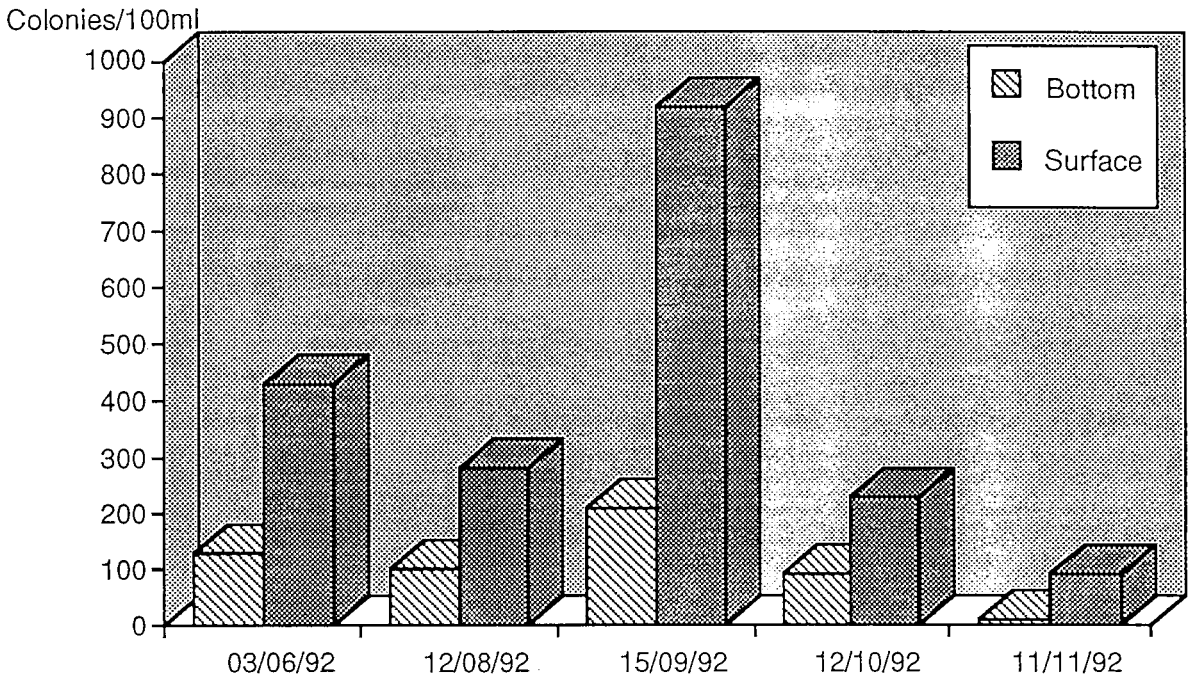


Figure 73: Faecal Coliform Results for Site 4, Main Wharf

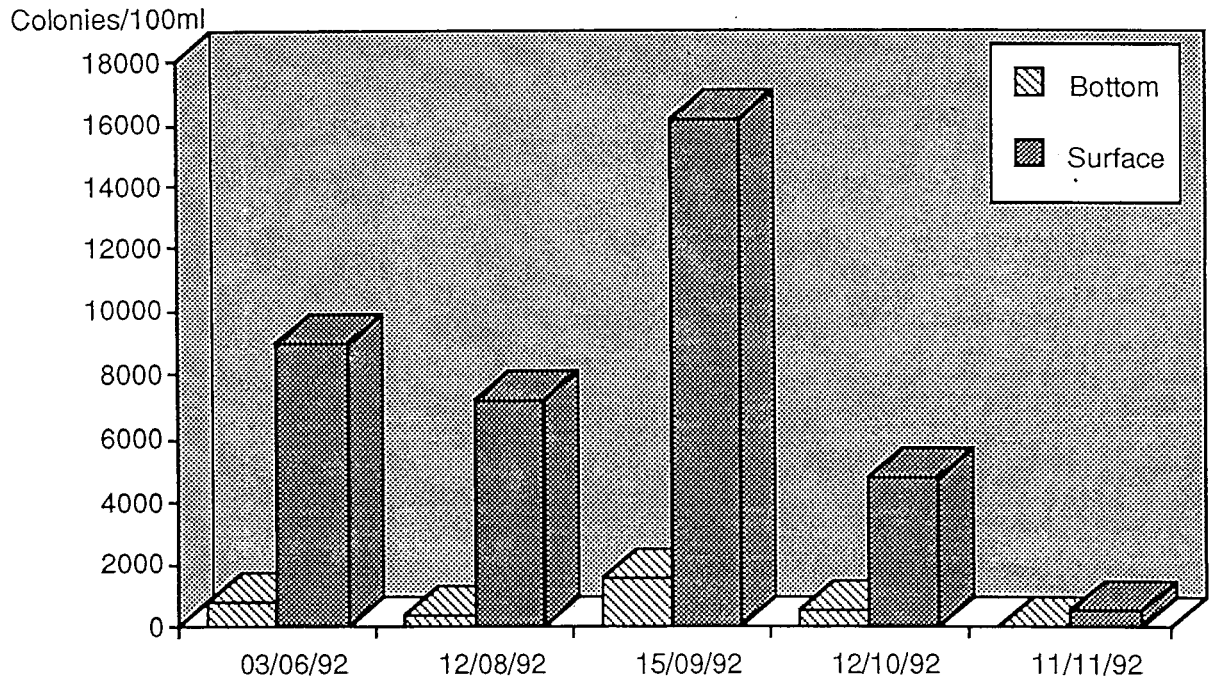


Figure 74: Total Coliform Results for Site 5, Landing Bay

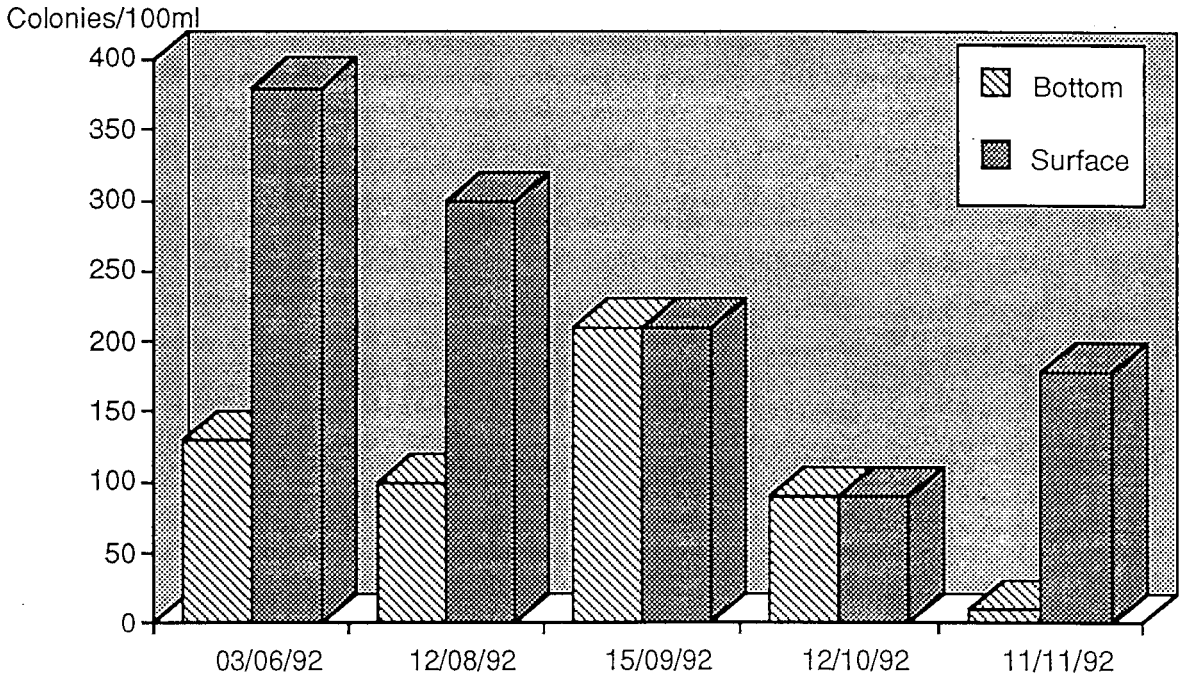


Figure 75: Faecal Coliform Results for Site 5, Landing Bay

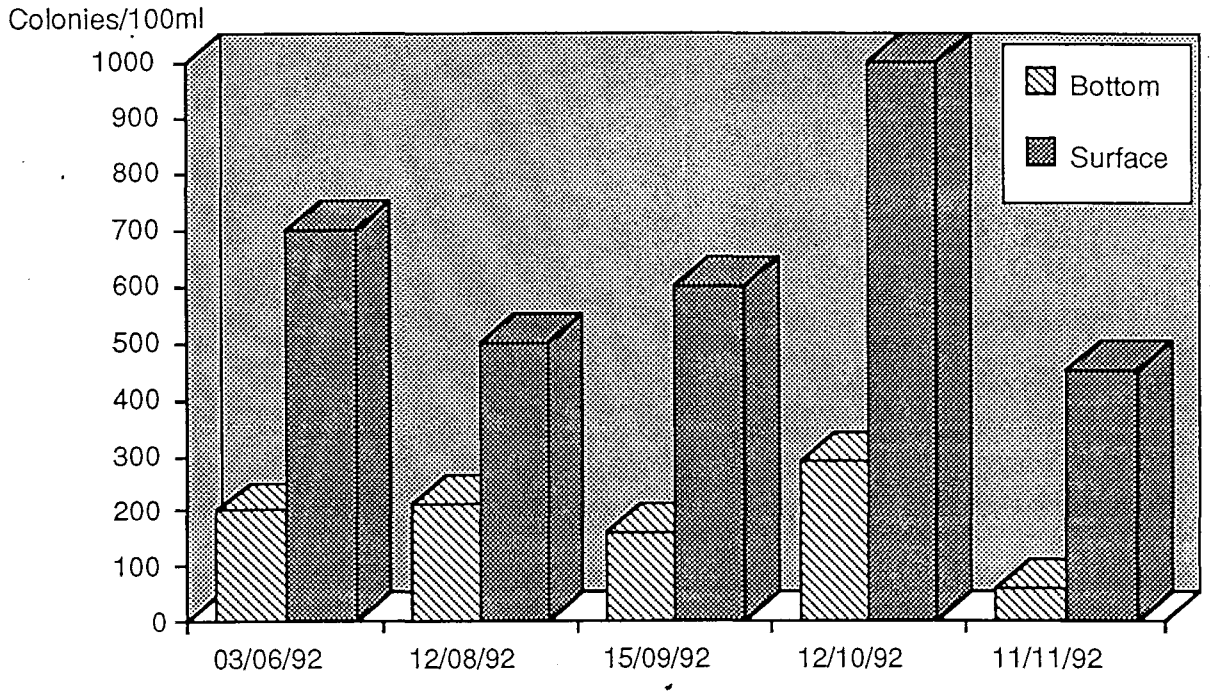


Figure 76: Total Coliform Results for Site 6, Markham River Mouth

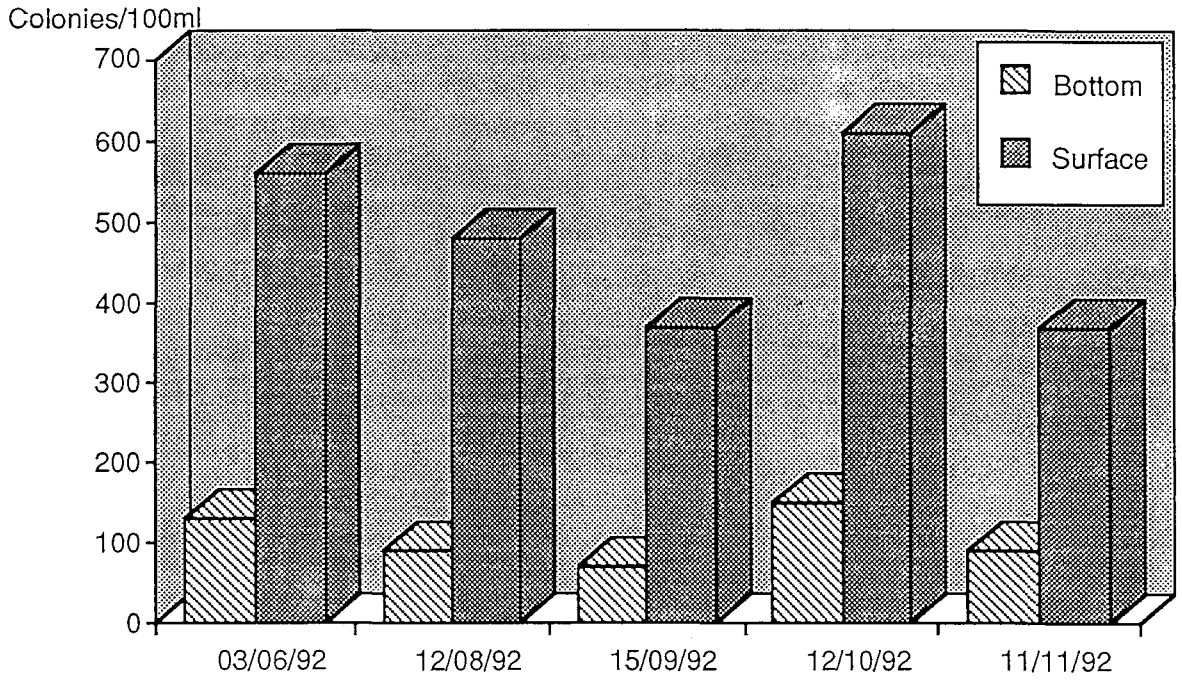


Figure 77: Faecal Coliform Results for Site 6, Markham River Mouth

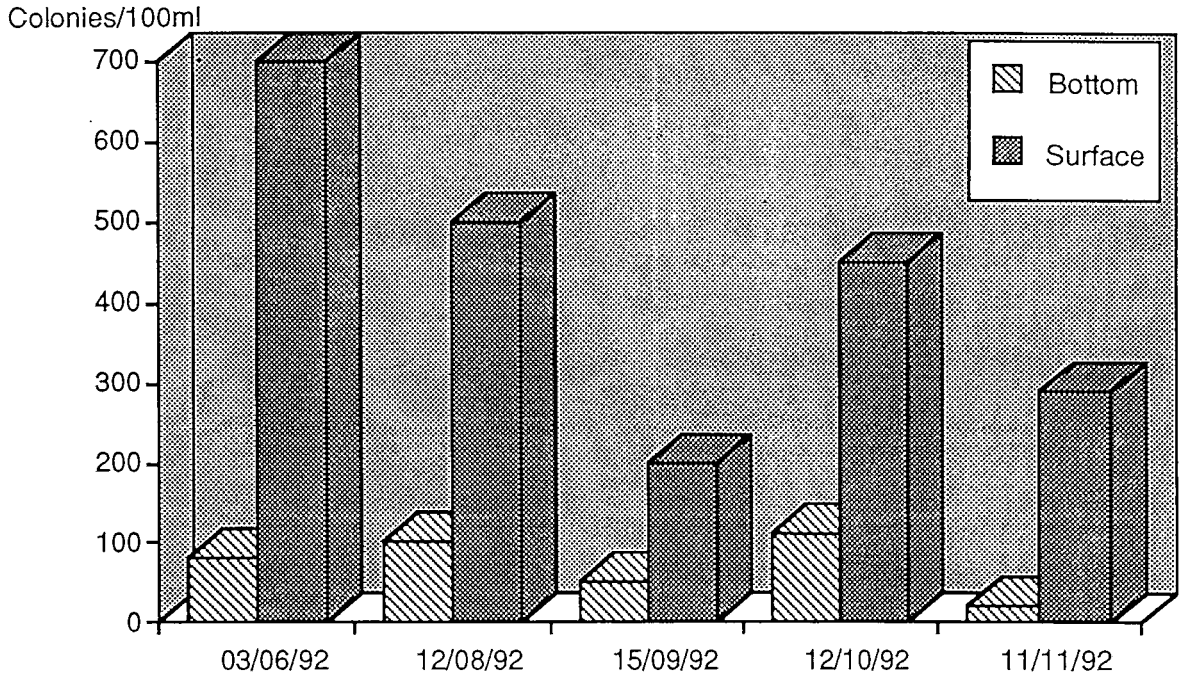


Figure 78: Total Coliform Results for Site 7, Labu Lakes Entrance

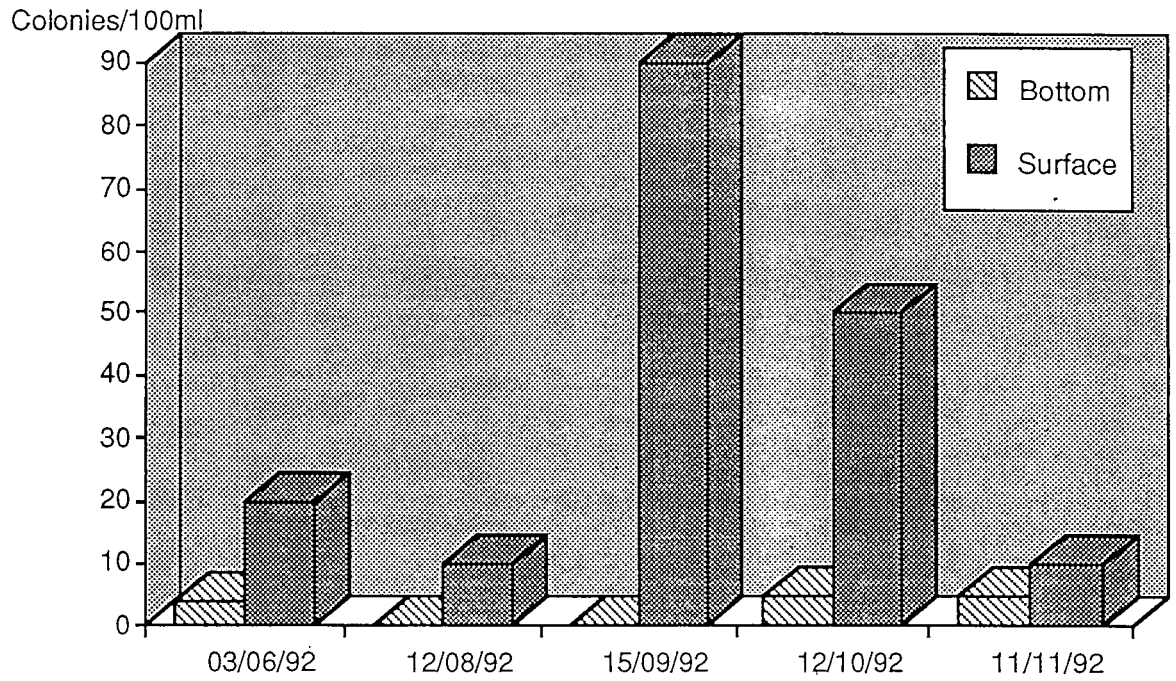


Figure 79: Faecal Coliform Results for Site 7, Labu Lakes Entrance

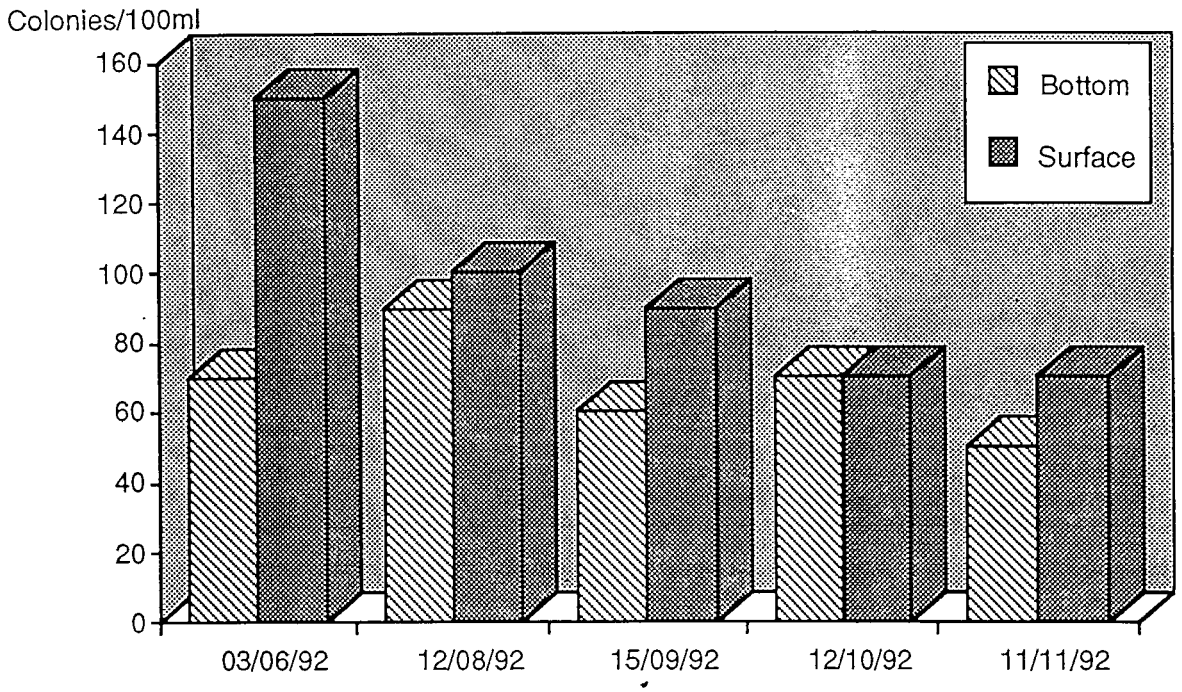


Figure 80: Total Coliform Results for Site 8, Sugar Loaf

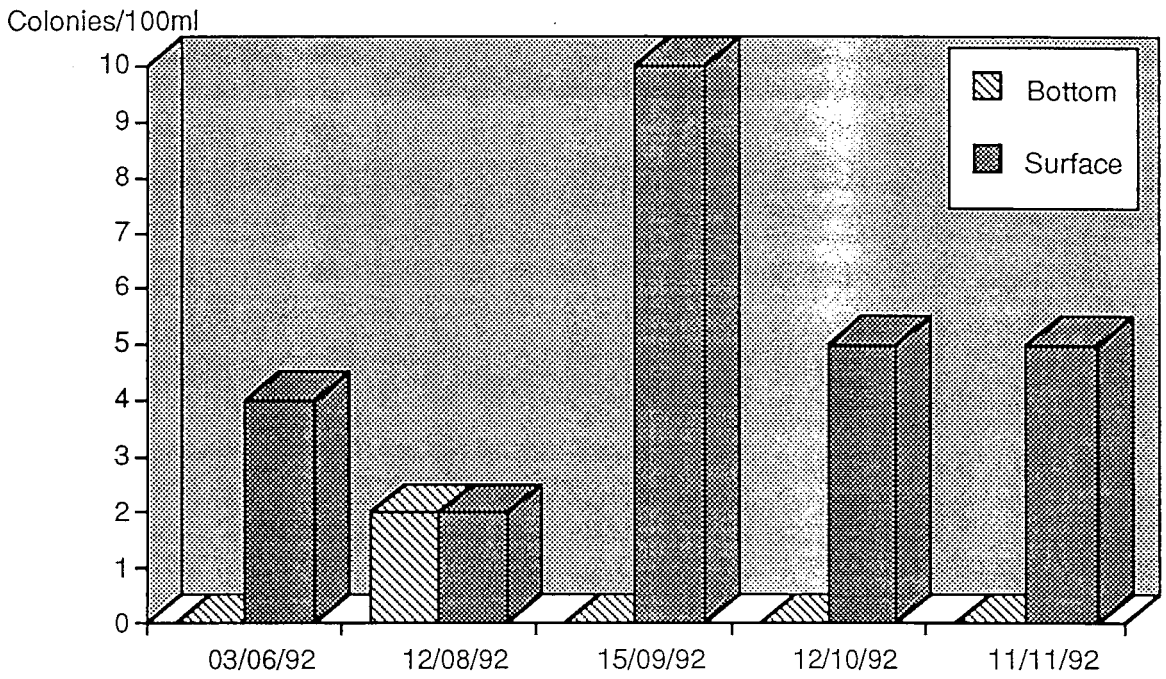


Figure 81: Faecal Coliform Results for Site 8, Sugar Loaf

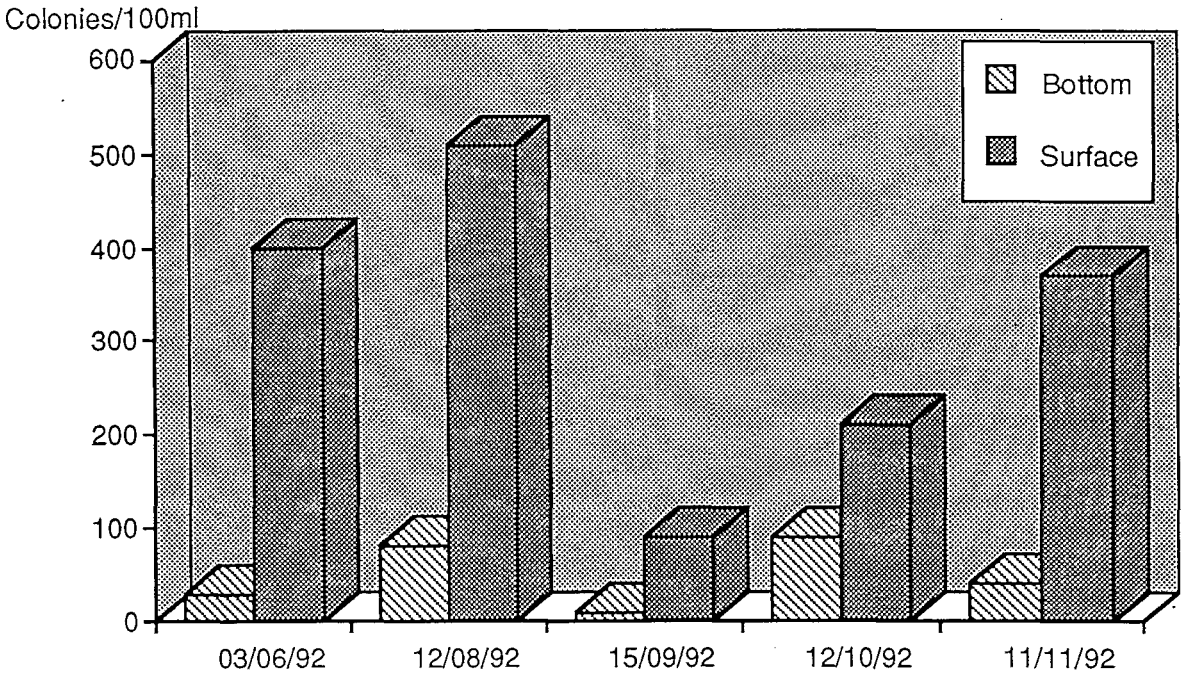


Figure 82: Total Coliform Results for Site 9, Halfway Reef

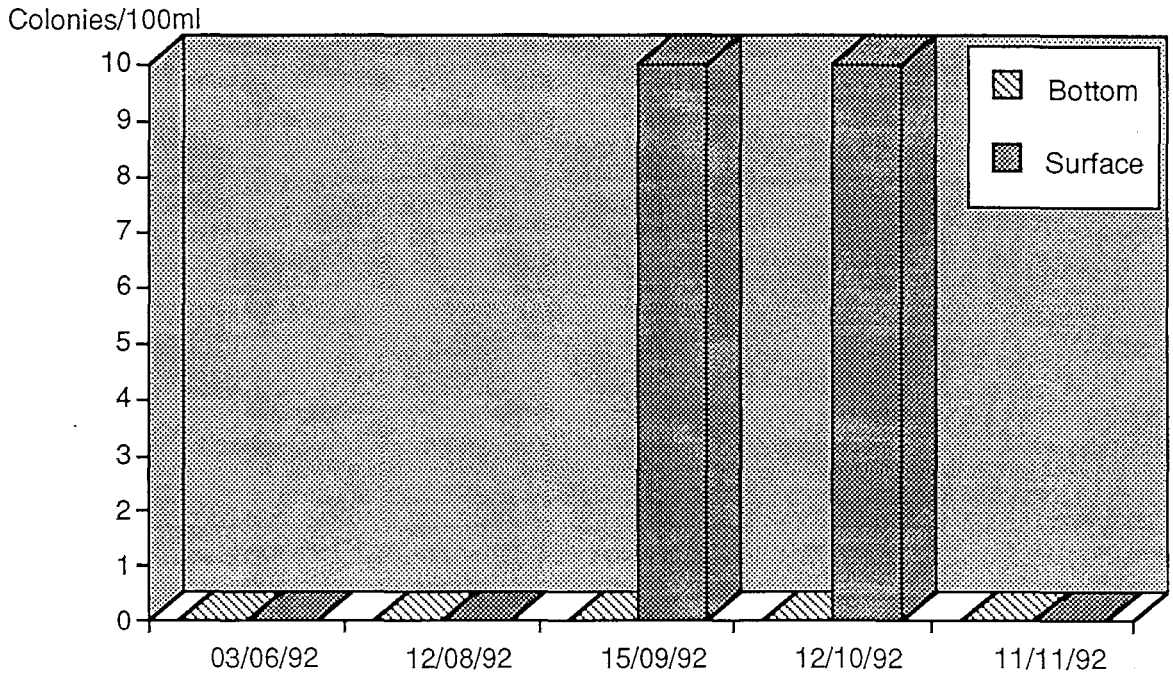


Figure 83: Faecal Coliform Results for Site 9, Halfway Reef

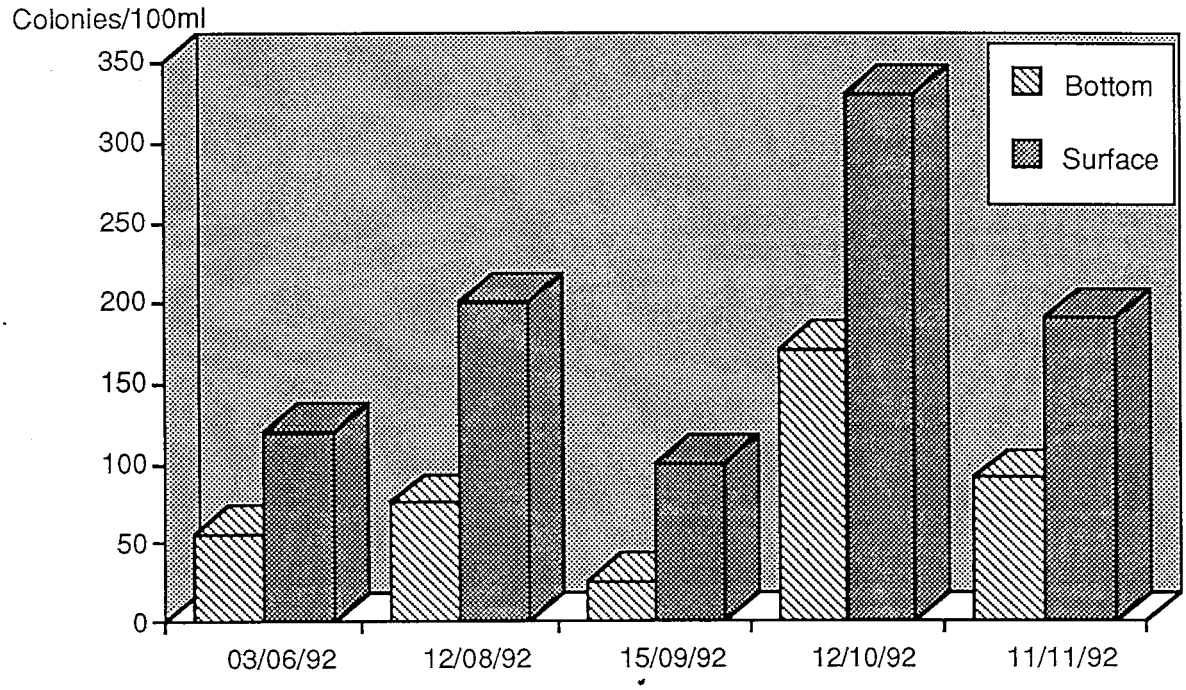


Figure 84: Total Coliform Results for Site 10, Schoolhouse Reef

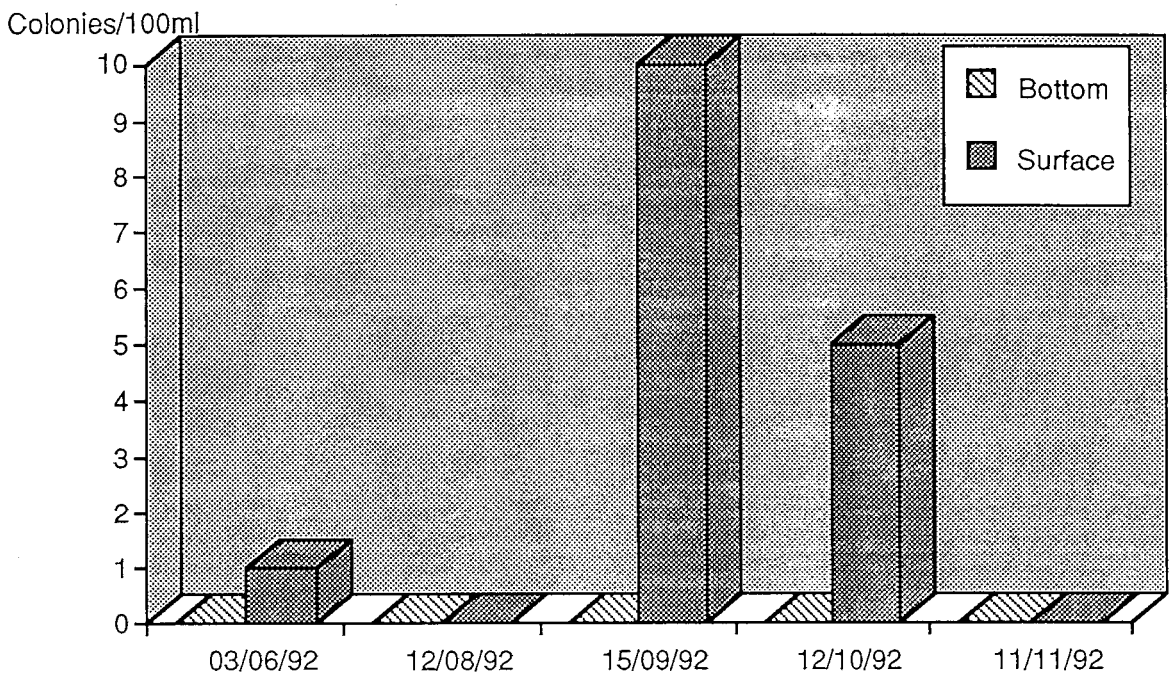


Figure 85: Faecal Coliform Results for Site 10, Schoolhouse Reef

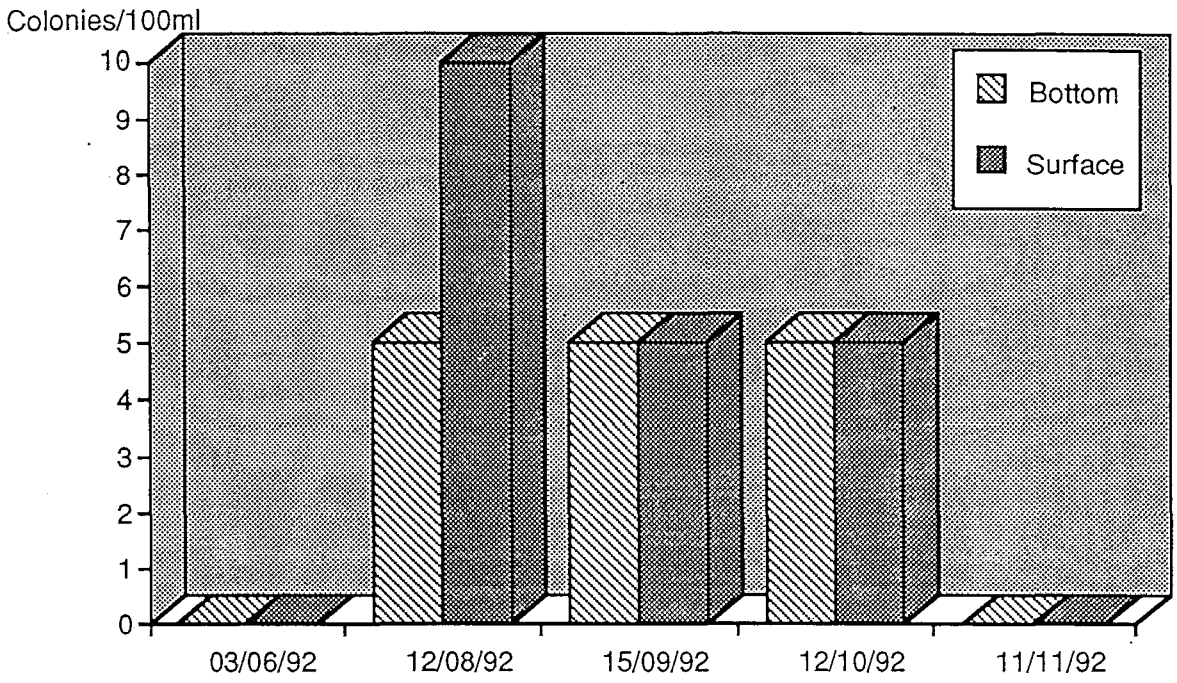


Figure 86: Total Coliform Results for Site 11, Narapela Reef

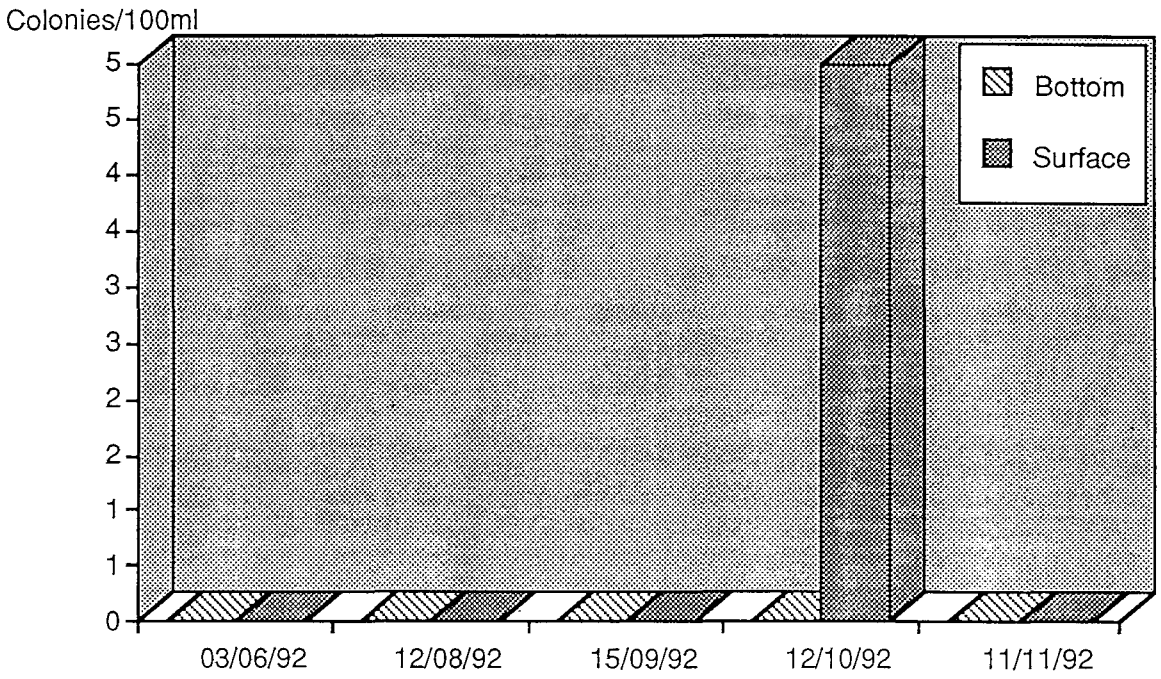


Figure 87: Faecal Coliform Results for Site 11, Narapela Reef

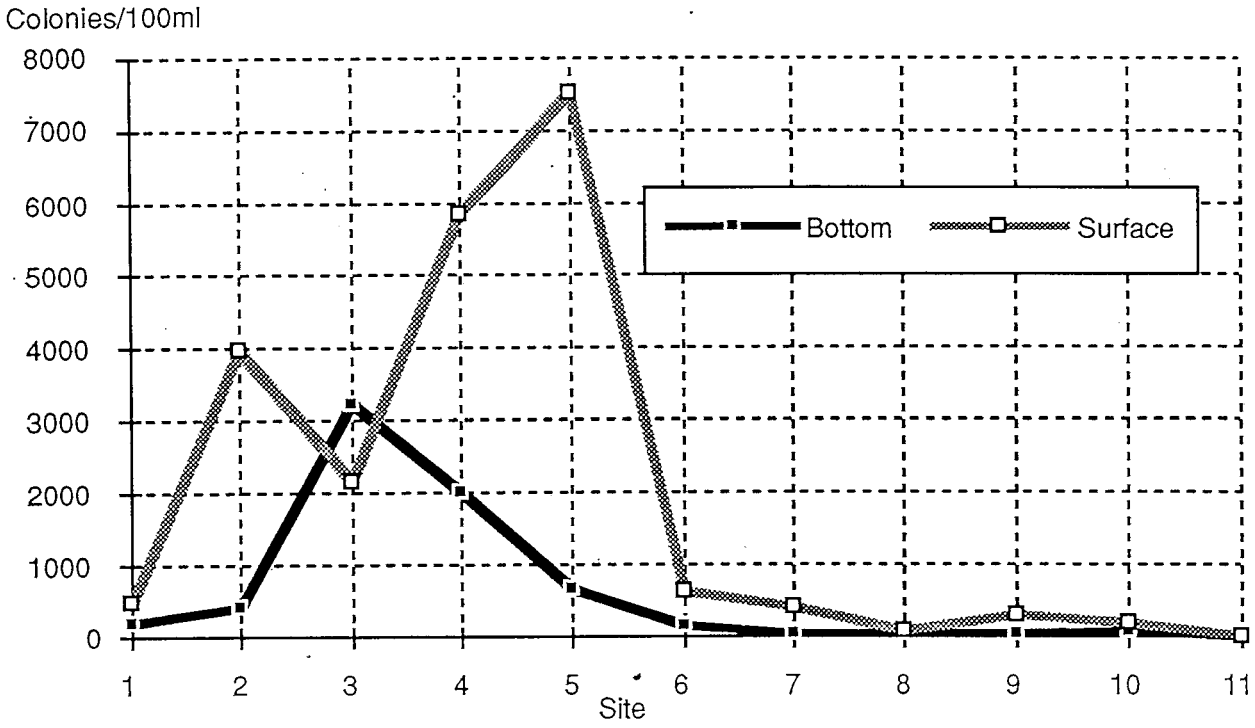


Figure 88: Average Total Coliform Results by Site

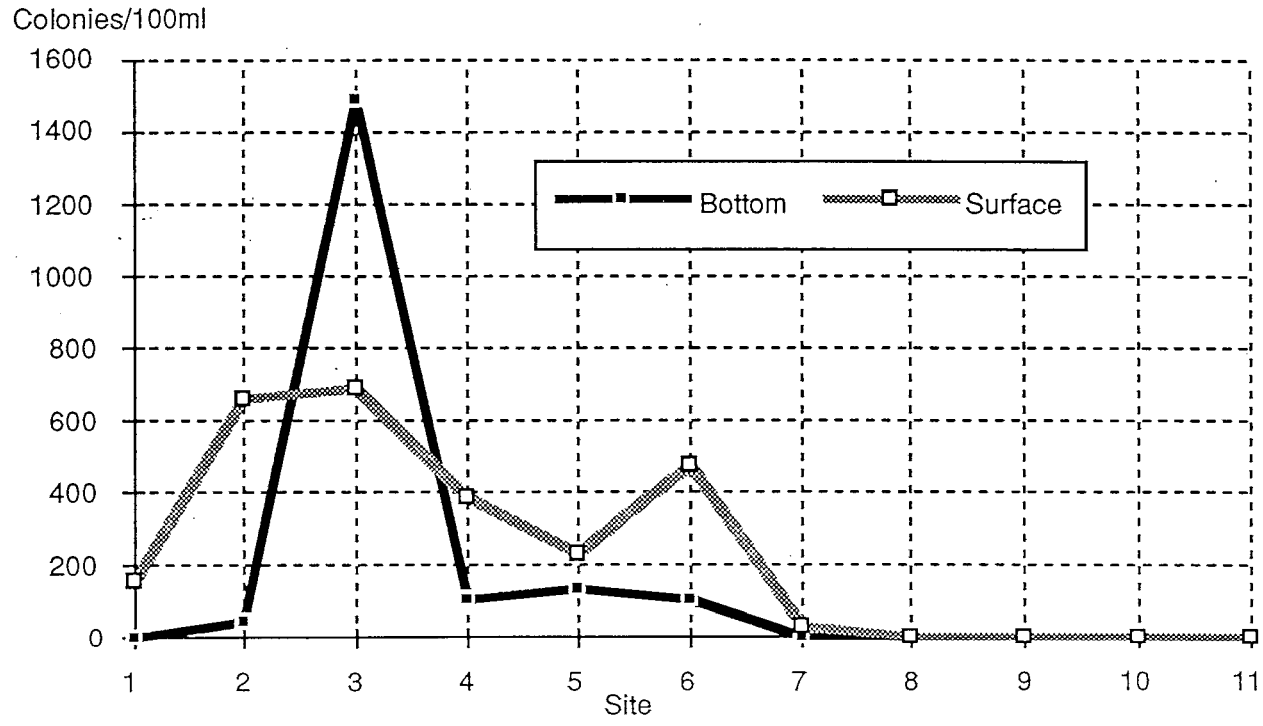


Figure 89: Average Faecal Coliform Results by Site

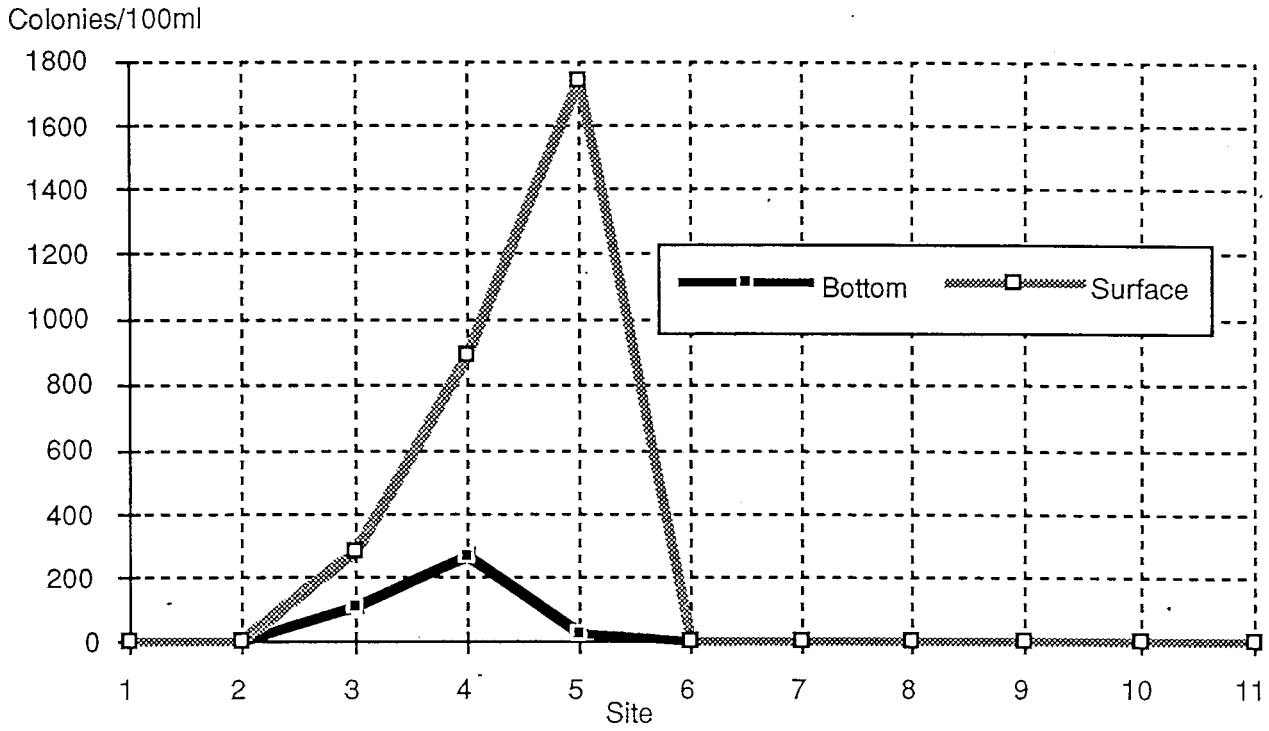


Figure 90: Average Faecal Streptococci Results by Site

Table 1: Total coliform results (colonies/100mL) for Lae City Interim Authority Samples.

Sample Date	Markham River	Landing Bay	Main Wharf	ACI Beach	SP Brewery
24-Sep-85	37600	47000	55000	1660	50000
02-Oct-85	37600	47000	55000	1660	50000
21-Nov-85	1200	1670	2100	320	1100
28-Feb-86	200	1900	18000	450	1000
30-Mar-86	4600	3800	2700	900	1100
29-Apr-86	9500	23000	19000	4300	1700
28-May-86	120	2800	100	30	1100
24-Mar-87	400	470	16000	1000	10000
28-Apr-87	1100	1800	4000	3200	8000
28-May-87	70	2500	0	4200	1400
07-Jul-87	950	370	20200	1350	550
27-Aug-87	200	0	5000	500	200
30-Sep-87	1015	530	17200	10300	740
27-Oct-87	0	0	350	865	700
24-Nov-87	10	100	140000	10	700
29-Dec-87	260	27	9600	460	10
27-Apr-88	900	6300	12000	6000	3200
25-May-88	200	275000	175000	110000	3100
29-Jun-88	500	200	2800	1600	2900
31-Aug-88	3000	2000	300000	12000	2150
27-Sep-88	500	250	510000	1100	4500
25-Oct-88	7000	2000	170000	1900	4700
29-Nov-88	22100	1700	45400	61000	20000
28-Dec-88	3180	130	10000	24180	4450
24-Jan-89	2550	760	8180	7000	2820
21-Feb-89	100	460	1200	850	660
29-Mar-89	2600	1700	76000	660	5550
25-Apr-89	40000	3000	50000	44000	46000
30-May-89	350	70	42700	2600	1500
27-Jun-89	820	1180	23600	7360	8500
25-Jul-89	800	54	12700	200	320
29-Aug-89	150	160	300	1530	410
26-Oct-89	5000	5100	140000	11000	6000
29-Nov-89	60	0	100	0	0
28-Dec-89	600	1700	400	400	300
31-Jan-90	100	1450	500	110	80
28-Feb-90	130	40	800	50	0
27-Mar-90	40	10	6000	40	30
25-Apr-90	530	800	57000	800	200
30-May-90	1700	400	50000	3300	2750

Table 1 continued: Total coliform results (colonies/100mL) for Lae City Interim Authority Samples.

Sample Date	DCA Point	End of Airport	Stewart Park	Voco Point	Bumbu River
24-Sep-85	6600	1280	2460	6700	33400
02-Oct-85	6600	1280	2460	6700	33400
21-Nov-85	3700	16000	700	4300	7200
28-Feb-86	800	310	1600	200	44000
30-Mar-86	49000	63000	13500	7150	3400
29-Apr-86	2600	3100	900	950	1000
28-May-86	5350	3400	2200	8000	21000
24-Mar-87	6000	9000	7000	5000	24000
28-Apr-87	3000	8000	13000	10000	7000
28-May-87	1200	13000	5000	4000	14000
07-Jul-87	36000	1300	1000	8000	1000
27-Aug-87	400	30000	300	8300	42000
30-Sep-87	2700	20000	4700	8200	14000
27-Oct-87	300	1000	60	9000	52000
24-Nov-87	100	5200	800	500	38000
29-Dec-87	1820	1800	1800	15100	8000
27-Apr-88	20000	12000	2000	120000	200000
25-May-88	80000	123000	83000	2400	38000
29-Jun-88	450	3500	2300	15000	300
31-Aug-88	8000	12000	8000	12000	60000
27-Sep-88	1600	35000	1100	3250	2650
25-Oct-88	21000	5000	1100	5000	37500
29-Nov-88	3600	10000	12000	30	180000
28-Dec-88	10	210	127	120	2510
24-Jan-89	20	3480	1270	4000	21000
21-Feb-89	140	2200	2270	650	136000
29-Mar-89	310	40000	280	6500	70000
25-Apr-89	8800	20000	1500	32000	10000
30-May-89	70000	17500	6800	8450	56000
27-Jun-89	4450	25000	263000	300	65000
25-Jul-89	31000	10000	320	23000	400
29-Aug-89	345	50000	4400	65000	630
26-Oct-89	4500	0	7700	400	130000
29-Nov-89	10	30	300	60	3000
28-Dec-89	60	7270	18000	80	600
31-Jan-90	150	140	700	1300	2000
28-Feb-90	0	40	30	600	0
27-Mar-90	50	400	50	4200	5000
25-Apr-90	800	28500	80	12100	182000
30-May-90	800	0	3000	6000	30000

Table 2: Fecal coliform results (colonies/100mL) for Lae City Interim Authority Samples.

Sample Date	Markham River	Landing Bay	Main Wharf	ACI Beach	SP Brewery
24-Sep-85	590	9500	2340	155	1440
02-Oct-85	590	9500	2340	155	1440
21-Nov-85	103	106	320	10	40
28-Feb-86	18	325	4000	0	0
30-Mar-86	400	2200	500	200	400
29-Apr-86	9200	3000	18000	3540	0
28-May-86	100	260	90	0	200
24-Mar-87	65	83	1650	900	1300
28-Apr-87	0	80	0	1850	170
28-May-87	60	5	0	10	1400
07-Jul-87	40	14	240	110	22
27-Aug-87	80	0	1000	10	60
30-Sep-87	300	0	17000	10000	500
27-Oct-87	0	0	34	50	125
24-Nov-87	4	3	5240	3	230
29-Dec-87	46	26	125	110	8
27-Apr-88	370	200	12000	1600	110
25-May-88	200	2000	50000	36000	300
29-Jun-88	210	85	460	110	135
31-Aug-88	1050	1100	400000	9000	950
27-Sep-88	400	60	27500	600	450
25-Oct-88	500	750	120000	60	550
29-Nov-88	19500	1200	43600	60000	0
28-Dec-88	750	130	10000	14910	520
24-Jan-89	2270	545	8000	7000	1780
21-Feb-89	90	460	1000	800	660
29-Mar-89	640	60	5200	150	340
25-Apr-89	20000	200	3500	10000	18000
30-May-89	130	30	7300	120	1500
27-Jun-89	170	260	2730	600	1450
25-Jul-89	490	54	7100	30	80
29-Aug-89	145	160	300	1530	400
26-Oct-89	2200	310	4000	360	2000
29-Nov-89	30	0	0	0	0
28-Dec-89	250	70	130	70	80
31-Jan-90	0	870	100	0	20
28-Feb-90	130	20	200	20	0
27-Mar-90	20	0	390	20	0
25-Apr-90	370	200	5350	90	50
30-May-90	60	30	7300	1000	570

Table 2 continued: Fecal coliform results (colonies/100mL) for Lae City Interim Authority Samples.

Sample Date	DCA Point	End of Airport	Stewart Park	Voco Point	Bumbu River
24-Sep-85	400	1330	1650	1600	9500
02-Oct-85	400	1000	1650	1600	9400
21-Nov-85	1700	2750	220	2710	3100
28-Feb-86	180	0	430	160	1600
30-Mar-86	10000	10500	3800	2700	1950
29-Apr-86	1700	600	535	580	1000
28-May-86	3000	1700	1850	1500	13000
24-Mar-87	200	4000	2000	950	1000
28-Apr-87	80	8000	950	10000	7000
28-May-87	730	660	300	1000	680
07-Jul-87	8000	33	51	28	20
27-Aug-87	150	27000	300	7000	41500
30-Sep-87	1100	6800	2400	2900	5600
27-Oct-87	25	70	60	4100	10500
24-Nov-87	30	300	300	20	160
29-Dec-87	160	2650	83	750	920
27-Apr-88	660	1200	200	14000	12000
25-May-88	2500	12000	3500	71	2000
29-Jun-88	130	150	110	3000	100
31-Aug-88	6100	6300	3000	1700	10000
27-Sep-88	800	13000	1100	270	420
25-Oct-88	115	480	60	1500	6550
29-Nov-88	700	4500	3700	10	27300
28-Dec-88	0	190	20	118	1180
24-Jan-89	20	2270	600	3000	7000
21-Feb-89	20	770	1360	130	124000
29-Mar-89	300	6000	60	2000	7900
25-Apr-89	1500	4400	420	4300	9000
30-May-89	10900	4600	550	2200	6300
27-Jun-89	1600	8700	70000	100	5180
25-Jul-89	7800	10000	240	23000	320
29-Aug-89	340	6800	4360	3500	620
26-Oct-89	3700	0	4100	200	24000
29-Nov-89	0	10	240	0	1200
28-Dec-89	60	430	400	0	300
31-Jan-90	10	70	0	40	2000
28-Feb-90	0	10	20	200	0
27-Mar-90	0	350	0	870	1200
25-Apr-90	100	7300	60	4900	35000
30-May-90	180		3000	125	24000

Table 3: Salinity (‰) depth profile transect from the mouth of the Markham River to Halfway Reef in the Huon Gulf.

Depth (meter)	Markham River Mouth	500 m from River Mouth	1000 m from River Mouth	1500 m from River Mouth
0.5	5.7	10.5	15.6	13.9
1.0	7.5	18.1	18.3	16.6
1.5	17.3	20.0	22.2	21.3
2.0	23.4	21.8	25.3	22.9
2.5	25.8	25.6	26.7	24.1
3.0	26.4	26.4	26.9	25.1
3.5	26.7	26.7	26.9	26.2
4.0	27.0	26.8	26.8	26.8
4.5	27.8			27.0
5.0	27.8			28.4
5.5	27.9			28.8
6.0	28.0			28.9
6.5				29.2
7.0				29.2
7.5				29.3

Depth (meter)	2000 m from River Mouth	2500 m from River Mouth	3000 m from River Mouth	Halfway Reef
0.5	15.4	15.6	15.8	20.4
1.0	15.9	17.5	17.0	22.3
1.5	19.9	20.3	19.9	22.9
2.0	22.6	21.7	20.4	23.6
2.5	23.9	22.2	22.5	24.3
3.0	25.5	22.1	23.5	25.2
3.5	27.0	22.9	24.1	26.5
4.0	27.1	23.6	25.3	26.7
4.5	27.1	26.6	26.7	28.6
5.0	27.3	27.0	27.0	28.7
5.5	28.6	27.6	27.8	28.7
6.0	28.9	28.6	28.5	28.9
6.5	29.0	28.8	28.6	29.0
7.0	29.0	28.9	28.9	29.2
7.5	29.0	28.9	29.0	29.2

Table 4: Dissolved oxygen (ppm) depth profile transect from the mouth of the Markham River to Halfway Reef in the Huon Gulf.

Depth (meter)	Markham River Mouth	500 m from River Mouth	1000 m from River Mouth	1500 m from River Mouth
0.5	6.55	6.40	6.01	6.24
1.0	6.31	6.12	5.82	6.22
1.5	5.73	6.13	6.00	5.76
2.0	5.54	5.82	5.84	5.81
2.5	5.51	5.72	5.88	5.95
3.0	5.33	5.73	5.84	5.94
3.5	4.99	5.59	5.70	5.76
4.0	5.00	5.57	5.72	5.82
4.5	4.85			5.58
5.0	4.72			5.56
5.5				5.45
6.0				5.51
6.5				5.52
7.0				5.64
7.5				5.56

Depth (meter)	2000 m from River Mouth	2500 m from River Mouth	3000 m from River Mouth	Halfway Reef
0.5	6.56	6.53	6.37	6.11
1.0	6.58	6.37	6.25	5.89
1.5	6.24	6.18	6.12	5.80
2.0	5.77	5.91	5.84	5.84
2.5	5.80	5.94	5.59	5.86
3.0	5.57	6.05	5.97	5.86
3.5	5.84	5.90	5.66	5.88
4.0	5.80	5.92	5.64	5.85
4.5	5.71	5.83	5.79	5.83
5.0	5.70	5.79	5.69	5.83
5.5	5.51	5.66	5.63	5.82
6.0	5.53	5.66	5.63	5.77
6.5	5.60	5.65	5.62	5.79
7.0	5.62	5.65	5.62	5.75
7.5	5.59	5.59	5.61	5.76

Table 5: Temperature (°C) depth profile transect from the mouth of the Markham River to Halfway Reef in the Huon Gulf.

Depth (meter)	Markham River Mouth	500 m from River Mouth	1000 m from River Mouth	1500 m from River Mouth
0.5	26.8	27.9	28.1	27.9
1.0	27.0	28.0	28.2	28.1
1.5	27.9	28.3	28.8	28.6
2.0	28.7	28.5	29.0	28.5
2.5	28.9	28.9	29.0	28.6
3.0	29.0	29.1	29.0	29.0
3.5	29.1	29.1	29.1	29.0
4.0	29.2	29.1	29.2	28.9
4.5	29.5			29.0
5.0	29.5			29.4
5.5				29.5
6.0				29.5
6.5				29.7
7.0				29.7
7.5				29.7

Depth (meter)	2000 m from River Mouth	2500 m from River Mouth	3000 m from River Mouth	Halfway Reef
0.5	28.2	28.2	28.4	28.6
1.0	28.1	28.3	28.4	28.4
1.5	28.4	28.4	28.7	28.4
2.0	28.3	28.3	28.5	28.3
2.5	28.5	28.3	28.3	28.5
3.0	28.9	28.3	28.4	28.7
3.5	28.9	28.3	28.5	29.0
4.0	29.0	28.4	28.8	29.0
4.5	29.0	28.8	28.8	29.6
5.0	29.1	29.0	29.0	29.7
5.5	29.5	29.2	29.3	29.7
6.0	29.6	29.5	29.5	29.7
6.5	29.7	29.6	29.6	29.7
7.0	29.7	29.7	29.7	29.8
7.5	29.7	29.7	29.8	29.8

Table 6: Laboratory measured physical parameters from transect of the mouth of the Markham River to Halfway Reef in the Huon Gulf.

Transect Site	pH		Colour (Hazen)	
	Surface	5m Depth	Surface	5m Depth
Markham River Mouth	7.2	8.1	20	15
500 m from River Mouth	7.2	8.0	15	5
1000 m from River Mouth	7.4	7.9	5	< 5
1500 m from River Mouth	7.6	8.0	< 5	< 5
2000 m from River Mouth	7.7	8.0	< 5	< 5
2500 m from River Mouth	7.6	8.1	< 5	< 5
3000 m from River Mouth	7.7	8.1	< 5	< 5
Halfway Reef	7.9	8.0	< 5	< 5

Transect Site	T.S.S (mg/L)		Turbidity (N.T.U)	
	Surface	5m Depth	Surface	5m Depth
Markham River Mouth	180	50	120	15
500 m from River Mouth	43	14	70	5.1
1000 m from River Mouth	14	7	25	3.5
1500 m from River Mouth	18	29	22	2.8
2000 m from River Mouth	16	26	18	3.1
2500 m from River Mouth	11	9	7.4	1.6
3000 m from River Mouth	14	8	5.7	1
Halfway Reef	10	10	0.2	0.4

Table 7: Total and Faecal Coliform Results (Colonies/100mL).

Site	Date	Time	Total Coliforms		Faecal Coliforms	
			Surface	Bottom	Surface	Bottom
1	03/06/92	06:45	600	310	180	10
1	12/08/92	07:25	785	300	290	0
1	15/09/92	06:20	500	210	100	10
1	12/10/92	06:00	280	70	120	0
1	11/11/92	06:30	350	200	90	5
2	03/06/92	07:30	1600	50	380	2
2	12/08/92	08:10	1400	20	410	0
2	15/09/92	07:00	13000	1900	1800	200
2	12/10/92	06:50	2100	100	410	30
2	11/11/92	07:15	1700	20	320	10
3	03/06/92	08:00	1300	1500	540	1200
3	12/08/92	08:45	1000	9000	400	3700
3	15/09/92	07:40	4500	3100	1200	1300
3	12/10/92	07:20	2300	1200	900	1000
3	11/11/92	08:00	1700	1400	400	250
4	03/06/92	08:40	7000	2800	430	130
4	12/08/92	09:20	5000	3300	280	100
4	15/09/92	08:15	12700	2700	920	210
4	12/10/92	08:00	4200	1200	230	90
4	11/11/92	09:10	380	50	90	10
5	03/06/92	09:00	9000	800	380	190
5	12/08/92	09:46	7150	400	300	210
5	15/09/92	08:45	16100	1600	210	190
5	12/10/92	08:20	4800	520	90	10
5	11/11/92	09:40	560	60	180	70
6	03/06/92	09:42	700	200	560	130
6	12/08/92	10:00	500	210	480	90
6	15/09/92	09:10	600	160	370	70
6	12/10/92	08:55	1000	290	610	150
6	11/11/92	10:15	450	60	370	90
7	03/06/92	18:15	700	80	20	4
7	12/08/92	10:20	500	100	10	0
7	15/09/92	09:40	200	50	90	0
7	12/10/92	10:00	450	110	50	5
7	11/11/92	10:50	290	20	10	5
8	03/06/92	13:10	150	70	4	0
8	12/08/92	12:15	100	90	2	2
8	15/09/92	10:50	90	60	10	0
8	12/10/92	11:10	70	70	5	0
8	11/11/92	11:55	70	50	5	0

Table 7 continued: Total and Faecal Coliform Results (Colonies /100mL).

Site	Date	Time	Total Coliforms		Faecal Coliforms	
			Surface	Bottom	Surface	Bottom
9	03/06/92	14:30	400	30	0	0
9	12/08/92	15:30	510	80	0	0
9	15/09/92	13:20	90	10	10	0
9	12/10/92	12:45	210	90	10	0
9	11/11/92	13:40	370	40	0	0
10	03/06/92	15:27	120	55	1	0
10	12/08/92	13:20	200	75	0	0
10	15/09/92	15:20	100	25	10	0
10	12/10/92	14:10	330	170	5	0
10	11/11/92	15:20	190	90	0	0
11	03/06/92	16:26	0	0	0	0
11	12/08/92	14:00	10	5	0	0
11	15/09/92	18:10	5	5	0	0
11	12/10/92	16:30	5	5	5	0
11	11/11/92	17:00	0	0	0	0

Table 8: Faecal Streptococci (colonies/100mL) and Biological Oxygen Demand Results.

Site	Date	Time	Faecal Streptococci		$BOD_{5\ day}$ (ppm)	
			Surface	Bottom	Surface	Bottom
1	03/06/92	06:45	0	0	1.1	0.5
1	12/08/92	07:25	0	0	0.7	0.3
1	15/09/92	06:20	0	0	1.3	0.4
1	12/10/92	06:00	0	0	1.0	0.3
1	11/11/92	06:30	0	0	1.9	0.7
2	03/06/92	07:30	0	0	0.8	0.2
2	12/08/92	08:10	0	0	0.4	0.2
2	15/09/92	07:00	10	0	2.9	0.3
2	12/10/92	06:50	0	0	2.1	0.4
2	11/11/92	07:15	15	0	1.6	0.2
3	03/06/92	08:00	230	90	2.1	0.3
3	12/08/92	08:45	500	200	1.5	0.2
3	15/09/92	07:40	420	190	2.7	0.3
3	12/10/92	07:20	100	20	2.9	0.2
3	11/11/92	08:00	190	70	1.8	0.4
4	03/06/92	08:40	800	110	1.1	0.3
4	12/08/92	09:20	1000	330	0.4	0.1
4	15/09/92	08:15	1900	600	3.0	0.3
4	12/10/92	08:00	560	210	2.6	0.5
4	11/11/92	09:10	190	90	1.2	0.1
5	03/06/92	09:00	1800	10	1.3	1.4
5	12/08/92	09:46	2300	5	1.2	1.1
5	15/09/92	08:45	2700	90	2.1	0.9
5	12/10/92	08:20	700	5	1.2	0.5
5	11/11/92	09:40	1200	20	1.4	0.1
6	03/06/92	09:42	0	0	1.6	0.3
6	12/08/92	10:00	0	0	0.8	0.2
6	15/09/92	09:10	10	5	1.1	0.3
6	12/10/92	08:55	20	0	0.9	0.5
6	11/11/92	10:15	0	0	1.0	0.4
7	03/06/92	18:15	0	0	0.3	0.3
7	12/08/92	10:20	0	0	0.6	0.3
7	15/09/92	09:40	0	0	2.1	0.5
7	12/10/92	10:00	0	0	1.9	0.7
7	11/11/92	10:50	0	0	1.0	0.4
8	03/06/92	13:10	0	0	0.7	0.1
8	12/08/92	12:15	0	0	0.4	0.1
8	15/09/92	10:50	0	0	0.7	0.2
8	12/10/92	11:10	0	0	1.0	0.1
8	11/11/92	11:55	0	0	0.9	0.2

Table 8 continued: Faecal Streptococci (colonies/100mL) and Biological Oxygen Demand Results.

Site	Date	Time	Faecal Streptococci		$BOD_{5\ day}$ (ppm)	
			Surface	Bottom	Surface	Bottom
9	03/06/92	14:30	0	0	0.1	0.1
9	12/08/92	15:30	0	0	0.6	0.3
9	15/09/92	13:20	0	0	0.7	0.1
9	12/10/92	12:45	0	0	0.4	0.2
9	11/11/92	13:40	0	0	0.7	0.2
10	03/06/92	15:27	0	0	0.7	0.1
10	12/08/92	13:20	0	0	0.3	0.1
10	15/09/92	15:20	0	0	0.4	0.1
10	12/10/92	14:10	0	0	0.9	0.2
10	11/11/92	15:20	0	0	0.5	0.1
11	03/06/92	16:26	0	0	0.1	0.1
11	12/08/92	14:00	0	0	0.2	0.1
11	15/09/92	18:10	0	0	0.1	0.1
11	12/10/92	16:30	0	0	0.1	0.1
11	11/11/92	17:00	0	0	0.2	0.2

Table 9: Average values by site for microbiological parameters (colonies/100mL) in water samples.

Site Name	Site Number	Total Coliforms (colonies/100ml)		Faecal Coliforms (colonies/100ml)	
		Surface	Bottom	Surface	Bottom
Busu River Mouth	1	503	218	156	5
Bumbu River Mouth	2	3960	418	664	48
Voco Point	3	2160	3240	688	1490
Lae Main Wharf	4	5856	2010	390	108
Landing Bay	5	7522	676	232	134
Markham River Mouth	6	650	184	478	106
Labu Lakes Entrance	7	428	72	36	3
Sugar Loaf	8	96	68	5	0
Halfway Reef	9	316	50	4	0
Schoolhouse Reef	10	188	83	3	0
Narapela Reef	11	4	3	1	0

Site Name	Site Number	Faecal Streptococci (colonies/100ml)		$BOD_{5\ day}$ (ppm)	
		Surface	Bottom	Surface	Bottom
Busu River Mouth	1	0	0	1	0
Bumbu River Mouth	2	5	0	2	0
Voco Point	3	288	114	2	0
Lae Main Wharf	4	890	268	2	0
Landing Bay	5	1740	26	1	1
Markham River Mouth	6	6	1	1	0
Labu Lakes Entrance	7	0	0	1	0
Sugar Loaf	8	0	0	1	0
Halfway Reef	9	0	0	1	0
Schoolhouse Reef	10	0	0	1	0
Narapela Reef	11	0	0	0	0

Table 10: Total suspended solids and pH results.

Site	Date	Time	pH		Total Suspended Solids (mg/L)	
			Surface	Bottom	Surface	Bottom
1	03/06/92	06:45	7.8	8.0	32	5
1	12/08/92	07:25	8.0	8.1	21	8
1	15/09/92	06:20	8.0	8.0	300	285
1	12/10/92	06:00	7.9	8.0	100	86
1	11/11/92	06:30	8.1	8.1	40	34
1	14/12/93	06:16	7.7	7.8	23	18
1	07/01/93	06:29	8.0	7.9	52	47
1	18/02/93	06:05	7.8	7.8	24	27
1	11/03/93	06:15	8.1	7.8	31	30
1	19/04/93	06:22	8.1	8.1	67	58
1	06/05/93	06:00	8.3	8.0	42	35
1	16/06/93	06:06	7.9	7.8	128	105
1	19/07/93	06:36	7.9	8.0	296	269
1	12/08/93	06:10	8.1	7.9	152	136
1	20/09/93	06:03	7.9	7.8	187	158
1	12/10/93	06:17	8.0	7.7	137	124
1	08/11/93	06:34	8.4	8.2	48	39
2	03/06/92	07:30	7.7	8.4	65	18
2	12/08/92	08:10	7.9	8.3	53	15
2	15/09/92	07:00	8.1	8.2	850	740
2	12/10/92	06:50	7.6	8.0	120	38
2	11/11/92	07:15	7.8	8.0	260	125
2	14/12/93	06:58	8.3	8.2	310	283
2	07/01/93	07:04	8.4	8.4	182	112
2	18/02/93	06:47	8.0	8.2	247	157
2	11/03/93	06:59	7.6	8.3	368	279
2	19/04/93	07:10	8.2	8.1	524	426
2	06/05/93	06:52	7.8	8.2	438	392
2	16/06/93	06:53	8.1	8.3	791	702
2	19/07/93	07:17	7.8	8.1	637	545
2	12/08/93	07:12	7.8	8.3	852	728
2	20/09/93	06:42	8.0	8.2	463	382
2	12/10/93	06:50	8.0	8.1	518	450
2	08/11/93	07:31	7.8	8.0	283	171
3	03/06/92	08:00	8.0	8.0	5	10
3	12/08/92	08:45	8.1	8.0	1	6
3	15/09/92	07:40	8.0	8.2	150	150
3	12/10/92	07:20	7.7	8.1	20	35
3	11/11/92	08:00	7.9	8.0	65	78
3	14/12/93	07:31	7.9	8.1	46	49
3	07/01/93	07:36	8.2	8.0	72	65
3	18/02/93	07:19	7.7	8.0	67	79
3	11/03/93	07:28	8.0	8.2	102	109
3	19/04/93	07:51	8.1	8.1	83	75
3	06/05/93	07:23	7.8	7.9	147	145
3	16/06/93	07:42	7.9	7.9	251	259

Table 10 continued: Total suspended solids and pH results.

Site	Date	Time	pH		Total Suspended Solids (mg/L)	
			Surface	Bottom	Surface	Bottom
3	19/07/93	07:34	7.9	7.7	184	172
3	12/08/93	07:40	8.1	7.9	212	220
3	20/09/93	07:14	8.2	7.9	124	137
3	12/10/93	07:22	7.8	8.1	92	83
3	08/11/93	08:04	8.1	8.3	45	49
4	03/06/92	08:40	7.9	7.9	48	12
4	12/08/92	09:20	8.1	8.1	26	9
4	15/09/92	08:15	8.0	8.0	1200	1000
4	12/10/92	08:00	8.1	8.0	145	120
4	11/11/92	09:10	7.8	7.9	230	210
4	14/12/93	08:12	8.1	8.0	45	42
4	07/01/93	08:15	8.2	8.1	26	29
4	18/02/93	08:01	8.1	8.2	34	40
4	11/03/93	08:17	8.3	8.0	58	48
4	19/04/93	08:39	8.0	8.1	157	149
4	06/05/93	08:26	8.2	8.0	48	50
4	16/06/93	08:29	8.0	8.0	59	55
4	19/07/93	08:09	8.3	8.1	532	496
4	12/08/93	08:42	7.9	8.2	114	102
4	20/09/93	08:34	8.2	8.3	46	49
4	12/10/93	08:16	8.2	8.2	65	71
4	08/11/93	08:47	8.3	8.1	51	55
5	03/06/92	09:00	7.9	8.1	36	38
5	12/08/92	09:46	8.1	8.2	28	33
5	15/09/92	08:45	8.0	8.0	1150	1100
5	12/10/92	08:20	8.0	8.1	270	250
5	11/11/92	09:40	7.9	8.0	150	150
5	14/12/93	08:32	8.1	8.2	50	45
5	07/01/93	08:41	8.2	8.3	27	30
5	18/02/93	08:52	8.2	8.3	36	41
5	11/03/93	08:46	8.2	8.2	51	55
5	19/04/93	09:06	8.0	8.1	152	160
5	06/05/93	09:17	8.2	8.1	42	36
5	16/06/93	09:09	8.1	8.0	55	51
5	19/07/93	08:43	8.2	8.3	502	510
5	12/08/93	09:12	8.3	8.2	82	76
5	20/09/93	09:31	8.2	8.0	54	58
5	12/10/93	08:41	8.3	8.2	71	62
5	08/11/93	09:26	8.3	8.3	55	50
6	03/06/92	09:42	8.3	8.2	630	40
6	12/08/92	10:00	8.5	8.1	520	29
6	15/09/92	09:10	8.0	8.0	890	120
6	12/10/92	08:55	8.1	7.9	450	57
6	11/11/92	10:15	7.9	7.9	520	90
6	14/12/93	09:06	8.1	8.3	380	200

Table 10 continued: Total suspended solids and pH results.

Site	Date	Time	pH		Total Suspended Solids (mg/L)	
			Surface	Bottom	Surface	Bottom
6	07/01/93	09:12	7.8	8.0	270	170
6	18/02/93	09:34	7.9	8.2	310	130
6	11/03/93	09:17	7.8	8.1	200	65
6	19/04/93	10:02	8.0	8.1	330	92
6	06/05/93	09:51	7.6	8.1	470	110
6	16/06/93	09:57	7.9	8.2	250	50
6	19/07/93	10:06	8.1	8.0	910	350
6	12/08/93	09:31	8.0	8.0	325	97
6	20/09/93	10:17	7.9	8.3	290	80
6	12/10/93	09:14	7.9	8.0	310	135
6	08/11/93	10:03	8.0	8.1	240	66
7	03/06/92	18:15	8.4	8.2	170	170
7	12/08/92	10:20	8.3	8.2	130	150
7	15/09/92	09:40	8.2	8.1	120	100
7	12/10/92	10:00	8.0	8.2	40	55
7	11/11/92	10:50	8.1	8.0	150	145
7	14/12/93	09:49	8.1	8.2	70	74
7	07/01/93	09:56	8.0	8.1	47	42
7	18/02/93	10:12	8.2	8.2	23	25
7	11/03/93	10:06	8.1	8.2	37	35
7	19/04/93	10:41	8.1	7.9	64	61
7	06/05/93	10:30	8.2	7.9	21	25
7	16/06/93	10:46	7.9	8.3	32	34
7	19/07/93	10:59	8.3	8.2	100	96
7	12/08/93	10:10	8.2	8.3	63	60
7	20/09/93	11:02	8.2	8.1	27	24
7	12/10/93	09:47	8.2	8.1	46	51
7	08/11/93	10:43	8.0	8.2	32	30
8	03/06/92	13:10	8.1	8.1	42	9
8	12/08/92	12:15	8.2	8.2	31	12
8	15/09/92	10:50	8.0	8.1	20	15
8	12/10/92	11:10	8.1	8.2	90	80
8	11/11/92	11:55	8.0	8.2	45	39
8	14/12/93	10:49	8.0	8.1	32	23
8	07/01/93	11:02	8.3	8.3	19	20
8	18/02/93	11:19	8.1	8.2	17	15
8	11/03/93	11:06	8.1	8.3	39	38
8	19/04/93	11:53	8.3	8.3	16	22
8	06/05/93	11:42	8.0	8.2	31	33
8	16/06/93	12:01	7.9	8.1	50	47
8	19/07/93	12:10	8.1	8.0	32	36
8	12/08/93	11:21	8.3	8.0	61	58
8	20/09/93	12:06	8.0	8.0	27	29
8	12/10/93	11:10	8.1	8.2	61	60
8	08/11/93	12:17	8.3	8.3	8	10

Table 10 continued: Total suspended solids and pH results.

Site	Date	Time	pH		Total Suspended Solids (mg/L)	
			Surface	Bottom	Surface	Bottom
9	03/06/92	14:30	8.2	8.2	20	20
9	12/08/92	15:30	8.2	8.2	33	33
9	15/09/92	13:20	8.1	8.3	45	31
9	12/10/92	12:45	8.1	8.2	27	22
9	11/11/92	13:40	8.2	8.3	15	21
9	14/12/93	12:56	8.2	7.9	5	6
9	07/01/93	13:12	8.1	8.2	11	12
9	18/02/93	13:31	8.2	8.2	12	9
9	11/03/93	13:09	8.1	8.1	17	18
9	19/04/93	14:06	8.1	8.0	8	7
9	06/05/93	13:52	8.1	8.2	5	6
9	16/06/93	14:15	8.1	8.1	10	12
9	19/07/93	14:26	8.0	8.1	4	8
9	12/08/93	13:30	8.2	8.2	9	12
9	20/09/93	14:16	8.3	8.3	21	18
9	12/10/93	13:19	8.1	7.9	7	10
9	08/11/93	14:29	8.1	8.1	5	7
10	03/06/92	15:27	8.4	8.4	26	18
10	12/08/92	13:20	8.5	8.4	27	34
10	15/09/92	15:20	8.2	8.3	10	12
10	12/10/92	14:10	8.3	8.4	18	13
10	11/11/92	15:20	8.0	8.3	8	11
10	14/12/93	14:31	8.0	8.3	8	7
10	07/01/93	14:42	8.3	8.1	3	2
10	18/02/93	15:06	8.2	8.4	12	18
10	11/03/93	14:47	8.3	8.3	7	8
10	19/04/93	15:31	8.2	8.1	4	5
10	06/05/93	15:12	8.0	8.2	7	6
10	16/06/93	15:47	8.1	8.2	3	2
10	19/07/93	15:53	8.1	8.2	11	9
10	12/08/93	15:00	8.2	8.2	2	3
10	20/09/93	15:39	8.1	8.3	2	5
10	12/10/93	14:51	8.3	8.3	5	2
10	08/11/93	15:56	8.2	8.2	2	3
11	03/06/92	16:26	8.4	8.5	27	23
11	12/08/92	14:00	8.5	8.5	31	31
11	15/09/92	18:10	8.2	8.4	20	18
11	12/10/92	16:30	8.2	8.4	17	23
11	11/11/92	17:00	8.1	8.5	28	21
11	14/12/93	16:00	8.2	8.3	6	5
11	07/01/93	16:12	8.3	8.4	15	12
11	18/02/93	16:39	8.3	8.3	2	5
11	11/03/93	16:20	8.1	8.3	4	7
11	19/04/93	17:10	8.3	8.4	7	5
11	06/05/93	17:21	8.1	8.0	2	5

Table 10 continued: Total suspended solids and pH results.

Site	Date	Time	pH		Total Suspended Solids (mg/L)	
			Surface	Bottom	Surface	Bottom
11	16/06/93	17:04	8.2	8.3	5	8
11	19/07/93	17:42	8.2	8.4	10	8
11	12/08/93	16:52	8.3	8.3	9	5
11	20/09/93	17:49	8.4	8.2	5	2
11	12/10/93	17:20	8.3	8.2	4	8
11	08/11/93	18:05	8.3	8.2	2	3

Table 11: Turbidity and colour results.

Site	Date	Time	Colour (Hazen)		Turbidity (N.T.U)	
			Surface	Bottom	Surface	Bottom
1	03/06/92	06:45	70	10	20	1.6
1	12/08/92	07:25	50	20	13	0.2
1	15/09/92	06:20	40	30	52	43.0
1	12/10/92	06:00	20	20	47	39.0
1	11/11/92	06:30	30	20	14	1.8
1	14/12/93	06:16	25	20	10	2.9
1	07/01/93	06:29	35	25	12	3.2
1	18/02/93	06:05	15	10	8	1.9
1	11/03/93	06:15	45	20	31	14.0
1	19/04/93	06:22	20	20	35	4.7
1	06/05/93	06:00	50	25	20	2.8
1	16/06/93	06:06	40	25	58	24.0
1	19/07/93	06:36	55	30	46	12.0
1	12/08/93	06:10	40	25	51	42.0
1	20/09/93	06:03	25	30	58	51.0
1	12/10/93	06:17	45	40	39	28.0
1	08/11/93	06:34	40	20	11	4.2
2	03/06/92	07:30	50	10	28	4.0
2	12/08/92	08:10	60	20	26	1.2
2	15/09/92	07:00	50	10	78	92.0
2	12/10/92	06:50	20	40	32	18.0
2	11/11/92	07:15	40	20	35	4.2
2	14/12/93	06:58	20	20	26	20.0
2	07/01/93	07:04	10	20	31	15.0
2	18/02/93	06:47	30	20	34	26.0
2	11/03/93	06:59	20	10	52	47.0
2	19/04/93	07:10	5	10	69	58.0
2	06/05/93	06:52	35	10	42	29.0
2	16/06/93	06:53	20	25	54	32.0
2	19/07/93	07:17	20	15	47	39.0
2	12/08/93	07:12	25	30	62	57.0
2	20/09/93	06:42	30	15	37	21.0
2	12/10/93	06:50	30	20	49	29.0
2	08/11/93	07:31	20	30	26	12.0
3	03/06/92	08:00	30	30	10	8.0
3	12/08/92	08:45	20	20	4.5	2.5
3	15/09/92	07:40	10	5	47.0	54.0
3	12/10/92	07:20	20	10	9.8	11.0
3	11/11/92	08:00	10	10	16.0	12.0
3	14/12/93	07:31	5	5	22.0	24.0
3	07/01/93	07:36	5	5	20.0	10.0
3	18/02/93	07:19	15	10	37.0	23.0
3	11/03/93	07:28	15	10	43.0	45.0
3	19/04/93	07:51	10	5	36.0	27.0
3	06/05/93	07:23	5	10	54.0	40.0
3	16/06/93	07:42	5	5	69.0	35.0

Table 11 continued: Turbidity and colour results.

Site	Date	Time	Colour (Hazen)		Turbidity (N.T.U)	
			Surface	Bottom	Surface	Bottom
3	19/07/93	07:34	5	5	47.0	35.0
3	12/08/93	07:40	30	5	76.0	53.0
3	20/09/93	07:14	10	10	19.0	22.0
3	12/10/93	07:22	5	10	35.0	30.0
3	08/11/93	08:04	20	5	22.0	10.0
4	03/06/92	08:40	60	20	40	1.6
4	12/08/92	09:20	50	20	20	0.6
4	15/09/92	08:15	100	20	380	375.0
4	12/10/92	08:00	50	30	68	74.0
4	11/11/92	09:10	60	40	72	62.0
4	14/12/93	08:12	50	20	22	25.0
4	07/01/93	08:15	25	20	27	29.0
4	18/02/93	08:01	20	10	29	31.0
4	11/03/93	08:17	15	5	25	28.0
4	19/04/93	08:39	20	15	52	47.0
4	06/05/93	08:26	30	20	19	22.0
4	16/06/93	08:29	15	20	36	32.0
4	19/07/93	08:09	20	15	79	69.0
4	12/08/93	08:42	40	20	24	31.0
4	20/09/93	08:34	40	10	13	15.0
4	12/10/93	08:16	15	10	26	20.0
4	08/11/93	08:47	20	15	17	14.0
5	03/06/92	09:00	40	40	25	22
5	12/08/92	09:46	30	40	22	22
5	15/09/92	08:45	30	20	350	360
5	12/10/92	08:20	50	50	87	72
5	11/11/92	09:40	20	30	79	86
5	14/12/93	08:32	25	15	24	27.0
5	07/01/93	08:41	10	5	31	24.0
5	18/02/93	08:52	15	30	24	27.0
5	11/03/93	08:46	15	10	32	34.0
5	19/04/93	09:06	20	5	47	52.0
5	06/05/93	09:17	20	5	23	19.0
5	16/06/93	09:09	30	25	31	26.0
5	19/07/93	08:43	5	15	84	80.0
5	12/08/93	09:12	25	20	27	31.0
5	20/09/93	09:31	35	25	10	12.0
5	12/10/93	08:41	15	30	23	20.0
5	08/11/93	09:26	15	10	19	16.0
6	03/06/92	09:42	50	10	200	21
6	12/08/92	10:00	30	20	140	8.4
6	15/09/92	09:10	20	10	290	21.0
6	12/10/92	08:55	10	5	120	19.0
6	11/11/92	10:15	30	20	130	27.0
6	14/12/93	09:06	20	5	110	42.0

Table 11 continued: Turbidity and colour results.

Site	Date	Time	Colour (Hazen)		Turbidity (N.T.U)	
			Surface	Bottom	Surface	Bottom
6	07/01/93	09:12	25	20	94	32.0
6	18/02/93	09:34	30	25	82	20.0
6	11/03/93	09:17	20	15	46	35.0
6	19/04/93	10:02	15	20	96	28.0
6	06/05/93	09:51	20	15	78	27.0
6	16/06/93	09:57	15	10	49	34.0
6	19/07/93	10:06	35	20	250	32.0
6	12/08/93	09:31	20	15	125	56.0
6	20/09/93	10:17	10	5	87	25.0
6	12/10/93	09:14	20	5	104	34.0
6	08/11/93	10:03	15	10	82	28.0
7	03/06/92	18:15	40	40	75	53
7	12/08/92	10:20	50	50	80	47
7	15/09/92	09:40	20	20	85	75
7	12/10/92	10:00	30	10	46	52
7	11/11/92	10:50	10	5	69	43
7	14/12/93	09:49	20	15	42	27.0
7	07/01/93	09:56	25	25	24	24.0
7	18/02/93	10:12	25	20	31	33.0
7	11/03/93	10:06	40	25	23	20.0
7	19/04/93	10:41	30	40	35	40.0
7	06/05/93	10:30	30	35	42	38.0
7	16/06/93	10:46	20	30	31	27.0
7	19/07/93	10:59	40	25	84	79.0
7	12/08/93	10:10	30	20	29	24.0
7	20/09/93	11:02	25	35	10	12.0
7	12/10/93	09:47	30	20	31	28.0
7	08/11/93	10:43	30	30	24	19.0
8	03/06/92	13:10	20	20	10	11.0
8	12/08/92	12:15	20	10	6.2	3.4
8	15/09/92	10:50	10	5	15.0	14.0
8	12/10/92	11:10	5	5	11.0	18.0
8	11/11/92	11:55	10	10	7.9	8.4
8	14/12/93	10:49	10	5	3.1	12.4
8	07/01/93	11:02	5	5	12.0	14.0
8	18/02/93	11:19	20	10	9.4	4.2
8	11/03/93	11:06	10	5	15.0	10.0
8	19/04/93	11:53	10	15	10.0	8.6
8	06/05/93	11:42	5	5	7.9	5.5
8	16/06/93	12:01	10	5	5.2	4.9
8	19/07/93	12:10	15	10	18.0	8.3
8	12/08/93	11:21	5	5	5.0	2.8
8	20/09/93	12:06	10	5	14.0	15.0
8	12/10/93	11:10	10	5	3.5	1.0
8	08/11/93	12:17	15	5	9.6	9.5

Table 11 continued: Turbidity and colour results.

Site	Date	Time	Colour (Hazen)		Turbidity (N.T.U)	
			Surface	Bottom	Surface	Bottom
9	03/06/92	14:30	10	10	1.0	1.0
9	12/08/92	15:30	15	20	0.3	0.8
9	15/09/92	13:20	5	10	2.1	1.8
9	12/10/92	12:45	5	<5	0.9	1.3
9	11/11/92	13:40	<5	5	1.6	1.2
9	14/12/93	12:56	<5	10	1.8	1.1
9	07/01/93	13:12	15	0	1.8	1.6
9	18/02/93	13:31	<5	5	1.0	0.9
9	11/03/93	13:09	10	<5	1.9	1.5
9	19/04/93	14:06	<5	10	1.3	0.7
9	06/05/93	13:52	<5	5	1.4	1.5
9	16/06/93	14:15	5	5	1.7	1.5
9	19/07/93	14:26	5	<5	1.8	1.4
9	12/08/93	13:30	10	5	2.6	1.6
9	20/09/93	14:16	15	5	2.1	1.7
9	12/10/93	13:19	<5	<5	1.8	1.9
9	08/11/93	14:29	15	5	2.5	1.1
10	03/06/92	15:27	5	5	1.5	0.5
10	12/08/92	13:20	5	20	0.7	0.7
10	15/09/92	15:20	5	5	3.1	1.6
10	12/10/92	14:10	<5	5	2.8	2.1
10	11/11/92	15:20	5	<5	1.3	1.8
10	14/12/93	14:31	<5	5	2.7	2.3
10	07/01/93	14:42	<5	10	1.8	2.3
10	18/02/93	15:06	<5	<5	1.9	1.0
10	11/03/93	14:47	5	10	2.1	1.4
10	19/04/93	15:31	10	<5	2.4	1.1
10	06/05/93	15:12	5	5	1.4	1.5
10	16/06/93	15:47	<5	<5	1.8	0.9
10	19/07/93	15:53	5	10	1.9	1.2
10	12/08/93	15:00	5	5	1.8	1.6
10	20/09/93	15:39	<5	<5	2.2	1.7
10	12/10/93	14:51	<5	<5	1.2	1.8
10	08/11/93	15:56	10	5	2.5	1.8
11	03/06/92	16:26	5	<5	1.1	0.5
11	12/08/92	14:00	20	<5	2.6	0.7
11	15/09/92	18:10	5	<5	1.8	2.3
11	12/10/92	16:30	<5	5	2.3	1.8
11	11/11/92	17:00	<5	<5	1.0	2.1
11	14/12/93	16:00	10	<5	1.2	1.9
11	07/01/93	16:12	<5	10	1.8	2.2
11	18/02/93	16:39	<5	<5	1.6	1.2
11	11/03/93	16:20	5	5	2.1	1.6
11	19/04/93	17:10	5	10	1.7	1.0
11	06/05/93	17:21	5	<5	1.5	1.3

Table 11 continued: Turbidity and colour results.

Site	Date	Time	Colour (Hazen)		Turbidity (N.T.U)	
			Surface	Bottom	Surface	Bottom
11	16/06/93	17:04	<5	<5	1.3	1.7
11	19/07/93	17:42	<5	5	2.3	1.6
11	12/08/93	16:52	10	10	0.9	2.2
11	20/09/93	17:49	5	5	2.8	2.1
11	12/10/93	17:20	5	<5	1.2	2.5
11	08/11/93	18:05	<5	<5	1.7	1.9

Table 12: Average values by site for physical parameters in water samples.

Site Name	Site Number	pH		Total Suspended Solids (mg/L)	
		Surface	Bottom	Surface	Bottom
Busu River Mouth	1	8.0	7.9	99	86
Bumbu River Mouth	2	7.9	8.2	409	327
Voco Point	3	8.0	8.0	98	101
Lae Main Wharf	4	8.1	8.1	170	149
Landing Bay	5	8.1	8.2	165	161
Markham River Mouth	6	8.0	8.1	429	111
Labu Lakes Entrance	7	8.1	8.1	69	69
Sugar Loaf	8	8.1	8.2	36	32
Halfway Reef	9	8.1	8.2	15	15
Schoolhouse Reef	10	8.2	8.3	9.1	9.2
Narapela Reef	11	8.3	8.3	11	11

Site Name	Site Number	Colour (Hazen)		Turbidity (N.T.U)	
		Surface	Bottom	Surface	Bottom
Busu River Mouth	1	38	23	31	16
Bumbu River Mouth	2	29	19	43	30
Voco Point	3	13	9.4	33	26
Lae Main Wharf	4	37	18	56	52
Landing Bay	5	24	22	55	55
Markham River Mouth	6	23	14	123	29
Labu Lakes Entrance	7	29	26	45	38
Sugar Loaf	8	11	7.7	10	8.9
Halfway Reef	9	6.5	5.6	1.6	1.3
Schoolhouse Reef	10	3.5	5.0	1.9	1.5
Narapela Reef	11	4.4	3.0	1.7	1.7

Table 13: Dissolved and Total Phosphorus Results

Site	Date	Time	Dissolved Phosphorus (µmole/L)		Total Phosphorus (µmole/L)	
			Surface	Bottom	Surface	Bottom
1	03/06/92	06:45	-	-	-	-
1	12/08/92	07:25	<0.2	<0.2	2.6	0.7
1	15/09/92	06:20	0.3	0.2	10.0	8.7
1	12/10/92	06:00	0.2	<0.2	3.9	0.9
1	11/11/92	06:30	<0.2	<0.2	1.3	<0.5
1	14/12/93	06:16	<0.2	<0.2	0.6	<0.5
1	07/01/93	06:29	<0.2	<0.2	0.7	<0.5
1	18/02/93	06:05	0.3	<0.2	9.1	6.3
1	11/03/93	06:15	0.5	0.2	1.4	<0.5
1	19/04/93	06:22	<0.2	<0.2	0.9	<0.5
1	06/05/93	06:00	<0.2	<0.2	1.7	<0.5
1	16/06/93	06:06	0.3	<0.2	1.9	<0.5
1	19/07/93	06:36	<0.2	<0.2	0.6	<0.5
1	12/08/93	06:10	<0.2	<0.2	3.0	0.7
1	20/09/93	06:03	<0.2	0.2	0.5	<0.5
1	12/10/93	06:17	<0.2	<0.2	2.1	0.5
1	08/11/93	06:34	<0.2	<0.2	0.7	<0.5
2	03/06/92	07:30	-	-	-	-
2	12/08/92	08:10	<0.2	<0.2	4.2	1.5
2	15/09/92	07:00	0.4	<0.2	8.7	6.8
2	12/10/92	06:50	<0.2	<0.2	2.9	0.9
2	11/11/92	07:15	0.2	<0.2	1.8	0.9
2	14/12/93	06:58	<0.2	<0.2	2.2	2.4
2	07/01/93	07:04	<0.2	<0.2	4.7	1.9
2	18/02/93	06:47	1.0	<0.2	2.2	0.8
2	11/03/93	06:59	0.4	<0.2	2.2	1.8
2	19/04/93	07:10	0.6	<0.2	1.6	1.1
2	06/05/93	06:52	<0.2	<0.2	3.4	0.3
2	16/06/93	06:53	1.3	<0.2	2.1	0.8
2	19/07/93	07:17	<0.2	<0.2	1.2	0.8
2	12/08/93	07:12	<0.2	<0.2	1.9	1.9
2	20/09/93	06:42	<0.2	<0.2	1.3	0.9
2	12/10/93	06:50	0.5	<0.2	6.3	2.2
2	08/11/93	07:31	0.2	<0.2	2.4	2.7
3	03/06/92	08:00	-	-	-	-
3	12/08/92	08:45	0.3	<0.2	2.0	0.7
3	15/09/92	07:40	0.3	<0.2	3.2	2.7
3	12/10/92	07:20	0.7	0.3	6.3	1.2
3	11/11/92	08:00	<0.2	<0.2	1.0	0.8
3	14/12/93	07:31	0.3	<0.2	2.7	0.6
3	07/01/93	07:36	0.3	<0.2	2.0	1.7
3	18/02/93	07:19	<0.2	<0.2	1.1	0.6
3	11/03/93	07:28	0.2	<0.2	2.9	0.5
3	19/04/93	07:51	0.3	<0.2	3.2	1.1
3	06/05/93	07:23	0.4	0.2	1.6	0.7
3	16/06/93	07:42	0.2	<0.2	1.7	0.6

Table 13 continued: Dissolved and Total Phosphorus Results.

Site	Date	Time	Dissolved Phosphorus (µmole/L)		Total Phosphorus (µmole/L)	
			Surface	Bottom	Surface	Bottom
3	19/07/93	07:34	<0.2	<0.2	2.6	0.9
3	12/08/93	07:40	0.4	<0.2	1.8	1.9
3	20/09/93	07:14	<0.2	<0.2	0.5	0.7
3	12/10/93	07:22	0.4	0.2	2.6	1.3
3	08/11/93	08:04	<0.2	<0.2	3.8	1.2
4	03/06/92	08:40	-	-	-	-
4	12/08/92	09:20	0.3	<0.2	2.1	0.6
4	15/09/92	08:15	0.8	<0.2	5.8	0.9
4	12/10/92	08:00	0.5	<0.2	3.6	0.4
4	11/11/92	09:10	<0.2	<0.2	1.9	0.2
4	14/12/93	08:12	<0.2	<0.2	3.7	0.2
4	07/01/93	08:15	0.3	<0.2	0.9	0.3
4	18/02/93	08:01	<0.2	<0.2	2.8	0.4
4	11/03/93	08:17	0.5	0.2	0.8	0.2
4	19/04/93	08:39	0.3	<0.2	1.2	0.5
4	06/05/93	08:26	<0.2	<0.2	2.6	0.4
4	16/06/93	08:29	0.4	<0.2	3.3	0.4
4	19/07/93	08:09	<0.2	<0.2	2.8	0.5
4	12/08/93	08:42	<0.2	<0.2	2.3	0.6
4	20/09/93	08:34	0.4	<0.2	0.7	0.2
4	12/10/93	08:16	<0.2	0.2	1.2	0.6
4	08/11/93	08:47	<0.2	<0.2	1.6	0.4
5	03/06/92	09:00	-	-	-	-
5	12/08/92	09:46	0.3	0.2	2.7	1.9
5	15/09/92	08:45	0.3	<0.2	4.1	2.4
5	12/10/92	08:20	0.2	<0.2	2.1	2.0
5	11/11/92	09:40	0.2	<0.2	3.8	1.9
5	14/12/93	08:32	0.4	<0.2	2.2	1.5
5	07/01/93	08:41	0.3	<0.2	2.2	1.7
5	18/02/93	08:52	0.4	<0.2	2.7	2.4
5	11/03/93	08:46	0.6	<0.2	2.9	2.7
5	19/04/93	09:06	<0.2	<0.2	1.8	0.9
5	06/05/93	09:17	<0.2	<0.2	3.7	2.9
5	16/06/93	09:09	0.2	<0.2	2.8	1.5
5	19/07/93	08:43	0.4	0.2	1.8	1.7
5	12/08/93	09:12	<0.2	<0.2	2.1	2.1
5	20/09/93	09:31	0.4	0.2	1.7	2.1
5	12/10/93	08:41	0.2	<0.2	1.4	1.7
5	08/11/93	09:26	0.3	<0.2	2.6	2.0
6	03/06/92	09:42	-	-	-	-
6	12/08/92	10:00	0.3	<0.2	6.2	1.0
6	15/09/92	09:10	0.2	0.2	4.2	1.7
6	12/10/92	08:55	<0.2	<0.2	7.2	2.4
6	11/11/92	10:15	<0.2	<0.2	3.6	1.6
6	14/12/93	09:06	0.2	<0.2	4.4	2.4

Table 13 continued: Dissolved and Total Phosphorus Results.

Site	Date	Time	Dissolved Phosphorus (µmole/L)		Total Phosphorus (µmole/L)	
			Surface	Bottom	Surface	Bottom
6	07/01/93	09:12	0.5	0.2	2.1	1.2
6	18/02/93	09:34	<0.2	<0.2	4.5	1.4
6	11/03/93	09:17	0.3	<0.2	4.4	1.9
6	19/04/93	10:02	0.7	0.2	4.5	1.5
6	06/05/93	09:51	<0.2	<0.2	1.7	2.3
6	16/06/93	09:57	0.2	<0.2	5.2	1.5
6	19/07/93	10:06	0.2	<0.2	3.8	1.6
6	12/08/93	09:31	0.4	<0.2	5.5	0.9
6	20/09/93	10:17	0.5	<0.2	5.3	2.4
6	12/10/93	09:14	<0.2	<0.2	4.9	1.5
6	08/11/93	10:03	0.6	0.2	3.0	1.4
7	03/06/92	18:15	-	-	-	-
7	12/08/92	10:20	0.2	<0.2	1.0	0.9
7	15/09/92	09:40	<0.2	<0.2	1.2	<0.5
7	12/10/92	10:00	0.4	<0.2	2.1	0.6
7	11/11/92	10:50	<0.2	<0.2	0.9	<0.5
7	14/12/93	09:49	0.4	<0.2	0.5	<0.5
7	07/01/93	09:56	0.2	<0.2	1.3	0.9
7	18/02/93	10:12	0.6	<0.2	1.3	<0.5
7	11/03/93	10:06	<0.2	<0.2	0.9	<0.5
7	19/04/93	10:41	0.3	<0.2	1.0	<0.5
7	06/05/93	10:30	<0.2	<0.2	1.7	0.6
7	16/06/93	10:46	0.6	<0.2	1.2	<0.5
7	19/07/93	10:59	<0.2	<0.2	0.7	<0.5
7	12/08/93	10:10	0.3	<0.2	1.6	<0.5
7	20/09/93	11:02	0.4	<0.2	1.5	0.8
7	12/10/93	09:47	0.3	<0.2	0.7	0.8
7	08/11/93	10:43	<0.2	<0.2	1.4	1.3
8	03/06/92	13:10	-	-	-	-
8	12/08/92	12:15	<0.2	<0.2	1.3	0.8
8	15/09/92	10:50	<0.2	0.4	4.2	0.7
8	12/10/92	11:10	0.3	<0.2	1.9	1.9
8	11/11/92	11:55	<0.2	<0.2	2.6	0.3
8	14/12/93	10:49	0.3	<0.2	1.3	0.5
8	07/01/93	11:02	1.1	0.2	2.5	0.2
8	18/02/93	11:19	0.5	<0.2	1.8	1.1
8	11/03/93	11:06	<0.2	<0.2	3.1	0.3
8	19/04/93	11:53	0.3	<0.2	2.3	0.6
8	06/05/93	11:42	0.2	<0.2	1.3	1.3
8	16/06/93	12:01	0.9	0.2	1.4	0.9
8	19/07/93	12:10	<0.2	<0.2	2.7	1.1
8	12/08/93	11:21	0.2	<0.2	1.9	0.7
8	20/09/93	12:06	0.7	<0.2	2.3	0.9
8	12/10/93	11:10	0.3	<0.2	2.1	0.1
8	08/11/93	12:17	<0.2	<0.2	2.6	0.3

Table 13 continued: Dissolved and Total Phosphorus Results.

Site	Date	Time	Dissolved Phosphorus (µmole/L)		Total Phosphorus (µmole/L)	
			Surface	Bottom	Surface	Bottom
9	03/06/92	14:30	-	-	-	-
9	12/08/92	15:30	<0.2	<0.2	0.9	0.5
9	15/09/92	13:20	<0.2	<0.2	1.0	<0.5
9	12/10/92	12:45	0.2	<0.2	2.3	1.2
9	11/11/92	13:40	0.2	<0.2	0.5	<0.5
9	14/12/93	12:56	0.2	<0.2	1.5	<0.5
9	07/01/93	13:12	<0.2	<0.2	0.5	<0.5
9	18/02/93	13:31	0.3	<0.2	1.5	<0.5
9	11/03/93	13:09	0.3	<0.2	0.6	<0.5
9	19/04/93	14:06	<0.2	<0.2	0.1	<0.5
9	06/05/93	13:52	0.3	<0.2	1.3	<0.5
9	16/06/93	14:15	0.2	<0.2	1.1	<0.5
9	19/07/93	14:26	0.2	<0.2	0.6	<0.5
9	12/08/93	13:30	<0.2	<0.2	0.6	<0.5
9	20/09/93	14:16	0.3	<0.2	0.8	<0.5
9	12/10/93	13:19	<0.2	<0.2	0.9	<0.5
9	08/11/93	14:29	0.5	<0.2	0.7	<0.5
10	03/06/92	15:27	-	-	-	-
10	12/08/92	13:20	<0.2	<0.2	0.5	<0.5
10	15/09/92	15:20	0.2	<0.2	0.3	<0.5
10	12/10/92	14:10	0.4	<0.2	0.8	<0.5
10	11/11/92	15:20	<0.2	0.2	0.3	0.5
10	14/12/93	14:31	0.2	<0.2	0.4	<0.5
10	07/01/93	14:42	<0.2	<0.2	0.6	<0.5
10	18/02/93	15:06	<0.2	0.2	1.1	0.5
10	11/03/93	14:47	0.2	<0.2	0.9	<0.5
10	19/04/93	15:31	0.3	<0.2	0.9	0.5
10	06/05/93	15:12	0.3	<0.2	1.1	0.6
10	16/06/93	15:47	0.4	0.3	0.5	<0.5
10	19/07/93	15:53	<0.2	0.2	0.7	<0.5
10	12/08/93	15:00	0.4	<0.2	0.6	<0.5
10	20/09/93	15:39	<0.2	<0.2	1.3	<0.5
10	12/10/93	14:51	<0.2	0.3	1.5	0.6
10	08/11/93	15:56	0.3	<0.2	0.6	<0.5
11	03/06/92	16:26	-	-	-	-
11	12/08/92	14:00	<0.2	<0.2	0.7	<0.5
11	15/09/92	18:10	<0.2	<0.2	0.9	0.5
11	12/10/92	16:30	0.2	<0.2	1.8	<0.5
11	11/11/92	17:00	<0.2	<0.2	0.8	<0.5
11	14/12/93	16:00	<0.2	<0.2	0.5	<0.5
11	07/01/93	16:12	<0.2	<0.2	0.5	<0.5
11	18/02/93	16:39	0.3	0.3	1.1	0.5
11	11/03/93	16:20	0.2	<0.2	0.9	<0.5
11	19/04/93	17:10	<0.2	<0.2	0.9	<0.5
11	06/05/93	17:21	<0.2	<0.2	0.3	<0.5

Table 13 continued: Dissolved and Total Phosphorus Results.

Site	Date	Time	Dissolved Phosphorus (µmole/L)		Total Phosphorus (µmole/L)	
			Surface	Bottom	Surface	Bottom
11	16/06/93	17:04	<0.2	0.2	0.3	0.5
11	19/07/93	17:42	<0.2	0.3	0.7	<0.5
11	12/08/93	16:52	0.2	<0.2	1.2	<0.5
11	20/09/93	17:49	<0.2	0.3	1.3	0.5
11	12/10/93	17:20	<0.2	<0.2	0.9	0.6
11	08/11/93	18:05	0.2	0.2	0.6	<0.5

Table 14: Nitrate and Nitrite Results

Site	Date	Time	Nitrate (µmole/L)		Nitrite (µmole/L)	
			Surface	Bottom	Surface	Bottom
1	03/06/92	06:45	-	-	-	-
1	12/08/92	07:25	<0.5	0.7	<0.015	<0.015
1	15/09/92	06:20	4.5	3.6	0.02	0.02
1	12/10/92	06:00	0.8	<0.5	<0.015	<0.015
1	11/11/92	06:30	<0.5	<0.5	<0.015	<0.015
1	14/12/93	06:16	<0.5	<0.5	<0.015	<0.015
1	07/01/93	06:29	<0.5	<0.5	<0.015	<0.015
1	18/02/93	06:05	0.6	<0.5	<0.015	<0.015
1	11/03/93	06:15	<0.5	<0.5	<0.015	<0.015
1	19/04/93	06:22	0.8	<0.5	<0.015	<0.015
1	06/05/93	06:00	<0.5	<0.5	<0.015	<0.015
1	16/06/93	06:06	<0.5	<0.5	<0.015	<0.015
1	19/07/93	06:36	4.1	0.6	<0.015	<0.015
1	12/08/93	06:10	<0.5	<0.5	<0.015	<0.015
1	20/09/93	06:03	<0.5	<0.5	<0.015	<0.015
1	12/10/93	06:17	<0.5	<0.5	<0.015	<0.015
1	08/11/93	06:34	<0.5	<0.5	<0.015	<0.015
2	03/06/92	07:30	-	-	-	-
2	12/08/92	08:10	1.7	1.4	<0.015	<0.015
2	15/09/92	07:00	2.6	3.1	<0.015	0.03
2	12/10/92	06:50	1.2	0.8	<0.015	<0.015
2	11/11/92	07:15	0.8	0.7	<0.015	<0.015
2	14/12/93	06:58	0.6	<0.5	<0.015	<0.015
2	07/01/93	07:04	1.3	0.9	<0.015	<0.015
2	18/02/93	06:47	1.0	0.6	<0.015	<0.015
2	11/03/93	06:59	0.8	<0.5	<0.015	<0.015
2	19/04/93	07:10	1.1	<0.5	<0.015	<0.015
2	06/05/93	06:52	0.5	<0.5	<0.015	<0.015
2	16/06/93	06:53	1.1	<0.5	<0.015	<0.015
2	19/07/93	07:17	1.3	0.6	<0.015	<0.015
2	12/08/93	07:12	0.7	1.5	<0.015	<0.015
2	20/09/93	06:42	1.3	0.6	<0.015	<0.015
2	12/10/93	06:50	0.9	<0.5	<0.015	<0.015
2	08/11/93	07:31	1.3	1.5	<0.015	<0.015
3	03/06/92	08:00	-	-	-	-
3	12/08/92	08:45	4.3	<0.5	0.10	0.02
3	15/09/92	07:40	2.3	<0.5	0.05	0.04
3	12/10/92	07:20	1.9	<0.5	<0.015	<0.015
3	11/11/92	08:00	1.1	<0.5	<0.015	<0.015
3	14/12/93	07:31	2.0	0.5	<0.015	<0.015
3	07/01/93	07:36	1.9	<0.5	0.03	0.02
3	18/02/93	07:19	1.5	<0.5	<0.015	<0.015
3	11/03/93	07:28	1.3	<0.5	0.04	<0.015
3	19/04/93	07:51	0.8	<0.5	0.05	<0.015
3	06/05/93	07:23	1.8	<0.5	<0.015	<0.015
3	16/06/93	07:42	2.1	<0.5	0.02	<0.015

Table 14 continued: Nitrate and Nitrite Results.

Site	Date	Time	Nitrate (µmole/L)		Nitrite (µmole/L)	
			Surface	Bottom	Surface	Bottom
3	19/07/93	07:34	0.4	<0.5	<0.015	<0.015
3	12/08/93	07:40	2.3	0.5	<0.015	<0.015
3	20/09/93	07:14	0.8	<0.5	0.02	<0.015
3	12/10/93	07:22	1.2	<0.5	<0.015	<0.015
3	08/11/93	08:04	2.5	<0.5	<0.015	<0.015
4	03/06/92	08:40	-	-	-	-
4	12/08/92	09:20	3.5	0.9	0.06	0.24
4	15/09/92	08:15	2.9	1.1	0.10	<0.015
4	12/10/92	08:00	4.2	0.3	0.03	0.02
4	11/11/92	09:10	2.6	0.7	<0.015	<0.015
4	14/12/93	08:12	2.4	1.3	<0.015	<0.015
4	07/01/93	08:15	2.6	1.4	0.03	<0.015
4	18/02/93	08:01	1.4	1.4	<0.015	<0.015
4	11/03/93	08:17	1.5	0.6	0.04	<0.015
4	19/04/93	08:39	2.7	0.7	<0.015	<0.015
4	06/05/93	08:26	2.3	0.7	<0.015	<0.015
4	16/06/93	08:29	0.6	0.5	0.10	<0.015
4	19/07/93	08:09	3.6	1.7	<0.015	<0.015
4	12/08/93	08:42	4.3	0.5	<0.015	<0.015
4	20/09/93	08:34	1.1	0.4	<0.015	<0.015
4	12/10/93	08:16	2.1	1.9	<0.015	<0.015
4	08/11/93	08:47	3.2	2.1	<0.015	<0.015
5	03/06/92	09:00	-	-	-	-
5	12/08/92	09:46	2.4	2.0	0.07	0.06
5	15/09/92	08:45	3.7	2.3	0.05	0.05
5	12/10/92	08:20	1.9	0.6	0.10	0.07
5	11/11/92	09:40	4.3	1.4	0.08	0.07
5	14/12/93	08:32	3.2	1.5	0.04	0.08
5	07/01/93	08:41	1.1	0.9	0.02	0.06
5	18/02/93	08:52	1.7	1.4	0.04	<0.015
5	11/03/93	08:46	2.4	1.3	<0.015	0.04
5	19/04/93	09:06	2.8	1.7	0.04	0.09
5	06/05/93	09:17	2.7	1.8	<0.015	<0.015
5	16/06/93	09:09	2.3	1.9	0.03	0.03
5	19/07/93	08:43	2.3	1.6	0.05	0.03
5	12/08/93	09:12	3.4	1.9	0.05	0.04
5	20/09/93	09:31	2.4	1.7	0.07	0.03
5	12/10/93	08:41	2.5	1.9	0.03	<0.015
5	08/11/93	09:26	2.1	1.6	0.07	0.05
6	03/06/92	09:42	-	-	-	-
6	12/08/92	10:00	3.5	<0.5	0.03	0.17
6	15/09/92	09:10	2.8	<0.5	0.05	0.20
6	12/10/92	08:55	4.2	<0.5	<0.015	<0.015
6	11/11/92	10:15	2.4	0.6	<0.015	<0.015
6	14/12/93	09:06	1.2	<0.5	<0.015	<0.015

Table 14 continued: Nitrate and Nitrite Results.

Site	Date	Time	Nitrate (µmole/L)		Nitrite (µmole/L)	
			Surface	Bottom	Surface	Bottom
6	07/01/93	09:12	2.0	<0.5	<0.015	<0.015
6	18/02/93	09:34	0.7	<0.5	<0.015	<0.015
6	11/03/93	09:17	2.5	0.6	0.04	<0.015
6	19/04/93	10:02	1.1	<0.5	<0.015	<0.015
6	06/05/93	09:51	0.7	<0.5	<0.015	<0.015
6	16/06/93	09:57	0.6	<0.5	<0.015	<0.015
6	19/07/93	10:06	0.9	<0.5	0.05	<0.015
6	12/08/93	09:31	1.1	0.5	<0.015	<0.015
6	20/09/93	10:17	0.8	<0.5	<0.015	<0.015
6	12/10/93	09:14	0.8	<0.5	<0.015	<0.015
6	08/11/93	10:03	1.3	<0.5	<0.015	<0.015
7	03/06/92	18:15	-	-	-	-
7	12/08/92	10:20	2.6	8.4	<0.015	2.0
7	15/09/92	09:40	1.9	1.0	<0.015	<0.015
7	12/10/92	10:00	2.9	0.7	<0.015	0.1
7	11/11/92	10:50	0.5	1.4	<0.015	<0.015
7	14/12/93	09:49	2.2	1.8	<0.015	<0.015
7	07/01/93	09:56	1.4	1.1	<0.015	<0.015
7	18/02/93	10:12	0.7	1.5	<0.015	<0.015
7	11/03/93	10:06	1.9	1.3	<0.015	<0.015
7	19/04/93	10:41	2.5	1.4	<0.015	<0.015
7	06/05/93	10:30	2.1	1.2	<0.015	<0.015
7	16/06/93	10:46	2.2	1.0	<0.015	<0.015
7	19/07/93	10:59	1.7	1.1	<0.015	<0.015
7	12/08/93	10:10	1.6	1.2	<0.015	<0.015
7	20/09/93	11:02	2.5	1.7	<0.015	<0.015
7	12/10/93	09:47	1.9	0.5	<0.015	<0.015
7	08/11/93	10:43	1.6	1.2	<0.015	<0.015
8	03/06/92	13:10	-	-	-	-
8	12/08/92	12:15	1.6	<0.5	<0.015	<0.015
8	15/09/92	10:50	1.0	<0.5	<0.015	<0.015
8	12/10/92	11:10	2.1	<0.5	<0.015	<0.015
8	11/11/92	11:55	0.9	0.5	<0.015	<0.015
8	14/12/93	10:49	0.4	<0.5	<0.015	<0.015
8	07/01/93	11:02	1.4	0.6	<0.015	<0.015
8	18/02/93	11:19	1.9	0.5	<0.015	<0.015
8	11/03/93	11:06	0.6	<0.5	<0.015	<0.015
8	19/04/93	11:53	1.1	<0.5	<0.015	<0.015
8	06/05/93	11:42	1.1	0.6	<0.015	<0.015
8	16/06/93	12:01	0.9	<0.5	<0.015	<0.015
8	19/07/93	12:10	0.3	<0.5	<0.015	<0.015
8	12/08/93	11:21	0.4	<0.5	<0.015	<0.015
8	20/09/93	12:06	1.4	<0.5	<0.015	<0.015
8	12/10/93	11:10	1.6	0.5	<0.015	<0.015
8	08/11/93	12:17	1.5	<0.5	<0.015	<0.015

Table 14 continued: Nitrate and Nitrite Results.

Site	Date	Time	Nitrate (µmole/L)		Nitrite (µmole/L)	
			Surface	Bottom	Surface	Bottom
9	03/06/92	14:30	-	-	-	-
9	12/08/92	15:30	<0.5	<0.5	<0.015	<0.015
9	15/09/92	13:20	<0.5	<0.5	<0.015	<0.015
9	12/10/92	12:45	0.5	<0.5	<0.015	<0.015
9	11/11/92	13:40	<0.5	<0.5	<0.015	<0.015
9	14/12/93	12:56	<0.5	<0.5	<0.015	<0.015
9	07/01/93	13:12	<0.5	<0.5	<0.015	<0.015
9	18/02/93	13:31	<0.5	<0.5	<0.015	<0.015
9	11/03/93	13:09	<0.5	<0.5	<0.015	<0.015
9	19/04/93	14:06	<0.5	<0.5	<0.015	<0.015
9	06/05/93	13:52	<0.5	<0.5	<0.015	<0.015
9	16/06/93	14:15	<0.5	<0.5	<0.015	<0.015
9	19/07/93	14:26	<0.5	<0.5	<0.015	<0.015
9	12/08/93	13:30	<0.5	<0.5	<0.015	<0.015
9	20/09/93	14:16	<0.5	<0.5	<0.015	<0.015
9	12/10/93	13:19	<0.5	<0.5	<0.015	<0.015
9	08/11/93	14:29	<0.5	<0.5	<0.015	<0.015
10	03/06/92	15:27	-	-	-	-
10	12/08/92	13:20	2.2	<0.5	<0.015	<0.015
10	15/09/92	15:20	1.2	<0.5	<0.015	<0.015
10	12/10/92	14:10	3.1	<0.5	<0.015	<0.015
10	11/11/92	15:20	2.1	0.5	<0.015	<0.015
10	14/12/93	14:31	2.1	<0.5	<0.015	<0.015
10	07/01/93	14:42	2.4	<0.5	<0.015	<0.015
10	18/02/93	15:06	2.8	0.6	<0.015	<0.015
10	11/03/93	14:47	2.1	<0.5	<0.015	<0.015
10	19/04/93	15:31	1.4	<0.5	<0.015	<0.015
10	06/05/93	15:12	2.9	0.5	<0.015	<0.015
10	16/06/93	15:47	1.6	<0.5	<0.015	<0.015
10	19/07/93	15:53	2.8	<0.5	<0.015	<0.015
10	12/08/93	15:00	1.8	<0.5	<0.015	<0.015
10	20/09/93	15:39	2.4	<0.5	<0.015	<0.015
10	12/10/93	14:51	1.3	<0.5	<0.015	<0.015
10	08/11/93	15:56	2.7	0.5	<0.015	<0.015
11	03/06/92	16:26	-	-	-	-
11	12/08/92	14:00	<0.5	<0.5	<0.015	<0.015
11	15/09/92	18:10	<0.5	<0.5	<0.015	<0.015
11	12/10/92	16:30	<0.5	<0.5	<0.015	<0.015
11	11/11/92	17:00	0.5	<0.5	<0.015	<0.015
11	14/12/93	16:00	<0.5	<0.5	<0.015	<0.015
11	07/01/93	16:12	<0.5	<0.5	<0.015	<0.015
11	18/02/93	16:39	<0.5	<0.5	<0.015	<0.015
11	11/03/93	16:20	0.5	<0.5	<0.015	<0.015
11	19/04/93	17:10	<0.5	<0.5	<0.015	<0.015
11	06/05/93	17:21	<0.5	<0.5	<0.015	<0.015

Table 14 continued: Nitrate and Nitrite Results.

Site	Date	Time	Nitrate (µmole/L)		Nitrite (µmole/L)	
			Surface	Bottom	Surface	Bottom
11	16/06/93	17:04	<0.5	<0.5	<0.015	<0.015
11	19/07/93	17:42	<0.5	<0.5	<0.015	<0.015
11	12/08/93	16:52	<0.5	0.5	<0.015	<0.015
11	20/09/93	17:49	<0.5	<0.5	<0.015	<0.015
11	12/10/93	17:20	0.6	<0.5	<0.015	<0.015
11	08/11/93	18:05	<0.5	<0.5	<0.015	<0.015

Table 15: Average values by site for chemical parameters in water samples.

Site Name	Site Number	Dissolved Phosphorus (µmole/L)		Total Phosphorus (µmole/L)	
		Surface	Bottom	Surface	Bottom
Busu River Mouth	1	0.3	0.2	2.6	3.0
Bumbu River Mouth	2	0.6	0.0	3.1	1.7
Voco Point	3	0.3	0.2	2.4	1.1
Lae Main Wharf	4	0.4	0.2	2.3	0.42
Landing Bay	5	0.3	0.2	2.5	2.0
Markham River Mouth	6	0.4	0.2	4.4	1.7
Labu Lakes Entrance	7	0.4	0.0	1.2	0.8
Sugar Loaf	8	0.5	0.3	2.2	0.7
Halfway Reef	9	0.3	0.0	0.9	0.8
Schoolhouse Reef	10	0.3	0.3	0.8	0.5
Narapela Reef	11	0.2	0.3	0.8	0.5

Site Name	Site Number	Nitrate (µmole/L)		Nitrite (µmole/L)	
		Surface	Bottom	Surface	Bottom
Busu River Mouth	1	2.2	1.6	<0.015	<0.015
Bumbu River Mouth	2	1.1	1.2	<0.015	<0.015
Voco Point	3	1.8	0.5	<0.015	<0.015
Lae Main Wharf	4	2.6	1.0	0.1	0.1
Landing Bay	5	2.6	1.6	0.1	0.1
Markham River Mouth	6	1.7	0.6	<0.015	0.2
Labu Lakes Entrance	7	1.9	1.7	<0.015	1.1
Sugar Loaf	8	1.1	0.5	<0.015	<0.015
Halfway Reef	9	0.5	0.0	<0.015	<0.015
Schoolhouse Reef	10	2.2	0.5	<0.015	<0.015
Narapela Reef	11	0.5	0.5	<0.015	<0.015

Table 16: Results for Sediment Metal Analysis.

Site	Date	Time	µg/g dry weight			
			Cadmium	Copper	Lead	Zinc
1	03/06/92	06:45	0.9	56	27	71
1	15/09/92	06:20	2.1	71	19	53
1	11/11/92	06:30	1.1	63	23	94
1	14/12/92	06:16	2.3	39	14	81
1	07/01/93	06:29	2.2	67	18	77
1	18/02/93	06:05	1.1	62	22	103
1	11/03/93	06:15	1.9	57	24	87
1	19/04/93	06:22	1.3	66	30	75
1	06/05/93	06:00	1.5	71	14	101
1	16/06/93	06:06	0.7	57	17	89
1	19/07/93	06:36	1.9	56	23	86
1	12/08/93	06:10	2.1	63	14	59
1	20/09/93	06:03	1.8	46	23	83
1	12/10/93	06:17	0.9	59	12	98
1	08/11/93	06:34	2.2	68	18	78
2	03/06/92	07:30	0.4	91	120	290
2	15/09/92	07:00	1.1	54	190	180
2	11/11/92	07:15	0.9	78	150	210
2	14/12/92	06:16	1.3	44	28	125
2	07/01/93	06:29	1.0	93	73	104
2	18/02/93	06:05	1.5	72	15	72
2	11/03/93	06:15	1.2	85	118	167
2	19/04/93	06:22	<0.05	86	63	91
2	06/05/93	06:00	1.2	76	57	103
2	16/06/93	06:06	0.5	90	46	192
2	19/07/93	06:36	1.1	82	105	155
2	12/08/93	06:10	0.7	94	109	127
2	20/09/93	06:03	0.9	74	78	134
2	12/10/93	06:17	0.8	51	87	95
2	08/11/93	06:34	1.1	96	42	108
3	03/06/92	08:00	0.6	62	220	95
3	15/09/92	07:40	0.9	48	370	210
3	11/11/92	08:00	1.7	71	180	150
3	14/12/92	06:16	1.3	59	24	83
3	07/01/93	06:29	0.8	86	120	54
3	18/02/93	06:05	1.0	48	91	85
3	11/03/93	06:15	1.6	94	152	24
3	19/04/93	06:22	1.7	76	30	32
3	06/05/93	06:00	0.5	63	85	102
3	16/06/93	06:06	0.9	30	52	46
3	19/07/93	06:36	2.1	96	92	151
3	12/08/93	06:10	0.4	55	43	96
3	20/09/93	06:03	1.1	86	57	95
3	12/10/93	06:17	0.7	53	112	67
3	08/11/93	06:34	1.1	92	83	72

Table 16 continued: Results for Sediment Metal Analysis.

Site	Date	Time	µg/g dry weight			
			Cadmium	Copper	Lead	Zinc
4	03/06/92	08:40	2.8	87	320	400
4	15/09/92	08:15	2.1	230	230	290
4	11/11/92	09:10	3.7	150	360	520
4	14/12/92	06:16	2.5	53	80	66
4	07/01/93	06:29	2.2	82	184	192
4	18/02/93	06:05	1.9	113	116	209
4	11/03/93	06:15	1.6	61	60	86
4	19/04/93	06:22	2.5	82	37	166
4	06/05/93	06:00	2.2	78	77	231
4	16/06/93	06:06	2.4	72	156	212
4	19/07/93	06:36	1.2	49	32	97
4	12/08/93	06:10	2.6	53	29	139
4	20/09/93	06:03	2.3	93	134	112
4	12/10/93	06:17	1.7	103	93	74
4	08/11/93	06:34	2.2	97	35	173
5	03/06/92	09:00	3.1	125	200	310
5	15/09/92	08:45	1.9	96	190	220
5	11/11/92	09:40	2.6	140	270	245
5	14/12/92	06:16	1.7	89	157	127
5	07/01/93	06:29	1.9	43	108	137
5	18/02/93	06:05	1.1	140	60	179
5	11/03/93	06:15	1.5	78	125	131
5	19/04/93	06:22	2.6	139	92	36
5	06/05/93	06:00	1.9	23	47	165
5	16/06/93	06:06	2.1	52	52	114
5	19/07/93	06:36	2.3	18	50	130
5	12/08/93	06:10	2.8	82	81	112
5	20/09/93	06:03	1.4	62	57	139
5	12/10/93	06:17	2.8	94	108	87
5	08/11/93	06:34	1.6	27	54	130
6	03/06/92	09:42	0.6	44	14	100
6	15/09/92	09:10	1.2	78	7	89
6	11/11/92	10:15	2.9	59	21	140
6	14/12/92	06:16	0.7	68	36	33
6	07/01/93	06:29	0.5	75	52	155
6	18/02/93	06:05	0.5	96	44	113
6	11/03/93	06:15	0.2	62	38	126
6	19/04/93	06:22	1.3	75	45	135
6	06/05/93	06:00	0.4	55	30	132
6	16/06/93	06:06	0.9	103	21	104
6	19/07/93	06:36	0.7	98	11	77
6	12/08/93	06:10	0.2	58	18	127
6	20/09/93	06:03	0.7	83	41	147
6	12/10/93	06:17	1.5	92	33	107
6	08/11/93	06:34	0.5	77	53	57

Table 16 continued: Results for Sediment Metal Analysis.

Site	Date	Time	µg/g dry weight			
			Cadmium	Copper	Lead	Zinc
7	03/06/92	18:15	0.5	82	7	53
7	15/09/92	09:40	2.1	71	9	91
7	11/11/92	10:50	1.1	95	17	72
7	14/12/92	06:16	0.5	61	13	99
7	07/01/93	06:29	0.3	71	29	133
7	18/02/93	06:05	1.1	49	39	103
7	11/03/93	06:15	1.4	54	24	109
7	19/04/93	06:22	0.5	96	11	114
7	06/05/93	06:00	0.6	91	14	149
7	16/06/93	06:06	0.5	58	14	61
7	19/07/93	06:36	0.2	71	37	79
7	12/08/93	06:10	0.2	34	12	140
7	20/09/93	06:03	1.0	86	41	66
7	12/10/93	06:17	0.2	29	28	104
7	08/11/93	06:34	0.4	81	33	162
8	03/06/92	13:10	1.9	51	12	78
8	15/09/92	10:50	0.5	93	9	100
8	11/11/92	11:55	1.3	72	10	51
8	14/12/92	06:16	0.4	58	26	35
8	07/01/93	06:29	0.7	24	18	29
8	18/02/93	06:05	0.2	18	28	36
8	11/03/93	06:15	0.7	22	10	21
8	19/04/93	06:22	<0.05	41	7	28
8	06/05/93	06:00	0.4	20	18	34
8	16/06/93	06:06	0.5	78	4	17
8	19/07/93	06:36	<0.05	32	13	42
8	12/08/93	06:10	0.8	57	15	15
8	20/09/93	06:03	<0.05	34	11	32
8	12/10/93	06:17	0.2	44	30	25
8	08/11/93	06:34	0.1	16	21	47
9	03/06/92	14:30	<0.05	1.7	<0.05	17
9	15/09/92	13:20	<0.05	0.6	<0.05	22
9	11/11/92	13:40	<0.05	2.1	0.2	36
9	14/12/92	06:16	<0.05	0.3	<0.05	7
9	07/01/93	06:29	<0.05	2.1	<0.05	14
9	18/02/93	06:05	<0.05	2.1	0.3	15
9	11/03/93	06:15	<0.05	1.7	<0.05	20
9	19/04/93	06:22	<0.05	1.5	0.4	6
9	06/05/93	06:00	<0.05	0.2	<0.05	19
9	16/06/93	06:06	<0.05	0.2	0.3	12
9	19/07/93	06:36	<0.05	1.7	0.1	18
9	12/08/93	06:10	<0.05	0.2	0.1	25
9	20/09/93	06:03	<0.05	1.0	<0.05	11
9	12/10/93	06:17	<0.05	0.2	0.1	4
9	08/11/93	06:34	<0.05	0.3	<0.05	7

Table 16 continued: Results for Sediment Metal Analysis.

Site	Date	Time	µg/g dry weight			
			Cadmium	Copper	Lead	Zinc
10	03/06/92	15:27	<0.05	0.9	<0.05	22
10	15/09/92	15:20	<0.05	1.5	0.1	38
10	11/11/92	15:20	<0.05	1.1	<0.05	16
10	14/12/92	06:16	<0.05	0.9	<0.05	8
10	07/01/93	06:29	<0.05	0.4	<0.05	22
10	18/02/93	06:05	<0.05	0.6	<0.05	12
10	11/03/93	06:15	<0.05	<0.1	<0.05	2
10	19/04/93	06:22	<0.05	0.7	0.1	5
10	06/05/93	06:00	<0.05	<0.1	<0.05	20
10	16/06/93	06:06	<0.05	0.2	<0.05	4
10	19/07/93	06:36	<0.05	1.4	<0.05	10
10	12/08/93	06:10	<0.05	0.4	<0.05	16
10	20/09/93	06:03	<0.05	0.6	0.1	11
10	12/10/93	06:17	<0.05	0.3	<0.05	8
10	08/11/93	06:34	<0.05	<0.1	<0.05	14
11	03/06/92	16:26	<0.05	0.5	<0.05	41
11	15/09/92	18:10	<0.05	0.9	<0.05	26
11	11/11/92	17:00	<0.05	1.1	<0.05	30
11	14/12/92	06:16	<0.05	0.8	<0.05	7
11	07/01/93	06:29	<0.05	0.3	<0.05	11
11	18/02/93	06:05	<0.05	0.2	<0.05	15
11	11/03/93	06:15	<0.05	<0.1	0.1	6
11	19/04/93	06:22	<0.05	0.5	<0.05	13
11	06/05/93	06:00	<0.05	0.5	<0.05	6
11	16/06/93	06:06	<0.05	0.2	<0.05	18
11	19/07/93	06:36	<0.05	<0.1	<0.05	4
11	12/08/93	06:10	<0.05	<0.1	<0.05	9
11	20/09/93	06:03	0.1	0.6	0.1	12
11	12/10/93	06:17	<0.05	0.2	<0.05	9
11	08/11/93	06:34	<0.05	<0.1	<0.05	4

Table 17: Average values by site for sediment metal results.

Site Name	Site Number	µg/g dry weight			
		Cadmium	Copper	Lead	Zinc
Busu River Mouth	1	1.6	60.1	19.9	82.3
Bumbu River Mouth	2	0.9	77.0	85.3	143.6
Voco Point	3	1.1	67.9	114.0	90.7
Lae Main Wharf	4	2.3	93.5	129.5	197.8
Landing Bay	5	2.1	80.5	110.1	150.7
Markham River Mouth	6	0.8	74.9	30.8	109.5
Labu Lakes Entrance	7	0.7	68.7	21.9	102.4
Sugar Loaf	8	0.6	44.0	15.5	39.3
Halfway Reef	9	<0.05	<0.05	<0.05	<0.05
Schoolhouse Reef	10	<0.05	<0.05	<0.05	<0.05
Narapela Reef	11	0.1	0.5	0.1	14.0

The Development and Application of Analytical Methods for the Evaluation of Tributyltin in Papua New Guinea Marine Waters

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ABSTRACT

Tributyltin (TBT) is an active ingredient incorporated in some antifouling paint formulations to protect boat and ship hulls from aquatic fouling organisms. TBT has been reported to cause sub-acute toxic effects on non-target organisms such as shellfish (oysters, mussels etc). Some larvae and zocal forms of bivalves, gastropods and crustaceans suffer from a minimum concentration of 0.1 µg/L TBT. Bans and regulations on the use of this pollutant has been imposed in countries like; Canada, USA, parts of Europe and Australia. However, TBT based antifouling paints are still being used in PNG and some other Pacific Island countries.

The South Pacific Regional Environmental Programme (SPREP) in view of the actions taken by western countries is particularly interested in monitoring this pollutant in the waters of the South Pacific. Shellfish form part of the diet of most island and coastal communities of the region. This pollutant poses detrimental effects on these communities as well as possible future commercial exploitation of these resources.

A suitable analytical method is rapid, with a detection limit low enough to detect TBT concentrations as low as 0.1µg/L using instruments currently available in the South Pacific. Analytical methods using a wide range of instrumental techniques have been reported in the literature for different matrices such as sea-water, sediments and shellfish tissue. The methodology to be developed will involve sampling and storage techniques through to the analysis of the samples.

This paper will present an overview of the literature survey and report on preliminary work carried out using Graphite Furnace AAS.

INTRODUCTION

Organotin compounds have a wide use in agriculture and industry; as pesticides and biocides, stabilizers in poly(vinylchloride) (PVC), catalysts in polyurethane foam synthesis and silicon rubbers. Triorganotins general formula R_3SnX, particularly tributyltin (TBT) compounds, are employed as wood and stone preservation fungicides, in disinfectants and in antifouling paint formulations.

Fouling is a major concern world-wide for many shipping companies, boat owners, the navy and fishing fleets. Fouling of ship hulls by slime forming bacteria, fungi and barnacles leads to economic losses due to accelerated corrosion and greater fuel consumption to maintain the same speed, as these organisms growing on the hull, slow down the vessel. [1,2,3,4]

The use of TBT based antifouling paints on ship hulls and marine installations took precedence over copper based paints mainly due to; it's broad spectrum of toxicity, non corrosiveness when applied to conductive substrates, it's low solubility, which makes it ideal for slow release of the toxicant into the water surrounding the hull, and its effectiveness over a longer period of time. Tributyltin oxide, tributyltin fluoride and triphenyltin fluoride are three typical additives added to these formulations with solubilities of 8-10 ppm, 6 ppm and 1 ppm respectively with a half life of about 20 days in sea water under normal sunlight conditions.[4] In sediments however it has a half life of 1.85 to 4 years.[5]

Degradation to its less toxic form is mainly by ultraviolet radiation, micro organisms and weak acids through step wise de-butylation eventually to inorganic tin which is the least toxic. [1]

$$(C_4H_9)_3\,Sn\,X \longrightarrow (C_4H_9)_2Sn\,X_2 \longrightarrow C_4H_9Sn\,X_3 \longrightarrow SnX_4 \quad (1.0)$$

Equation 1.0 Step wise removal of a butyl group to Sn^{4+}

BIOLOGICAL IMPLICATIONS

The broad spectrum of toxicity of TBT has caused some sub-acute toxic effects on some non-target aquatic organisms. As mentioned above, TBT is not very soluble, and therefore tends to adsorb on particulates and sediments. Bivalves and gastropods, being filter feeders are mostly affected. From as low as 0.05 - 1.0 µg/L TBT has been found to kill many larvae and zoeal forms of shellfish and cause growth reduction, reduced reproduction and shell malformation to the adult species. This has led to a lot of western countries eg; Canada, the UK, USA, France

and Australia imposing bans and proposed regulations regarding the use of TBT based antifouling paints.[6,7,8,9,10] TBT based antifouling paints are still being used in PNG and other countries of the South Pacific. In view of the actions taken by these western countries, the South Pacific Regional Environmental Programme (SPREP) is concerned with this substance still being used in the region.

MARINE POLLUTION MONITORING BY SPREP

The South Pacific Regional Environmental Programme is an overall framework for regional corporation on environmental issues. At the SPREP convention in Noumea in 1986, marine pollution was identified as the major problem affecting the quality of the oceans and coastal areas of the South Pacific. SPREP's priority marine pollution problems include: destruction of coastal ecosystems, lowering of water quality, changing ocean processes and properties and climatic change and sea-level rise. The SPREP action plan requested the development and implementation of pollution control measures by all countries of the region. The work presented in this paper will contribute towards monitoring and research in the first two problem areas; ie, destruction of coastal ecosystems and lowering of water quality.[11]

Shellfish form part of the diet of most of the island and coastal communities of the region as well as having economic value. Shellfish farming is an industry of its own in some western countries. PNG as well as the South Pacific has a potential to develop this industry as the regions resources are vast. TBT poses a detrimental threat to our coastal communities as well as the future commercial exploitation of our resources. In order to evaluate the possible environmental effect of TBT, a reliable analytical method is needed.

ANALYTICAL METHODS

Several analytical methods which have been applied to different environmental matrices have been reported in literature. Hydride generation atomic absorption spectrophotometry (HG-AAS) is one such method. It has been used for the determination of total tin and organotins in sea water and estuarine waters[12,13]. Graphite furnace atomic absorption spectrophotometry (GFAAS) is another method used to analyse TBT in coastal sediments and mussel tissue[14]. High performance liquid chromatography was used to speciate the organotins and subsequent detection by coupling a graphite furnace atomic absorption spectrophotometer (HPLC-AAS) for sea water[15]. High performance liquid chromatography was also used with reverse-pulse amperometric detection of organotins in sea water[16]. An electrochemical method anodic stripping voltametry (ASV) has been used to analyse TBT in natural waters including sea-water[17,18,19].

Gas chromatography is another separation technique and it has been reported to provide good separation of organotins in various matrices. Gas chromatography coupled with ion trap spectrometry (GC-ITS) has also been reported for the analysis of natural waters and sediments[20,21] and gas chromatography flame photometric detection (GC-FPD)was also reported to be used for sea water[22,23] . Trace metals in sea water can be analysed using inductively coupled plasma and related techniques[24], and this method could also be applied for tin.

HYDRIDE GENERATION - AAS

The method involves the generation of volatile tin hydrides in a reaction by the addition of sodium tetrahydroborate. The hydrides are purged from solution with helium gas and trapped on a "U" tube or chromatographic column kept at liquid nitrogen temperature. The butyltin hydrides are speciated by removing the liquid nitrogen and heating the column or "U" tube. They come off according to their boiling points, and are detected by AAS employing a quartz furnace.[12,13]

The advantages of this method are that, the hydride generation step is simple and the added step of a chromatographic column aids the speciation of the organotins. The disadvantages are that, liquid nitrogen would be a very expensive necessity and that the "U" tube is not available commercially and would need to be packed manually.

SOLVENT EXTRACTION / GRAPHITE FURNACE - AAS

This is a solvent extraction method with spectrophotometric detection. The solvent extraction step enables direct determination of TBT using graphite furnace AAS. The method involves, the extraction of the organotins into an appropriate organic solvent followed by back extraction into an aqueous nitric acid solution and the TBT is determined by graphite furnace AAS as inorganic tin. [25]

The organotins from the sample are extracted with n-hexane. The organic extract is then washed with sodium hydroxide to eliminate interfering di-butyl and mono-butyl species by forming precipitates removable by centrifugation. The organotins in the organic phase are back extracted into nitric acid, the organic phase evaporated and the TBT in the nitric acid phase determined by graphite furnace AAS. Instrumental parameters are that of elemental tin.[14]

The advantages of this method are that; the instrument is available in PNG and several other countries of the region, solvent extraction is selective for TBT which enables only TBT to be determined relatively quickly and interference with the less toxic species of mono- and di-

butyltin is eliminated with a sodium hydroxide wash. The disadvantages however are that; the extraction and preconcentration procedure is quite lengthy and increases the possibility of contamination due to the many steps involved. Graphite tubes and argon gas are also expensive and that matrix and spectral interferences can cause problems.

HIGH PERFORMANCE LIQUID CHROMATOGRAPHY - AAS

This is a speciation technique which involves the separation of the organotins by high performance liquid chromatography, followed by determination of the respective eluents by graphite furnace AAS.
The sample is injected into the HPLC system and separation is effected with the aid of an appropriate stationary phase (ie. column). By interfacing the HPLC system with a graphite furnace very low (pg or ng) levels could be determined. This method has been applied for sea-water matrices.[15]

The advantages of this method would be that; both pieces of instruments are available in the region, the use of gradient elution enables better separation of the organotin species and that one has a greater control of the flow rate. The disadvantages of this method would be that the operation of a graphite furnace AA is again relatively expensive.

ANODIC STRIPPING VOLTAMETRY (ASV)

ASV is an electrochemical method for direct TBT determination. The analyte is electrodeposited at a mercury drop electrode, then anodically stripping or re-oxidising it to produce a current proportional to the analyte concentration.[26] This method has been used to analyse TBT in natural and sea-waters.[17,18,19]

The advantages of this method would be that the instrument is available in PNG and several other countries of the region. Contamination during sample handling would be reduced, as it would also require less sample handling and manipulation by the analyst. The disadvantage however, is that it is difficult for speciation and quantitation as there are double peak overlaps possibly due to the presence of di-butyltin (DBT) and mono-butyltin (MBT).

OTHER METHODS

Other methods reported in literature not discussed include; high performance liquid chromatography with reverse-pulse amperometric detection, gas chromatography mass spectrometry (GC-MS), inductively coupled plasma mass spectrometry (ICP-MS), gas chromatography

flame photometric detection (GC-FPD) and gas chromatography ion trap spectrometry (GC-ITS).

These are speciation methods with very low detection limits. However, they also involve very expensive instrumentation which are currently not available in the South Pacific.

PRELIMINARY RESULTS FOR SOLVENT EXTRACTION/GRAPHITE FURNACE - AAS

Experimentation

Some preliminary work has been done using the Graphite Furnace - AAS technique. This method was adopted from Cardellichio *et.al.*[14]

Principle

The procedure involves the extraction of the organotins into n-hexane followed by washing the extract with sodium hydroxide before back extracting into nitric acid. The sodium hydroxide wash eliminates the interfering species of mono- and di-butyltin. The organic phase is evaporated and the aqueous phase made up to volume before analysis. Instrumental parameters are that of inorganic tin as organotins are converted to inorganic tin when back extracted with nitric acid. Analytical wavelength is set at 235.5 nm with a slit width of 0.5nm.

Experimentation

Solvent extraction enables the direct determination of TBT using graphite furnace - AAS detection. The organic solvent (n-hexane) being non-polar is very selective of TBT. The more polar mono- and di-butyltin passes into the aqueous layer. To eliminate the possibility of dibutyltin adhering to the TBT (dibutyltin is slightly more non polar than mono-butyltin), the organic extract is washed with dilute sodium hydroxide. The degradation products form precipitates with sodium hydroxide which are removable by centrifugation.

Standards were prepared fresh from 1000 ppm Sn as standards stored in ordinary polyethylene bottles were found to be unstable upon storage. A smooth curve was observed for calibrations up to 150 ppb as the high standard. Maximum absorbance values are 0.3 and 0.7 for 50 ppb and 150 ppb respectively. A typical calibration for 150 µg/L Sn is shown is figure 1.0.

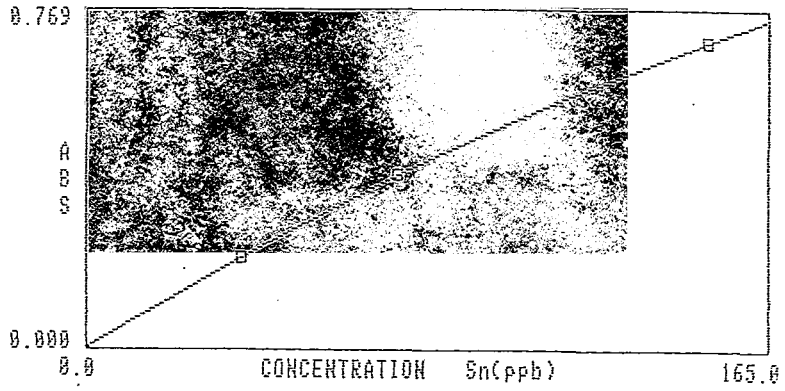

Figure 1. Typical calibration graph for Aqueous 150 µg/L Sn with no chemical modifier.

To test whether inorganic tin passes through the extraction step, a sample of 50 ppb Sn was taken through the extraction process along with ultra-pure water as blank. Absorbance readings obtained for the tin extracts were the same as blank extracts as seen in figure 2.

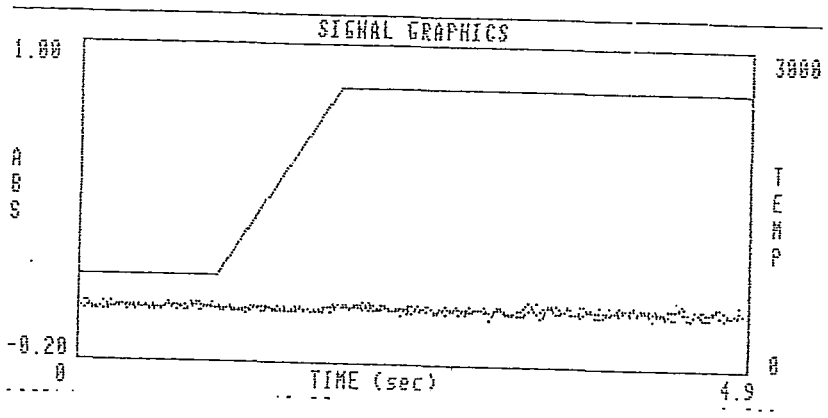

Figure 2*a* Atomisation profile for 0 ppb Sn (Ultra-pure water in 0.5% HNO_3)

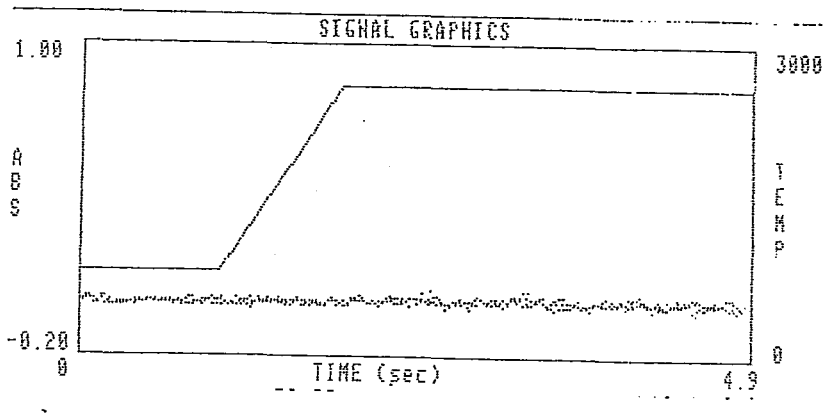

Figure *b* Atomisation profile for 10 mls of 50 ppb taken through the extraction step.

Sodium chloride was found to interfere with the tin atomisation peak. The addition of HCl releases the TBT adsorbed onto particulates in the water before extraction into the organic phase. Sodium hydroxide is added to eliminate the mono- and the di-butyltin species and sodium chloride may form as a result. This may interfere with the tin atomisation peak as can be seen in figure 3a and 3b where the atomisation peak of sodium chloride is very similar to that of tin.

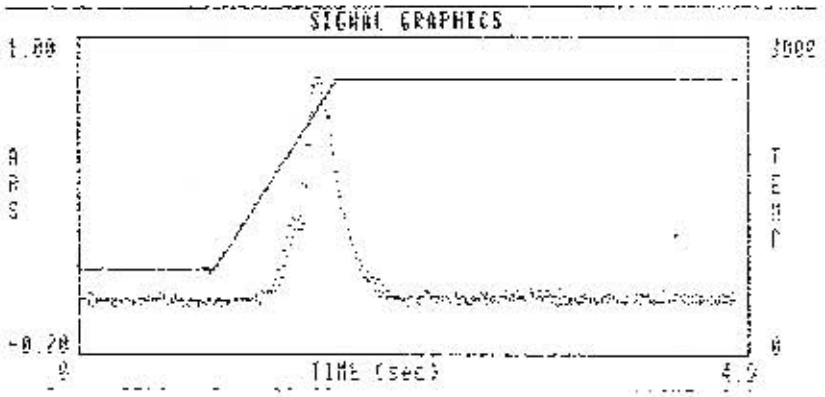

Figure *3a* Atomisation peak for 150 ppb Sn

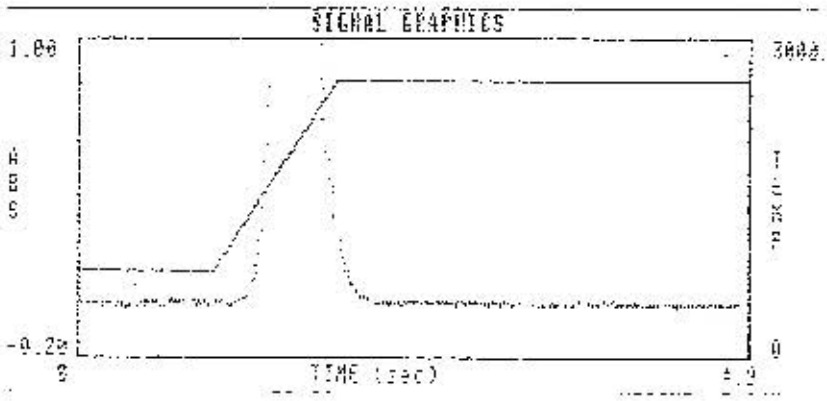

Figure *3b* Atomisation peak of 0.1 % NaCl.

This problem was improved by washing the organic extract three times with sodium hydroxide to remove most of the chloride into the aqueous phase and discarded. Atomisation peaks of the blank extracts with the HCl digest step omitted were very similar to the peaks of extracts with the sodium hydroxide wash step omitted. Hence, the conclusion would be that sodium chloride is formed on the addition of reagents and when washed three times with excess sodium hydroxide, there is no atomisation peak and a fairly straight baseline is observed. Therefore inorganic tin does not pass through the extraction process, and whatever Sn reading obtained will be that of TBT.

Several other methods mentioned earlier will be investigated and the method with the best sensitivity and detection limit will be chosen for routine laboratory analysis. The final results will also be shared with SPREP to assist in their pollution monitoring programme.

REFERENCES

1. Craig, P.J., (1986), Organometallic compounds in the environment- Principles and Reactions, John Wiley & Sons, New York.

2. Monaghan, C.P., Kulkarni, V.H. and Good, M. I., (1978), Release Mechanisms of Organotin Toxicants from Coating Surfaces: A Leaching Model for Antifouling Coatings, in, Organometals and Organometalloids - Occurrence and Fate in the Environment, Brinckman, F.E. & Bellama, J.M., eds., ACS Symposium Series, American Chemical Society, USA.

3. Evans, C.J. and Karpel, S., (1985), Organotin compounds in Modern Technology, Journal of Organometallic Chemistry , Library 16, Elsevier Science Publishers, Amsterdam, The Netherlands.

4. Zuckerman, J.J., Reisdorf, R.P., Ellis III, H.V. and Wilkinson, R.R., (1978), Organotins in Biology and the Environment, in, Organometals and Organometalloids - Occurrence and Fate in the Environment, Brinckman, F.E. & Bellama, eds., ACS Symposium Series, American Chemical Society, USA.

5. Kilby, G.W. and Batley, G.E., (1991), Techniques for Assessing Accelerated Sedimentation, Investigation Report CET/LH/IROO32.

6. Waldock, M.J. and Thain, J.E., (1983), Shell Thickening in *Crassostrea gigas*: Organotin Antifouling or Sediment Induced ?, *Marine Pollution Bulletin*, Vol 14, pp: 411-415.

7. Laughlin, R.B. Jr., Gusstafson, R.G. and Pendoley, P., (1989), Acute toxicology of Tributyltin (TBT) to Early Life History Stages of the Hard Shell clam, *Mercenaria mercenaria*, *Bulletin of Environmental Contamination and Toxicology*, 42, pp: 352-358.

8. Bryan, G.W., Gibbs, P.E., Hummerstone, L.G., and Burt, G.R., (1986), The decline of the gastropod *Nucella lapillus* around South-West England : Evidence for the effect of tributyltin from antifouling paints, *J. Mar. biol. Ass.* UK, 66, pp 611-640.

9. Batley, G.E., Mann, K.J., Brockbank,C.I. and Maltz, A., (1989), Tributyltin in Sydney Harbour and Georges River Waters, *Aust. J. Mar. Freshwater Res*, 40, pp: 39-48.

10. Batley, G.E., Scammell, M.S. and Brockbank, C.I., (1992), The impact of the banning of tributyltin-based antifouling paints on the Sydney rock oyster,*Saccostrea commercialis*, *The Science of the Total Environment*, 122, pp: 301-314

11. Currey, N.A. and Benko, W.I. (1990), South Pacific Regional Environmental Programme Marine Coastal Pollution (SPREP-POL), Proceedings of the Torres Straight Baseline Study Conference, Kewarra Beach, Cairns, Queensland.

12. Valkirs, A.O., *et. al*, (1987), Di- and Tributyltin Species in Marine and Estuarine Waters. Inter-laboratory Comparison of Two Ultra-trace Analytical Methods Employing hydride Generation and Atomic Absorption or Flame Photometric Detection, *Analyst*, vol 12, pp: 17-21.

13. Waldock *et.al.*, (1989), The Determination of total tin and organotin compounds in environmental samples, *Aquatic Environmental Protection: Analytical Methods*, No. 4.

14. Cardellicchio,N., Geraci, S., Marra,C. and Paterno., (1992), Determination of tributyltin oxide in coastal marine sediments and mussels by electrothermal atomic absorption spectrometry, *Applied Organometallic chemistry*, Vol. 6, 241-246.

15. Brinckman, F.E., Blair, W.R., Jewett, K.L. and Iverson, W.P., (1977), Application of a Liquid Chromatograph Coupled with a Flameless Atomic Absorption detector for Speciation of Trace Organometallic compounds, Journal of Chromatographic Science, Vol 15, pp: 493- 503.

16. Chen-wen Whang and Wen-Li Tsai, (1989), Analysis of triorganotin compounds by High Performance Liquid Chromatoraphy with Reverse-Pulse amperometric detection, *Journal of the Chinese Chemical Society*, 36 : 179-186

17. Florence, M. and Batley, G., (1988), Chemical Speciation and Trace Element Toxicity, *Chemistry in Australia*, Oct.1988 pp : 363- 368.

18. Kenis, P. and Zirino, A., (1983), Quantitative Measurement of Tributyltin oxide in sea water by Differential Pulse Anodic Stripping Voltametry, *Analytica Chimica Acta*, 149, pp: 157-166.

19. van den Berg, C.M.G. and Khan, S.H., (1991), Electroanalysis for Organotin in natural waters Including sea-water by Cathodic Stripping Voltammetry, *Analyst*, Vol 116, pp : 585-588.

20. Hattori, Y., Kobayashi, A., Takemoto, S., Takami, K., Kuge, Y., Sugimae, A. and Nakamoto, M., (1984), Determination of Trialkyltin, Dialkyltin and Triphenyltin compounds in Environmental water and sediments, *Journal of Chromatography*, 315, pp : 341-349.

21. Reader, S. and Pelletier, E., (1992), Identification and determination of butyltin compounds by gas chromatography-ion trap spectrometry, *Analytica Chimica Acta*, 262 : 307-314.

22. Gomez-Ariza,J.L., Morales, E. and Ruiz-Benitez, M. (1992), GC FPD method for the simultaneous speciation of butyltin and phenyltin compounds in waters, *Applied Organometallic Chemistry*, Vol 6, 279-286.

23. Muller, M.D., (1987), Comprehensive Trace Level Determination of Organotin Compounds in Environmental samples Using High-Resolution Gas Chromatography with Flame Photometric Detection, *Analytical Chemistry*, 59, pp : 6117-623.

24. Bloxham, M.J., Hill, S.J. and Worfold, P.J., (1993), Analysis of Trace Metals in Sea-water by Inductively Coupled Plasma Mass Spectrometry and Related Techniques, Analytical Proceedings, Vol 30 pp: 159-161.

25. Christian, G.D., (1980), Analytical Chemistry, 3rd edition, John Wiley & Sons Inc., New York

26. Skoog, D.A., (1985), Principles of Instrumental Analysis, 3rd Edition, CBS College Publishing, Tokyo, Japan.