74

A TECHNICAL REPORT

ON THE

WATER QUALITY

OF

PRINCESS ROYAL HARBOUR, ALBANY

JULY 1980

DEPARTMENT OF
CONSERVATION & ENVIRONMENT
WESTERN AUSTRALIA

BULLETIN Nº 74

A TECHNICAL REPORT ON THE

WATER QUALITY OF

PRINCESS ROYAL HARBOUR, ALBANY

by

R.P. Atkins

Botany Department

The University of Western Australia

J.B. Iveson

Public Health Enteric Diseases Unit

State Health Laboratory Services, Perth, W.A.

R.A. Field, I.N. Parker

Planning and Research Branch

Department of Conservation and Environment

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SUMMARY OF FINDINGS AND RECOMMENDATIONS

Nutrient Inputs - Borthwick's Abattoir and the main drain are the two most important nutrient inputs into the harbour. The PWD sewage treatment plant at King Point is also considered important with respect to Middleton Beach.

Bacteriological Inputs - With the exception of the Albany Superphosphate Company and Albany Woollen Mills effluents, all the discharges are heavily loaded with faecal coliforms and 15 serotypes of *Salmonella* were isolated. Forty six isolations were identified during the period of sampling. These discharges are largely responsible for the poor bacteriological quality of some areas of the harbour and Sound.

Water Movement - Although the understanding of water circulation processes in Princess Royal Harbour is not complete, the monitoring programme has shown that exchange with the ocean is satisfactory to allow dispersal of nutrients discharged into the shipping zone. However, there is a reduced water movement on the extensive shallow shelf.

Water Quality - Overall nutrient levels in Princess Royal Harbour are low, with little seasonal variation. This would suggest that the harbour is sufficiently well flushed to cope with present nutrient loads. Nitrogen is the nutrient considered to be more likely to be limiting phytoplankton growth. Chlorophyll a levels are also low with little seasonal variation.

The bacteriological quality of the harbour water, away from the shipping zone, is from satisfactory to slightly polluted. The bacteriological quality of the water in the wharf area is poor.

Problem Areas - the location of the three major discharges (sewage outfall, Borthwick's Abattoir, and main drain adjacent to fertiliser plant) creates three areas of concern.

1. Middleton Beach: a primary contact recreation area where nutrient levels could result in phytoplankton levels reaching bloom conditions under poor water mixing conditions, especially if discharge rates were raised. Occasional high faecal coliform levels occur and indicate the need for continuing monitoring.

2. Wharf front: an area where public access is limited. Nutrients appear to disperse sufficiently rapidly before appreciable accumulation occurs in the water column. However, bacteriologically this area is polluted.

3. Western Shallow Shelf (extending from the Yacht Club around the flats to the Town Jetty): the main drain near the fertiliser plant is the major nutrient source. The area is characterised by reduced water movement, higher nutrient levels and higher productivity of macroalgae amongst seagrasses. High nutrient levels over seagrass beds can result in their degradation and ultimate loss. Such a loss could lead to erosion of the sediments on the shelf and a reduction in diversity of the animal communities such as mussels and worms which live in these sediments. Macroalgae could grow to nuisance proportions in this area where nutrients are higher and water movement is reduced. This could result in large "drifts" of algae

accumulating in the shallow water and shoreline, where it will decompose, releasing unpleasant odours and leave a black ooze over the sandy bottom.

RECOMMENDATIONS

1. Water movement is important for the understanding of nutrient dispersal from discharges and the ultimate fate of these nutrients in the harbour system. Little is known of this and accordingly a study of the currents and tidal influence on the harbour should be undertaken. This study should include waters in King George Sound outside the harbour and adjacent to Middleton Beach.

2. Effluent should not be released in shallow near-shore areas as poor dispersal allows nutrients to accumulate. If industries are to continue discharging into the harbour this should be done in the shipping area where there is minimum public contact and maximum dispersal of nutrients.

3. Release of industrial discharge at King Point or near there should be treated with caution.

4. Investigate the possible extension of the PWD sewage outfall father into the Sound, particularly with regard to water movement.

5. There be a reduction in the suspended solids load in the effluents that are discharged from Borthwicks and the PWD sewage treatment plant.

6. Investigate the input arising from the Albany Superphosphate Company into the main drain to determine firstly how much of the nutrient levels observed at the Elleker Road site are attributable to the fertiliser plant and how much comes from the catchment upstream, and secondly by what process the nutrients from the plant find their way into the drain.

7. Mussels from the Deep Water Jetty, Town Jetty and Wharf area were found to be regularly contaminated with high levels of faecal coliforms and several *Salmonella* serotypes. The public is entitled to adequate warning about the potential dangers from consumption of mussels harvested from these localities.

8. Nutrients were found to accumulate in the waters at Wooding Point and on the Western Shallow Shelf. In order to determine whether nutrients and heavy metals accumulate long enough in these areas so as to be incorporated into the sediments, an investigation should be undertaken of the nutrient and heavy metal content of sediments in these and similar areas.

9. Establish a regular monitoring programme so as to maintain some confidence in the water quality of Princess Royal Harbour and Middleton Beach. Bacteriological monitoring of Middleton Beach appears essential.

10. Undertake a biological survey of the bottom plants and animals of the harbour. Compile a list of the species dominant and make an assessment of the health of some organisms. As the health of seagrass can provide a useful index of water quality it is important to map the distribution of these plants within the harbour.

1. INTRODUCTION

1.1 Study Objectives

In response to a request by the Albany Waterways Management Advisory Committee, the Department of Conservation and Environment asked the Wetlands Study Group Laboratory, Botany Department, University of Western Australia, to participate with them in a survey of the water quality of Princess Royal Harbour and examine the effect waste discharge might have on this water quality.

1.2 Description of the Area

Princess Royal Harbour is an embayment 28.8 x 10^6 m^2 (Government Chemical Laboratories, 1978) on the south coast of Western Australia. The town of Albany is centred on the northern shore of the harbour, which is characterised by a deep basin with a sandy marginal shelf around the western and southern shores. There is a deeper, dredged area around the wharf in the shipping area (Fig. 1.1). Rainfall is probably the only significant natural source of fresh water; there are no rivers discharging into the system.

1.3 Description of Inputs

The water quality of the harbour is influenced by several inputs:

(1) storm water runoff from the town;

(2) drainage channels;

(3) industrial effluents;

(4) discharge from ships; and

(5) sewage.

The industrial processes which discharge directly into the harbour are (Fig. 1.1):

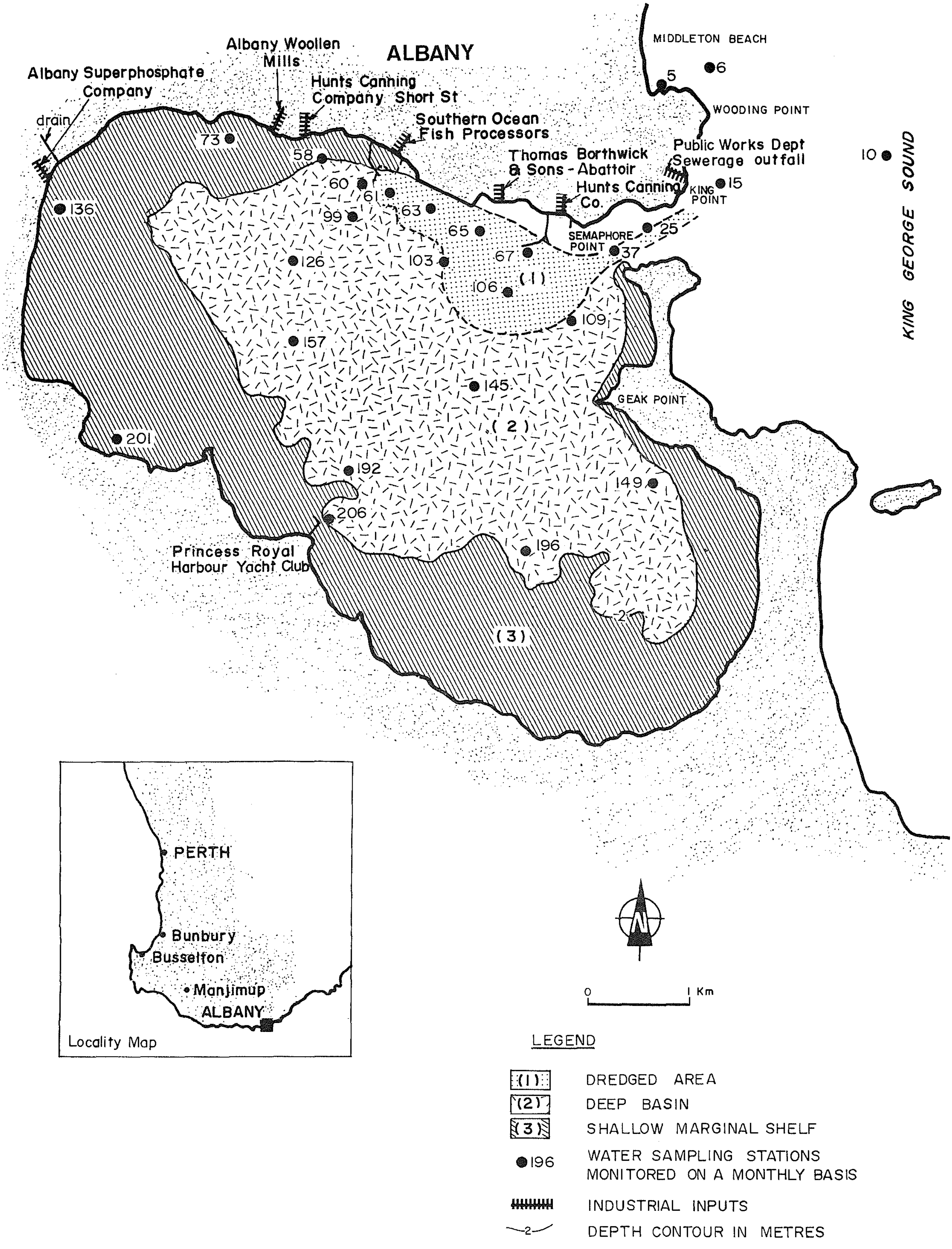
(1) Thomas Borthwick & Sons Abattoir (TB) for cattle and sheep, usually operating for 16 hours daily for more than ten months of the year.

(2) Hunts Canning Co. "East", Semaphore Point (HC(e)) for fish freezing, thawing and cleaning and vegetable processing - seasonally operative for approximately six months of the year - mostly eight hours daily.

(3) Hunts Canning Co. "West", Short Street (HC(w)) for fish thawing, cleaning and processing - 12 months of the year - mainly eight hours daily.

(4) Southern Ocean Fish Processors, (SOFP), thawing, cleaning and processing fish. The Company ceased operations in April 1979.

(5) Albany Woollen Mills, (AWM), wool spinning, weaving and dying for 12 months of the year - mostly on a 24 hour shift.



PRINCESS ROYAL HARBOUR

Figure 1·1

1.3 (Cont'd)

(6) Albany Superphosphate Co., (ASPC), manufacture of superphosphate for nine to ten months of the year - operating on a 24 hour shift.

The Public Works Department discharge releases sewage effluent into King George Sound at King Point.

1.4 Sampling

A sampling programme was set up to:

(1) assess the general water quality;

(2) look at spatial distribution of selected environmental parameters;

(3) assess the seasonal changes of these parameters; and

(4) assess any need for more detailed studies which might be required.

The Albany Port Authority boat the 'Avon' was used to collect most samples, but samples from the marginal shelf and Middleton Beach were collected from the shore. Sampling commenced on 19 December 1978 and continued until 3 December 1979 at monthly intervals. Twenty four stations were selected with respect to industrial discharge points and possible problem areas (Fig. 1.1). Station 10, approximately 2 km offshore in King George Sound, was chosen as a 'control' station, to represent marine water. Two extra stations (60, 73) were included in September 1979. Sampling was carried out in one to two days. Ammonium nitrogen NH_4-N, nitrate/nitrite nitrogen NO_3/NO_2-N, Kjeldahl nitrogen (assumed to be organic nitrogen), orthophosphate PO_4-P, and total phosphorus were the nutrients sampled. Chlorophyll a, salinity, water temperature and water transparency readings were made, and bacteriological samples taken at certain stations.

2. PHYSICO - CHEMICAL DATA

2.1 Introduction

Salinity, temperature and light penetration were measured at each station. Salinity is measured as total dissolved salts in the water using an instrument that records electrical conductivity. By comparing levels inside the harbour with that of the ocean, salinity provides information relevant to the magnitute of water exchange between the harbour and King George Sound, and the exchange of water between the central part of the harbour and the shallow banks around the western and southern margins. Poor exchange of embayment waters with the ocean is indicated by an increase in salinity through evaporation during summer, and a decrease in salinity through dilution with fresh water inputs such as storm water and rainfall during the winter months.

Temperature and salinity variations with depth indicate the degree of stratification of the water column.

Light penetration is used to determine the euphotic zone, below which photosynthesis-dependant organisms do not grow. It also gives a measure of suspended material in the water, such as phytoplankton, detritus and sediments.

2.2 Methods

(1) The various physical and chemical parameters were measured using relevant equipment, viz: Salinity in parts per thousand (^{o}/oo) total dissolved salts, using a Hamon Salinity/temperature Bridge (Autolab, Yeo Kal Pty. Ltd., Sydney).

(2) Temperature, measured in ^{o}C using the Hamon Salinity/Temperature Bridge.

(3) Light penetration in metres using the Secchi Disc which delineates the 1-15 per cent transmission zone (Wetzel, 1975).

(4) Meteorological data, recorded for Albany Airport and obtained from the Bureau of Meteorology, Perth, W.A.

(5) Water exchange with the Sound was calculated as follows:

change in tide height x surface area of harbour = Volume of water changed (Vc)

$$\text{Per cent exchange} = \frac{\text{Vc}}{\text{Total volume}} \times 100 \text{ per cent}$$

2.3 Data

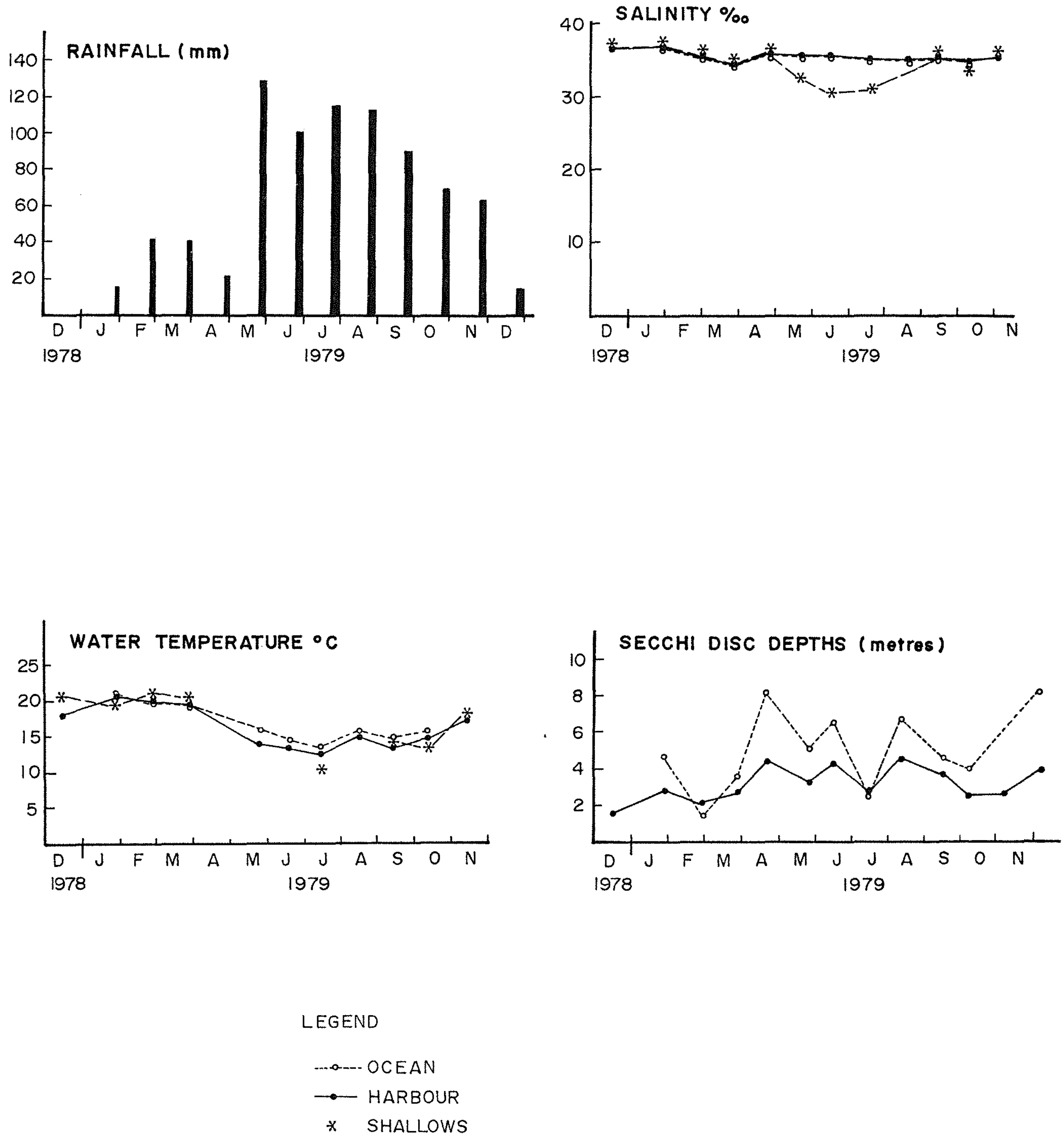
The mean of surface and bottom data were calculated for each parameter at each station. Stations were then divided into three groups.

(1) station 10 - open Sound station;

(2) 6, 15 - stations adjacent to PWD discharge; and

(3) all harbour stations excluding 25 and 37.

The mean of all stations in each group was calculated for each parameter. Time series curves were drawn for salinity, water temperature and secchi depth (Fig. 2.1).



MEAN SEASONAL VARIATION OF PHYSICO- CHEMICAL DATA

Figure 2·1

2.3 (Cont'd)

There is a consistent rainfall for seven months of the year, with no substantial dry season (Fig. 2.1), and consequently the salinity did not change significantly in the deep water areas, but during the period of high rainfall there was a drop of approximately $4^{o}/oo$ on the shallow banks. Water temperature decreased by approximately $5^{o}C$ during the winter months. Water transparency was variable, and is probably dominated by wind conditions.

Table 2.1 is a summary of general conditions influencing water movement taken from Steedman and Craig (1979). Wind speed has been classified into four classes.

Class 1. < 2.9 knots (1.5 ms^{-1}) Calm conditions.

Class 2. 2.9 to 9.8 knots (5 ms^{-1}) 9.8 knots is the minimum wind speed required to operate the wind driven model for water movement in Cockburn Sound.

Class 3. 9.8 to 29.4 knots (15 ms^{-1}) Conditions regularly experienced.

Class 4. > 29.4 knots Storm events usually caused by low pressure systems and cold fronts.

These criteria were used to gain some idea of how often and to what degree wind in the Albany area may influence water movement. This is essentially speculation as there are no water circulation data to support this. The wind data are presented in three forms. Firstly, an average of conditions for the week before each cruise; secondly, conditions experienced at the meteorological station averaged for the day of sampling; and thirdly, field observations on board the 'Avon' averaged for the time of sampling. The type of pressure system influencing the area on the day of sampling and the major influences for the previous week have also been documented and considered.

The prevailing wind is south easterly swinging to the north west quarter during storm conditions. Wind strength average is in the class 2 range.

The tide data are measurements from the change in water level at the Port Authority tide gauge during the day of sampling. Tidal fluctuations on sampling days do not differ greatly.

Water exchange with the Sound is the per cent of total harbour volume moved by an incoming or outgoing tide. This was calculated using tide gauge information supplied by the Albany Port Authority, and the harbour area and volume figures were taken from the Government Chemical Laboratories (1978) report. The average exchange calculated from Government Chemical Laboratories data is 24 per cent.

The only general industrial discharge figures available are periods provided by the industries. Discharge data collected by Government Chemical Laboratories for 18 June 1979 will be discussed in Chapter 3.

TABLE 2.1

SUMMARY OF SYNOPTIC CONDITIONS, TIDE VARIATION, AND INDUSTRIAL DISCHARGE FOR EACH CRUISE

CRUISE NO	AVERAGE FOR WEEK BEFORE DATE		ON DAY OF TRIP		FIELD OBSERVATIONS		TIDE		INDUSTRIAL DISCHARGE							PRESSURE SYSTEMS ON DAY OF CRUISE AND GENERAL CONDITIONS FOR WEEK BEFORE
DATE	WIND CLASS	DIRECTION	WIND CLASS	DIRECTION	WIND CLASS	DIRECTION	AM	PM	ASPC	AWM	HC(w)	SOFP	TB	HC(e)	PWD	
1 19.12.78	3	SE	2-3	SE	3	SE	Out	In	*	*	*	*	*	*	*	High (for five days)
2 31.01.79	2-3	SE	1-3	S/SE	3	SE	Out	In	*	*	*	*	*	*	*	High (two days)
3 27.02.79	2	SE	2-3	SE	3	SE	In	Out	*	*	*	*	*	*	*	High (two days)
4 27.03.79	2	WSE Swing	1-3	E/NE	3	SE	In	Out	*	*	*	*	*	*	*	High (one day, series of fronts over week)
5 01.05.79	2	N-E	1-3	S-NW	2	S	In	Out	*	*	*	*	*	*	*	Front
6 21.05.79	2	W-N	3	SW	3	SW	In	Out	*	*	*	*	*	*	*	High (two fronts before this)
7 18.06.79	2	NW	1-3	NW	3-4	NW	In	Out		*	*		*[1]	*	*	High (front approaching two fronts before)
8 24.07.79	3	S-W-N Swing	1-3	S-W	3	SW	In	Out		*	*			*	*	High (two fronts before)
9 14.08.79	2	NW/SW	1-2	NW-SW	2	W/NW	Out	In		*	*		*	*	*	Front day before followed by calm
10 10.09.79	2-3	W/SW	1-3	SW-W	3	SW	Out	In		*	*		*	*	*	High (front previous day)
11 10.10.79	3	S-W-N	3-4	NW	3	NW	Out	In		*	*		*	*	*	Low (three fronts previous week)
12 05.11.79	2	E/SE	3	E	3-4	SE			*	*	*		*	*	*	High (low previous day)
13 04.12.79	3	SE/SW	2-3	SW	2	SW			*	*	*		*	*	*	High (low previous day

[1] One mutton chain operating   * Industry discharging

2.4 Discussion

The data show that the water column is well mixed vertically in the deeper areas, and that the exchange with the Sound is sufficient to allow relatively rapid flushing of the harbour. The resident time of water on the shallow shelf is sufficiently long for there to be lower salinity in winter than in the deeper water.

Water transparency is probably wind dependent, and dredging in the early part of 1979 probably reduced light penetration to a certain degree. The average wind speed for the week preceding sampling was usually in class 2, though this was measured at the airfield several kilometres from the harbour. Wind speeds on the harbour are usually appreciably higher. Using the Cockburn Sound experience and the estimated wind speed for each cruise it is suspected that wind plays a major part in water circulation in the harbour.

In summary the harbour is well mixed and the exchange with the Sound is sufficient to prevent hypersalinity in summer and low salinity in winter. For comparison, the average salinities of Peel Inlet range from less than 10 $^{o}/oo$ in winter to as high as 50 $^{o}/oo$ in summer as a result of poor exchange with the ocean (salinity 35 $^{o}/oo$), and a large volume of fresh water input from rivers and direct rainfall during winter (McComb *et al*). The annual range for Princess Royal Harbour on the other hand, is 31 $^{o}/oo$ to 37 $^{o}/oo$.

There is thought to be a longer resident time of water on the shelf, and wind is considered to be important factor in influencing water movement.

3. NUTRIENTS AND PHYTOPLANKTON

3.1 Introduction

Most of the industries discharging into Princess Royal Harbour are concerned with processing animal and vegetable materials, which result in a highly organic discharge. The exception is the fertiliser plant which is engaged in the processing of rock phosphate.

Nutrient enrichment, especially by nitrogen and phosphorus, is a major stimulant for algal growth in water bodies in general, causing blooms of microscopic planktonic algae and larger plants, or macrophytes. These blooms upset the base of the normal food chains, and water 'blooms' of phytoplankton, and rotting masses of plant material may result (Provosoli, 1969). Nutrient accumulation may not necessarily result in blooms, as other factors such as colour and turbidity, which reduce light transparency of the water, can suppress algal growth (Lund, 1969).

This chapter looks at the nitrogen and phosphorus levels in the waters and shows how their distribution and concentration changes seasonally. The relationships between the different measured parameters, and especially their relationship with chlorophyll a levels (which measure phytoplankton biomass) will be discussed in relation to nutrient input and distribution.

3.2 Methods

3.2.1 Sample Collection

Water samples were collected from 0.1 m below the surface at all stations and 1 m above the bottom at stations greater than 3 m deep. The surface sample was collected in a plastic bucket and the bottom sample in a five litre Niskin type bottle.

A two litre water sample was filtered through a Whatman GF/C filter which was then folded and stored on ice in the dark in a brown manila envelope. On return to the laboratory the filters were deep frozen until chlorophyll a analyses could be done.

For nutrient determinations a 250 mL water sample was filtered through a sterile, 0.45 μ Millipore membrane filter. The first 50 mL was discarded, and a 100 mL sample placed in a whirlpak (Nasco) on ice for PO_4-P determination. In addition five samples were collected and stored in Whirlpaks for NH_4-N, NO_3-N, organic nitrogen, total phosphorus and one spare, and stored on ice. On return to the laboratory the samples were deep frozen until they were analysed.

3.2.2 Analysis

All nutrient and chlorophyll a analyses were carried out by the Wetlands Study Group Laboratory, Botany Department, University of Western Australia. Refer to Appendix (3) for description of analytical procedures.

3.2.3 Data Manipulation

Statistics

The data were analysed using the SPSS package statistics computer programme (Nie *et al*, 1975). Firstly, a multiple regression analysis was carried out, which provided a correlation matrix for determining the relationships between variables. Secondly, a

3.2.3 (Cont'd)
single regression approach was used to place an order of priority on variables according to how well they were correlated with chlorophyll levels. All correlation coefficients were tested for their level of significance.

Mapping
Three cruises were chosen for mapping the distribution of NH_4-N, NO_3/NO_2-N, organic N, PO_4-P, organic P and chlorophyll a.

The mapping was done using a computer package programme, SYMAP, Version 5.20. The programme is provided with a map outline and sample station co-ordinates, with the data for each station for the variable being mapped. SYMAP uses these data to interpolate the values between stations, taking into consideration the distance between them. The values are divided into five equal classes between the maximum and minimum value. Contour lines are printed which include stations of the same class; these are interpolated into areas where no data points exist. These areas need to be treated with caution when interpreting maps.

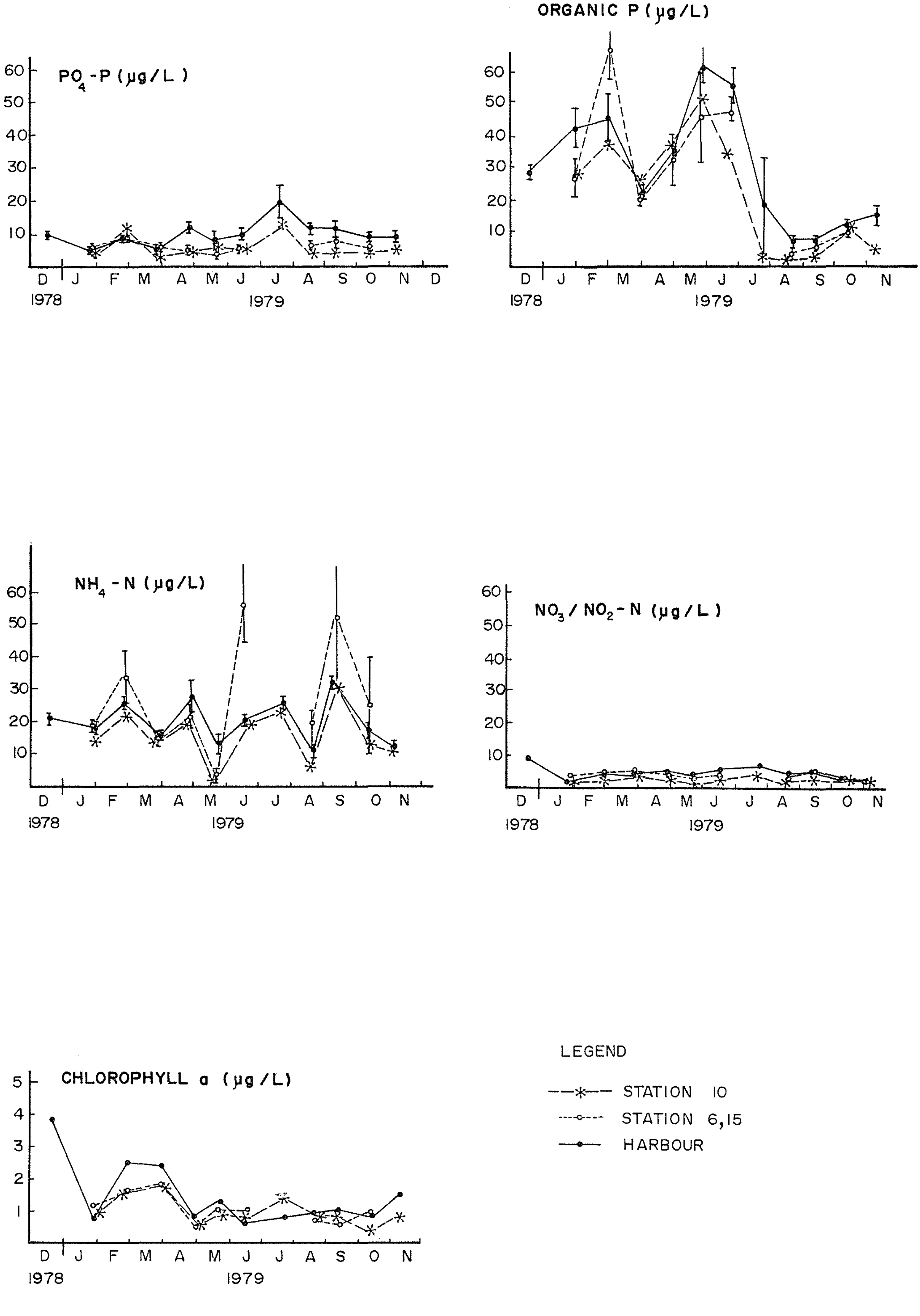
3.3 Data

3.3.1 Monthly Nutrient Means
Time series curves were drawn for PO_4-P, organic P, NH_4-N, NO_3/NO_2-N, chlorophyll a (Fig. 3.1).

3.3.2 Chlorophyll and Nutrient Correlation
All the data, surface and bottom, were used in the multiple regression. Figure 3.2 shows the significance levels for the 1 x 1 correlation coefficients, and whether there are complex relationships between the measured parameters. This precludes the use of conventional multiple regression analyses, which assume that the parameters are independent. However, by running a series of multiple regressions on different sets of parameters, some relationships can be established. Table 3.1 shows the amount of variance in chlorophyll a which is accounted for by different suites of variables in separate multiple regression analyses. The major portion of the chlorophyll a variation was accounted for by the physico - chemical parameters, 30.9 per cent or 21.1 per cent without secchi. Nutrients only accounted for 17.7 per cent of the variation and inorganic nutrients only 8.0 per cent. The total accounted for by all variables reached only 46 per cent.

The multiple regressions have established which group of parameters is the most important. Single linear regressions were used to sort the parameters into an order of importance, using the correlation coefficient (R) and testing its level of significance. Table 3.2 lists the variables in order of importance with respect to chlorophyll a levels. Negative correlation shows that the variable increases as chlorophyll a increases.

Note the Secchi readings show a negative correlation as the more turbid the water the less the penetration of light and the smaller the Secchi depth.



MONTHLY NUTRIENT LEVELS OF HARBOUR WATERS
for three different areas - mean of surface & bottom

Figure 3·1

FIGURE 3.2

THE LEVELS OF SIGNIFICANCE FOR THE 1 X 1 CORRELATION COEFFICIENTS FROM THE MULTIPLE REGRESSION

	PO_4-P	ORGANIC P	TOTAL P	NH_4-N	NO_3-N	ORGANIC N	TOTAL N	INORGANIC N	CHLOROPHYLL A	DEPTH	SALINITY	TEMPERATURE
ORGANIC P	-**											
TOTAL P	NS	**										
NH_4-N	**	NS	*									
NO_3-N	**	NS	NS	**								
ORGANIC N	NS	-*	NS	NS	NS							
TOTAL N	NS	-*	NS	NS	NS	**						
ORGANIC N	**	NS	*	**	**	NS	NS					
CHLOROPHYLL <u>A</u>	NS	**	**	NS	**	-**	-**	*				
DEPTH	NS	NS	NS	NS	NS	NS	NS	NS	NS			
SALINITY	**	**	**	NS	NS	NS	NS	NS	NS	NS		
TEMPERATURE	-**	**	**	NS	-*	-**	-**	NS	**	NS	-*	
SECCHI	-**	-*	-**	-**	-**	**	**	-**	-**	*	NS	-**

LEVELS OF SIGNIFICANCE

* = $0.01 < p < 0.05$
** = $p < 0.01$
NS = Not significant

TABLE 3.1

THE PER CENT VARIATION OF CHLOROPHYLL A ACCOUNTED FOR BY EACH GROUP OF VARIABLES IN THE MULTIPLE REGRESSION

(a) All Data

PO_4-P	ORGANIC P	TOTAL P	NH_4-N	NO_3/NO_2-N	TOTAL INORGANIC N	ORGANIC N	TOTAL N	DEPTH	SALINITY	TEMPERATURE	SECCHI	TOTAL
+	+	+	+	+	+	+	+	+	+	+	—	35.2%
—	—	—	—	—	—	—	—	+	+	+	—	21.1%
+	+	+	+	+	+	+	+	—	—	—	—	16.5%
+	—	—	+	+	+	—	—	—	—	—	—	8.0%
(b) Bottom Data (including Secchi)												
+	+	+	+	+	+	+	+	+	+	+	+	46.1%
—	—	—	—	—	—	—	—	+	+	+	+	30.9%
+	+	+	+	+	+	+	+	—	—	—	—	17.7%
+	—	—	+	+	+	—	—	—	—	—	—	6.5%

TABLE 3.2

THE CORRELATION COEFFICIENTS R AND LEVEL OF SIGNIFICANCE OF R FOR THE SINGLE REGRESSIONS OF CHLOROPHYLL A AND EACH PARAMETER

PARAMETER	R	SIGNIFICANCE R	PER CENT SIGNIFICANCE
Secchi	- .47679	.00001	99.9
Temperature	+ .45889	.00001	99.9
Organic P	+ .17750	.00014	99.9
Total P	+ .17083	.00021	99.9
Organic N	- .09653	.02525	95
Total N	- .09435	.02696	95
Total Inorganic N	+ .09256	.02888	95
NO_3/NO_2-N	+ .08602	.03705	95
Depth	- .07573	.05779	NS
PO_4-P	+ .07102	.07240	NS
NH_4-N	+ .06964	.07664	NS
Salinity	- .07064	.07822	NS

3.3.2 (Cont'd)
The variables are divided into three levels of significance. Secchi and temperature are the two most significantly correlated variables, followed by organic N and P. Total N and P are predominantly organic and appear at similar levels of significance as organic N and P.

3.3.3 Nutrient Distribution
In order to discuss the effects of industrial discharge and synoptic conditions on nutrient distribution, Table 2.1 was consulted and three cruises of differing conditions chosen for SYMAP analysis. Table 3.3 is a summary of the data from Table 2.1.

Figure 3.3a, 3.4a and 3.5a are the SYMAPS for the February, June and August cruises, respectively. The class intervals are between the highest and lowest value of each data set and divided into five classes of equal size, and so vary between parameters and with each cruise. With each cruise set is the synoptic chart for the day and the tide gauge trace (Fig. 3.3b, 3.4b, 3.6c). Table 3.4 shows the N:P ratios for the three cruises and the mean for all cruises; these are split into the three areas used for the monthly mean time series figures.

3.3.4 Nutrient Input
Mr. H.D. Cooke from the Government Chemical Laboratories sampled the industrial discharge into the harbour on 18 June 1979. Table 3.5 shows the flows, nitrogen and phosphorus concentration and loads released to the harbour. The data in Table 3.6 were extracted from the Government Chemical Laboratories Report (1978) to calculate yearly average loads, using the average yearly flows given in the report. Elleker Road and Frenchman's Bay Road sample points are on the main drain discharging into the harbour near the ASPC discharge point. Elleker Road sample point is immediately downstream from ASPC and Frenchman's Bay Road sample point is downstream of the farmland separating ASPC from the harbour. Loads per day have been calculated assuming an eight hour shift in industry and 24 hour flow in the main drain. Nitrogen loads for the drain in inorganic N (NH_4-N + NO_3/NO_2-N) as no organic N data are available. This also applies to ASPC on Table 3.6.

3.4 Discussion

3.4.1 Seasonal Variation (Figure 3.1)
There is little seasonal variation except that chlorophyll a levels are higher during the summer months. Nutrient variations are slight although organic P shows some significant changes; however, no recognisable trend is evident. Nutrient levels in general are low.

NH_4-N in the station 6 and 15 area, adjacent to the PWD discharge, peaks significantly higher than the other areas on some occasions. This reflects the influence of the sewage input to that area. It must be noted that the trend for station 10 follows closely to that of the harbour levels; it must be assumed that station 10 is subject to influence from the harbour waters and cannot be considered a control station.

TABLE 3.3

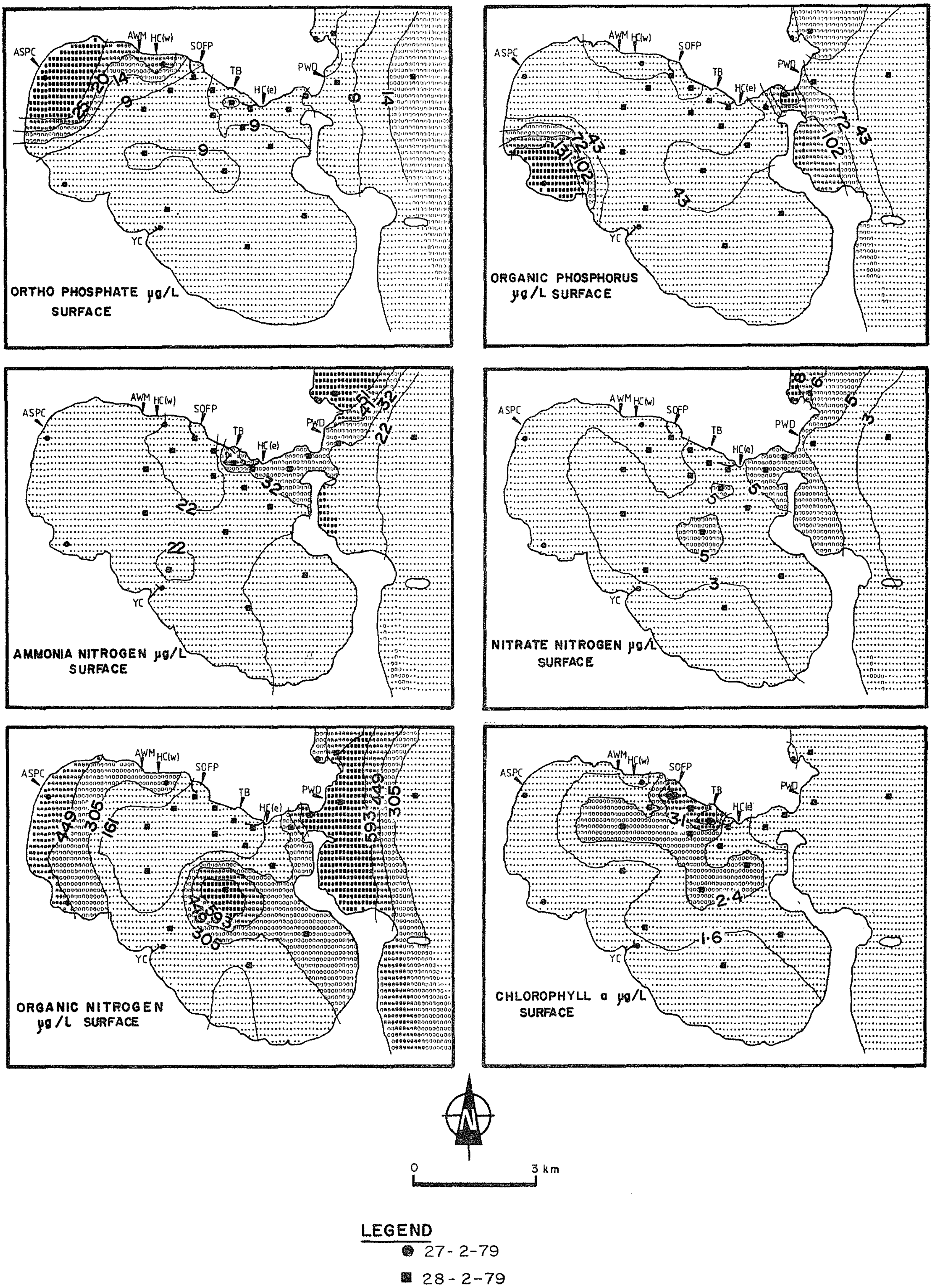
A SUMMARY OF SYNOPTIC, TIDE AND INDUSTRIAL DISCHARGE FOR THE CRUISES USED FOR MAPPING

(Data extracted from Table 2.1)

CRUISE NO	DATE	CONDITIONS AVERAGED FOR WEEK BEFORE CRUISE			CONDITIONS ON DAY OF SAMPLING					INDUSTRIAL DISCHARGE						
		WIND CLASS	DIRECTION	SYNOPTIC	WIND[1] CLASS	DIRECTION	SYNOPTIC	TIDE AM	TIDE PM	ASPC	AWM	HC(w)	SOFP	TB	HC(e)	PWD
3	27.02.79	2	SE	High pressure dominated front 25/2 front 21, 22/2 storm	2-3 (3)	SE	High pressure influence	In	Out	ON	ON	ON	ON	ON	ON	ON
7	18.06.79	2	NW	13, 16/6 strong front 13 and 16 June	1-3 (3-4)	NW	High pressure front approaching	In	Out	OFF	ON	ON	OFF	RED[2]	ON	ON
9	14.08.79	2	NW/SW	Mild high pressure dominated	1-2 (2)	NW/SW	Light front 13/8 followed by calm conditions	Out	In	OFF	ON	ON	OFF	ON	ON	ON

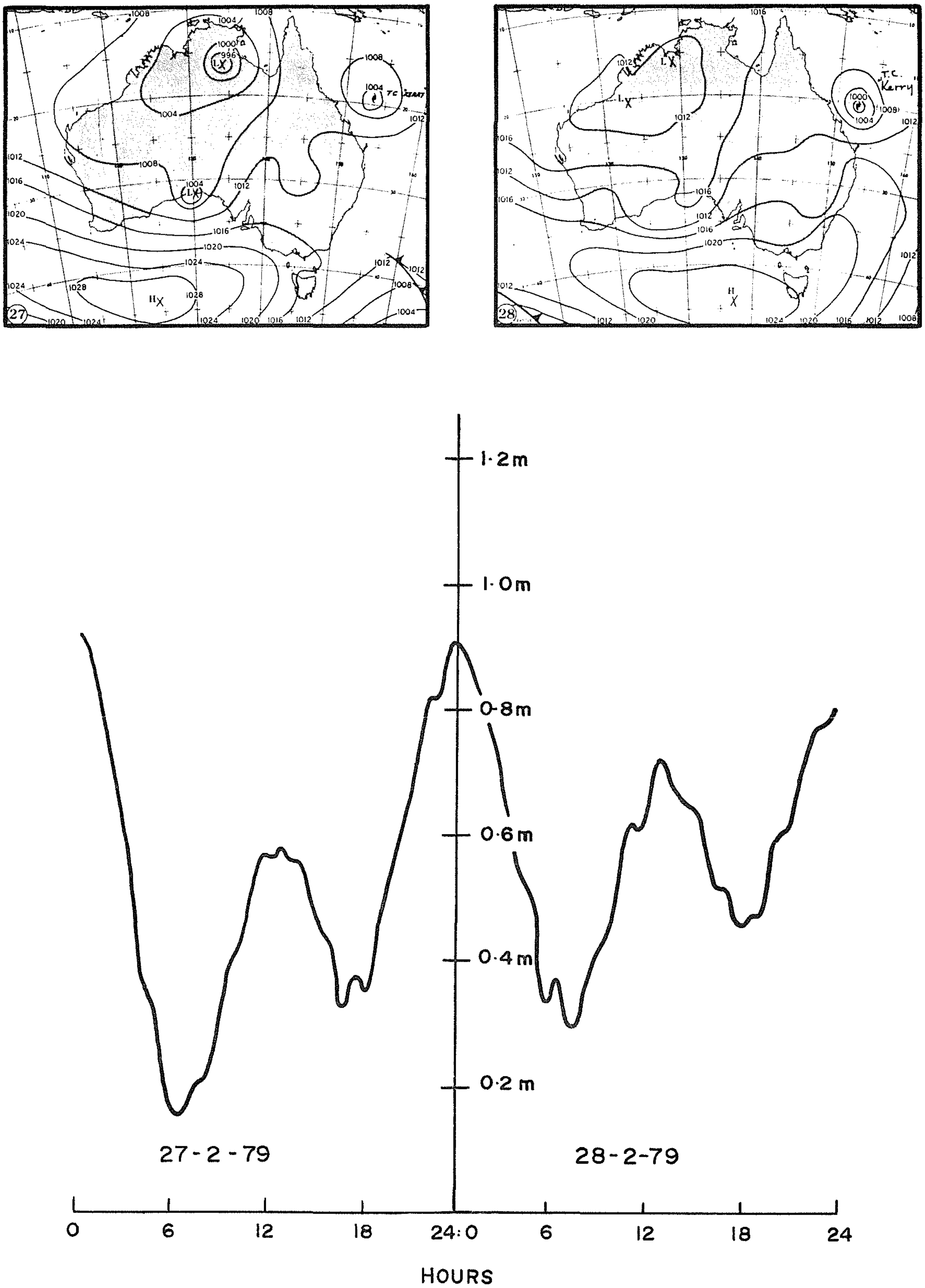
[1] Wind class in brackets based on observations made on board 'Avon'

[2] One mutton chain operating



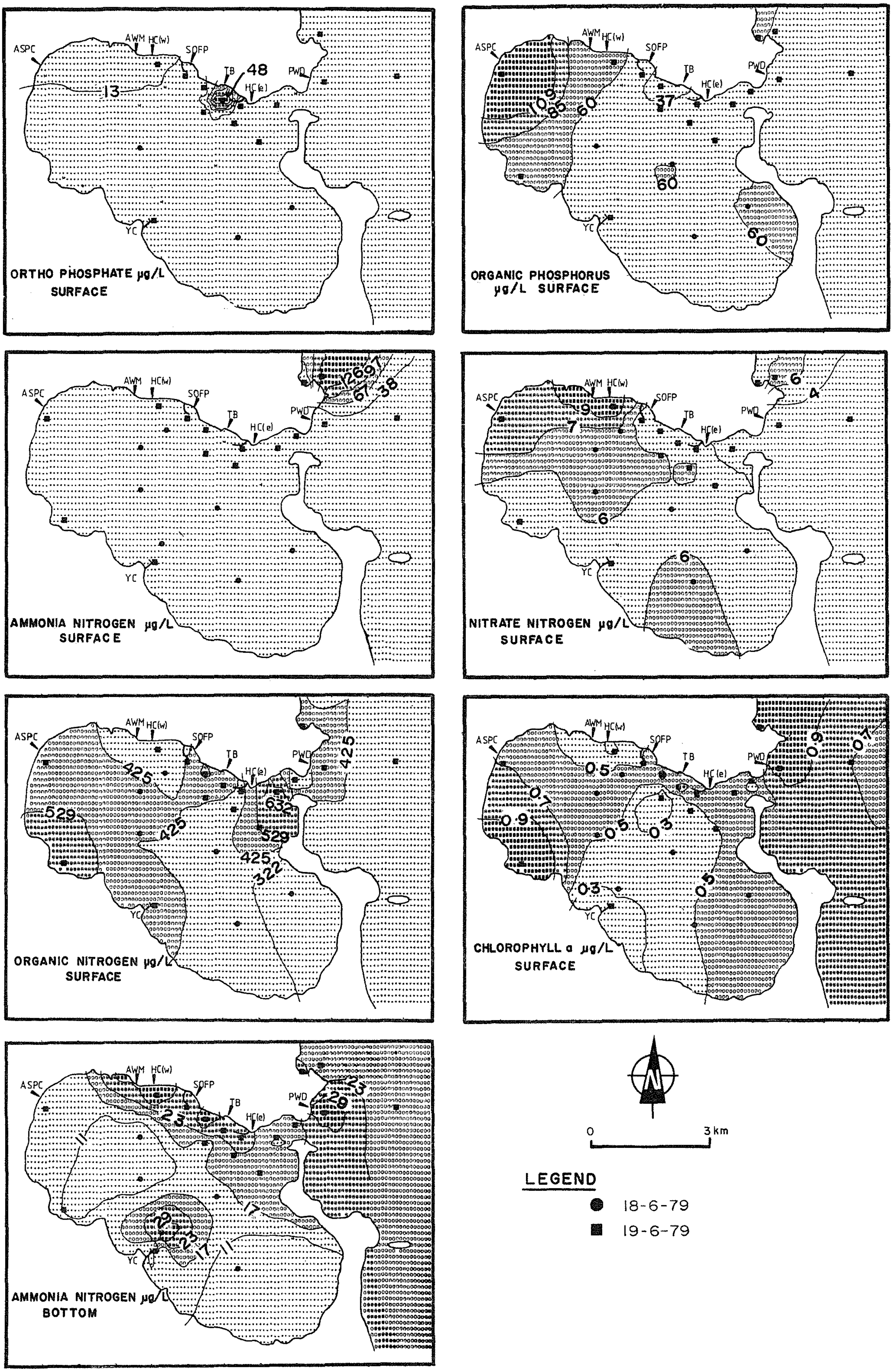
PRINCESS ROYAL HARBOUR NUTRIENTS DISTRIBUTION FOR FEBRUARY 1979

Figure 3·3a



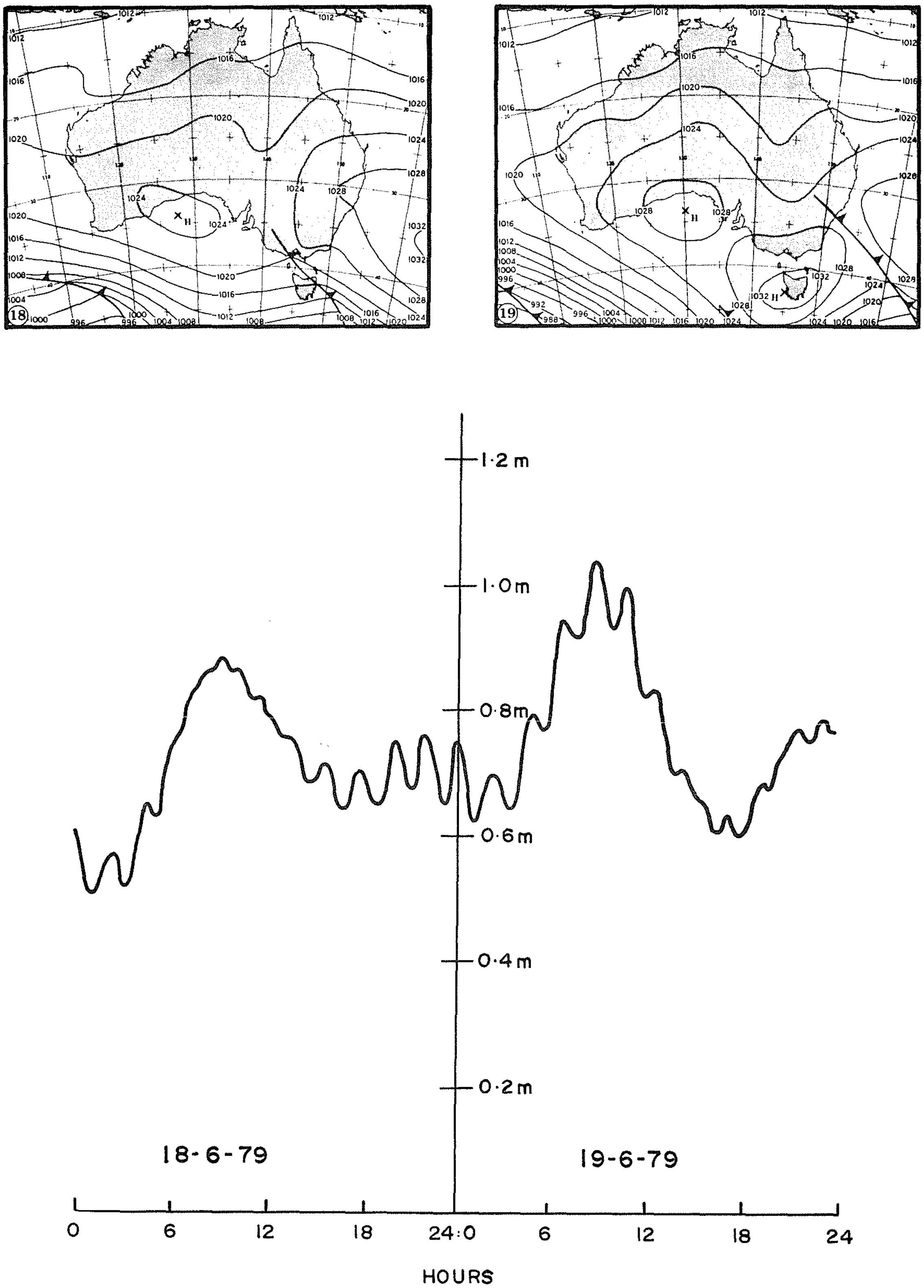
SYNOPTIC CHART DATA
FOR SAMPLING PERIOD 27-28/2/79

Figure 3·3 b



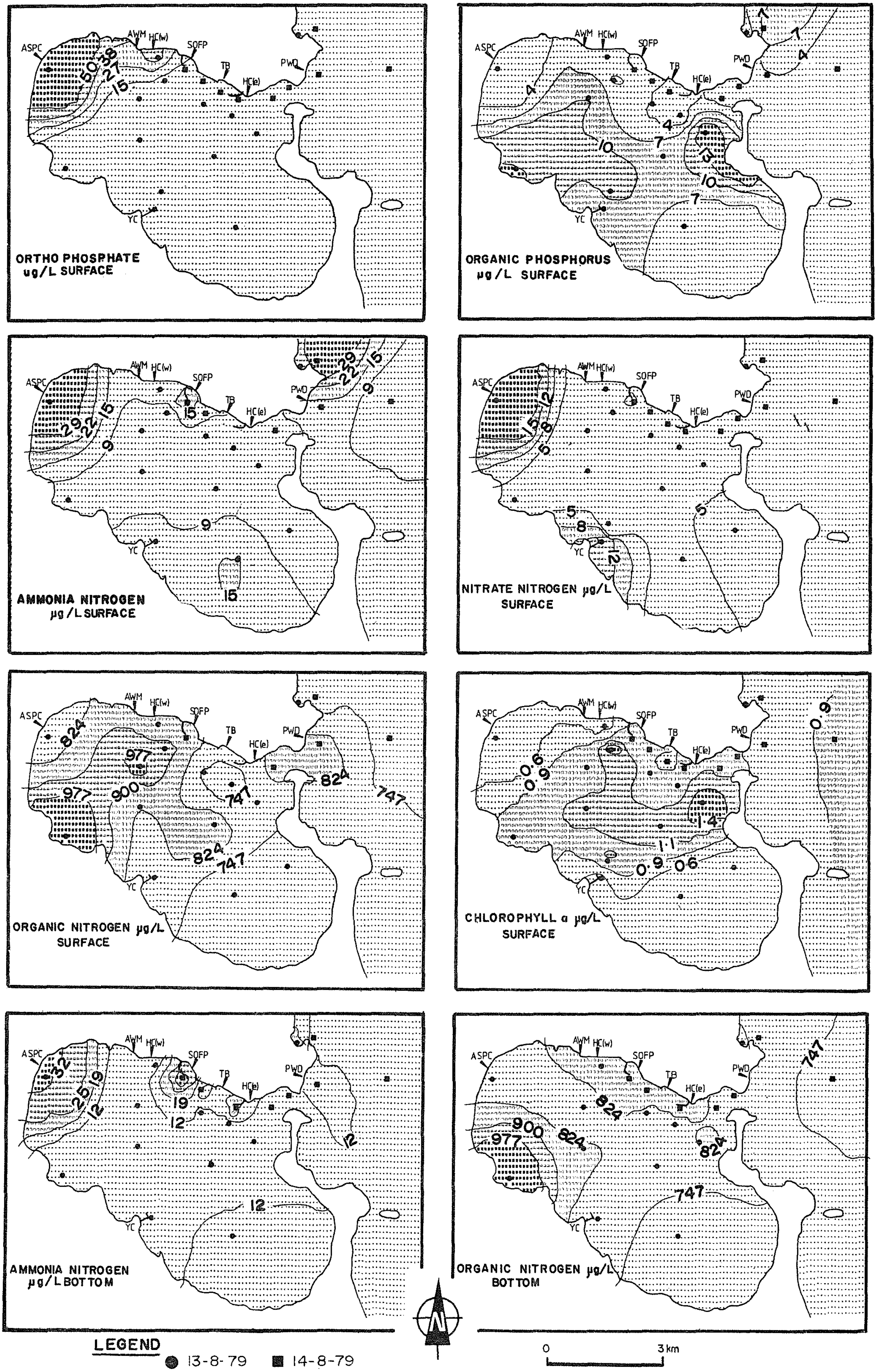
PRINCESS ROYAL HARBOUR NUTRIENTS DISTRIBUTION - JUNE 1979

Figure 3.4a



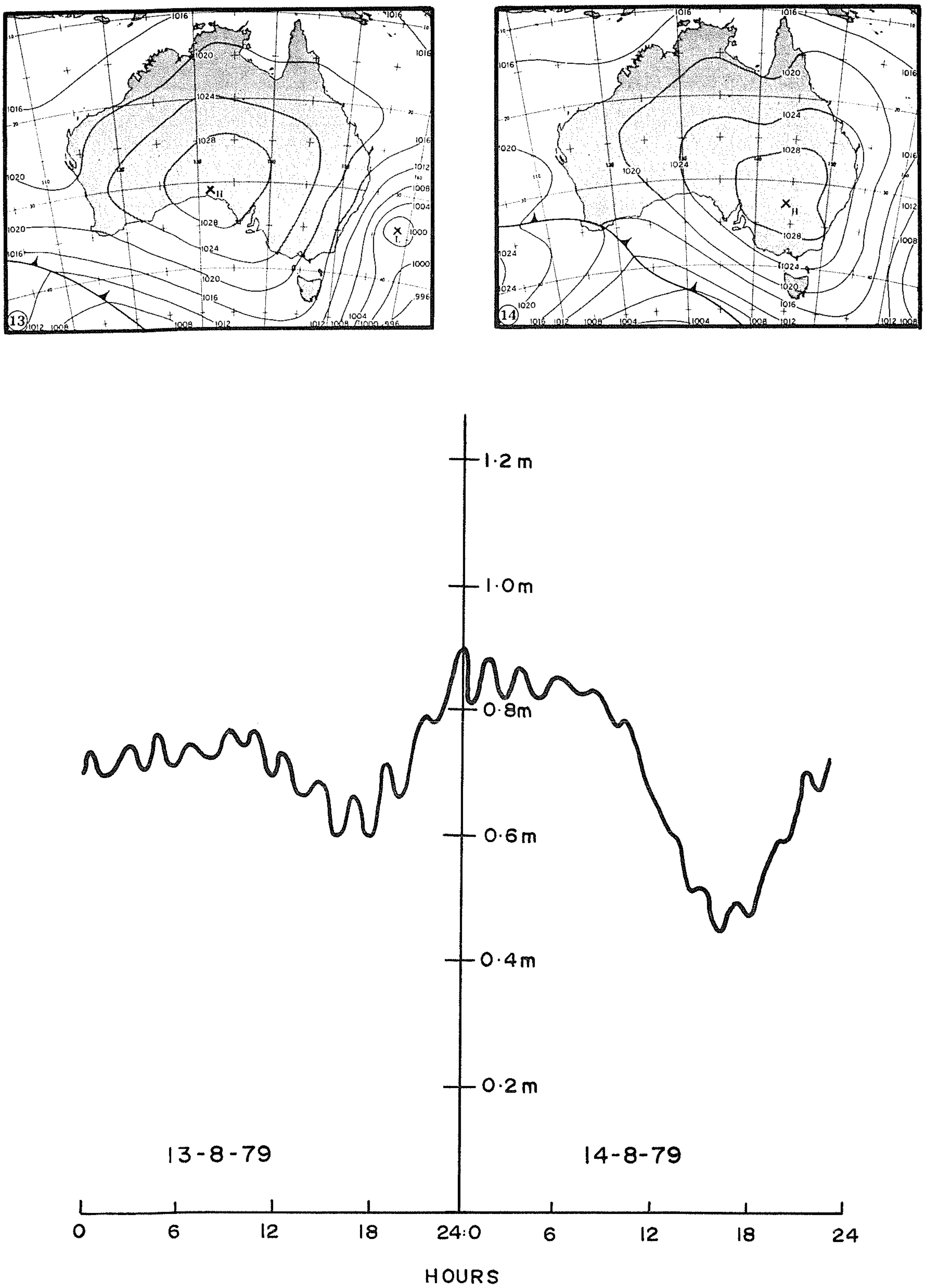
SYNOPTIC CHART DATA
FOR SAMPLING PERIOD 18-19/6/79

Figure 3·4 b



LEGEND
● 13-8-79 ■ 14-8-79

PRINCESS ROYAL HARBOUR NUTRIENTS DISTRIBUTION-AUGUST 1979



SYNOPTIC CHART DATA
FOR SAMPLING PERIOD 13-14/8/79

Figure 3·5b

TABLE 3.4

N : P RATIOS

(calculated from inorganic totals as atoms)

CRUISE	STATION 10	STATIONS 6, 15	HARBOUR STATIONS
February	4.8 : 1	9.3 : 1	7.4 : 1
June	10 : 1	26.8 : 1	5.8 : 1
August	5 : 1	7.9 : 1	3.1 : 1
Mean (all cruises)	7.1 : 1	11.7 : 1	5.5 : 1

TABLE 3.5

NUTRIENT LOADS FROM INDUSTRIAL DISCHARGES 18 JUNE, 1979 CALCULATED FROM DATA COLLECTED BY THE GOVERNMENT CHEMICAL LABORATORIES

INDUSTRY	Flow m^3/h	NH_4 $\mu g\ L^{-1}$	NO_3 $\mu g\ L^{-1}$	Kj N $\mu g\ L^{-1}$	TP $\mu g\ L^{-1}$	Kj N g/h	TP g/h	LOADS g/day 8 h for trade 24 h for drains N	P
AWM	6			13000	17000	78	102	624	816
TB	40			81000	21000	3240	840	25920	6720
HC(e)	6.9			74000	7100	511	49	4088	392
HC(w)	16			54000	7500	864	120	6912	960
						Inorganic N			
Elleker Road	340	3100	350		7600	846	2584	20304	62016
Frenchman's Bay Road	1500	1000	670		2700	1394	4050	33456	97200

TABLE 3.6

NUTRIENT LOADS FROM INDUSTRIAL DISCHARGE AVERAGED FROM 27.04.77 TO 25.01.78
DATA BASED ON QUARTERLY SAMPLING

(Government Chemical Laboratories Report, 1978)

INDUSTRY	FLOW m^3/h	NH_4 $\mu g\ L^{-1}$	NO_3 $\mu g\ L^{-1}$	Kj N $\mu g\ L^{-1}$	TP $\mu g\ L^{-1}$	Kj N g/h	TP g/h	LOAD/DAY 8 h for trade 24 h for drains N	P
ASPC	12 Cow St.	90	22	-	12000	0.9 Inorganic N	144	7.2	1152
AWM	6 Cow St.			17000		102		816	
TB	190 (72 - 240)			106000		20140		161120	
HC(e)	10 (9 - 14)			62000		620		4960	
HC(w)	18 (19 - 32)			570000		10260 Inorganic N		82080	
Elleker Road	220 (63 - 350)	870	240		6800	160	1496	3840	35904
Frenchman's	420 (110 - 600)	530	320		2900	203	1218	4872	29232
Ornamental Lake, Input	1400	110	30		100	130	140	3120	3360

3.4.2 Trophic Status

There are no real guidelines for the trophic status of marine embayments in Australia. Sawyer (1947, 1952) said that nuisance algal growth could be expected when the concentration of inorganic P and N equalled or exceeded 10 μg L^{-1} and 300 μg L^{-1} respectively. These figures may be used as a guide as they are not necessarily applicable to this situation. However, it can be noted that the PO_4-P concentration is below 10 μg L^{-1} for much of the year and does not go beyond 20 μg L^{-1}. Inorganic nitrogen (NH_4-N + NO_3/NO_2-N) is well below 300 μg L^{-1} all year. The chlorophyll a data show that the phytoplankton biomass level never reached nuisance proportions. In Cockburn Sound chlorophyll levels reach nuisance proportions between 10 and 20 μg L^{-1} when it is easily visible and the dissolved oxygen level of the water decreases due to phytoplankton decomposition. Levels of this order could cause a deterioration of seagrass in Princess Royal Harbour as a result of shading from phytoplankton (Chiffings, pers. comm., 1980).

Vollenweider's (1971) table for trophic levels in lakes is widely used for classifying water bodies.

	Total P (μg L^{-1})	Inorganic N (μg L^{-1})
ultra-oligotrophic	<5	<200
oligo-mesotrophic	5 - 10	200 - 400
meso-eutrophic	10 - 30	300 - 650
eu-polytrophic	30 - 100	500 - 1500
polytrophic	>100	>1500

The yearly average total phosphorus level is 34 μg L^{-1} which places the water body in the eu-polytrophic class. Total inorganic nitrogen, however, has a yearly average of 23 μg L^{-1} which places the water body in the ultra-oligotrophic class.

Vollenweider quotes a classification based on chlorophyll from Sakamoto (1966) -

oligotrophic	.3 - 2.5 μg L^{-1}
mesotrophic	1 - 15 μg L^{-1}
eutrophic	5 - 140 μg L^{-1}

The yearly average for this water body is 1.4 μg L^{-1} with a peak of 3.8 μg L^{-1} which places it in the mesotrophic class. Overall Princess Royal Harbour might be classified as a mesotrophic water body in comparison with these fresh water data.

3.4.3 Interaction of Phytoplankton and Environmental Parameters

The physico - chemical parameters are the group most strongly correlated with chlorophyll a.

A.W. Chiffings, Department of Conservation and Environment

3.4.3 (Cont'd)

Secchi depth may be a result of suspended sediment and/or phytoplankton. As chlorophyll a levels are low, the former is most likely. This could result in the release of nutrients into the water column; however, as inorganic nutrients do not appear to correlate very significantly the influence of any nutrient release of this nature on phytoplankton growth is minor.

Temperature is the next most significant parameter, and this suggests that phytoplankton changes are dominated by seasonal temperature changes.

Some of the organic N and P in the water is tied up in the phytoplankton, the remainder probably originates from wind stirring of sediments, and trade wastes and is unavailable for phytoplankton uptake. Inorganic nitrogen shows some correlation with chlorophyll, which suggests that these levels may at least partly control or limit phytoplankton growth. From Table 3.1 all the parameters measured account for up to 46.1 per cent of the variability of phytoplankton growth, indicating that factors other than nutrients and physico - chemical have a strong influence on growth of phytoplankton.

Nevertheless the spread of the chlorophyll levels is not very wide, and the levels are low, and it is not surprising to find rather poor correlations in such data sets. Water circulation may also disperse nutrients from outfalls before phytoplankton populations can significantly increase.

3.4.4 N:P Ratios

Generally the N:P ratios (Table 3.4) indicate that, if a nutrient is limiting phytoplankton growth, then that would be nitrogen rather than phosphorus, particularly in the harbour. If N:P (calculated for the inorganics per atom) is between 10:1 and 15:1 in seawater, neither nitrogen nor phosphorus are considered limiting (Riley and Chester, 1971).

3.4.5 Industrial Discharge

Of the industrial discharges (Table 3.5 and 3.6), Borthwicks is the major source of N and P. However, during periods of peak flow of the main drain, this nutrient source also becomes important.

The main drain discharges near the ASPC discharge point, and coloured water from the drain has been observed along the shore as far as the Town Jetty. A further analysis of the drain effluent would be necessary to determine the contributions of the ASPC discharge to start of the discharge from both sources.

Nutrient levels in the drain at Elleker Road almost certainly originate mainly from the fertiliser plant and to a lesser degree the Robinson Estate (Government Chemical Laboratories Report, 1978). The Frenchman's Bay sample point provides data for the effluent prior to its release into the harbour, and by difference the contribution from the farmland down stream from the fertiliser plant can be calculated. Using the yearly average data in Table 3.6, all of the P and 79 per cent of the N of this drain comes from ASPC. During periods of high flow (Table 3.5) the farmland contributes 36 per cent of the P and 39 per cent of the N. The data of Table 3.6 even suggest that the farmland may act as a sink for P at times, probably during low flow periods.

3.4.5 (Cont'd)
Comparing the main drain input with the ASPC discharge point, the drain discharges approximately 29 times more P and 700 times more N. It can be assumed that the drain is the major nutrient source of this area, deriving most of its nutrient from runoff from the ASPC plant. To evaluate this further, the drain could be sampled upstream from the ASPC plant.

3.4.6 Nutrient Distribution and Cruises
A comparison of the SYMAP maps for the three cruises, February, June and August give some insight to potential problem areas. However, as the data show, the picture is not clear cut. A brief description of each cruise is in order.

1. February Cruise (Figure 3.3a). The area where PO_4-P levels are highest extends from the wharf area past the discharge points and across the shallow western shelf.

   Within this area there are two regimes of high organic P, one from SOFP to AWM, and the other in the southwest of the shelf. The highest levels of PO_4-P are adjacent to the TB and ASPC discharge points. PO_4-P and organic P levels are also high in the channel leading to King George Sound. High levels of inorganic nitrogen occur in the channel, and in an area which extends from the PWD discharge to station 6 off Wooding Point. High levels of organic nitrogen occur in three areas, adjacent to the PWD outfall, on the east side of the Central basin, and on the western shelf. Phytoplankton biomass (chlorophyll a) levels are highest in the deeper area of the harbour and extending to the SOFP and TB discharge points.

   During the period of sampling all industries were discharging and the tide was flowing out with a SE wind blowing. The calculated exchange was 32 per cent out during sampling period.

2. June Cruise (Figure 3.4a) The high PO_4-P concentrations are more localised in two areas: An area between TB and HC(e) where the highest levels occur, and an area on the western shelf between ASPC and just east of HC(w). Organic phosphorus levels are highest on the western shelf and a small area on the eastern shelf.

   Inorganic nitrogen levels are highest in the station 6 zone. NH_4-N levels are also significant in a band extending from the PWD to AWM. This is illustrated in the map of bottom water. The high maximum range of the surface class intervals resulting from the high NH_4-N value at station 6 has marked the distribution of low levels. Phytoplankton biomass levels are highest on the shallow shelf and around discharge points.

   SOFP and ASPC were not processing, and TB were operating one mutton chain, a strong NW wind was blowing and tidal exchange was reduced to 16 per cent flowing in during the period of sample collection.

3. August Cruise (Figure 3.5a) PO_4-P levels were higher on the western shelf between HC(w). Organic P was low at the discharge

3.4.6 (Cont'd)

points, with the exception of the PWD outfall. The two areas of highest organic P levels are the southwest of the western shelf and on the eastern side of the harbour adjacent to Geak Point at station 109.

There are two areas of high NH_4-N levels, one on the western shelf and extending around to HC(e) (see surface and bottom maps), and the other, the typical surface high concentration, extending from the PWD to Middleton beach. A third area of NH_4-N is over the southeast shelf to the east of the yacht club.

NO_3/NO_2-N levels are highest on the western shelf near ASPC with some indication of higher NO_3/NO_2-N levels at the yacht club. Organic nitrogen levels are highest on the southwest of the eastern shelf where the highest level of organic P is present. Organic nitrogen levels are also high in the Central Basin and in a band from AWM to the PWD.

Phytoplankton biomass levels are highest in the Central Basin.

SOFP and ASPC were the only industries not in production during sampling. Tidal exchange was 12 per cent with flow inwards during the sampling period. Wind conditions were light, probably not having much influence on the system.

3.4.7 Conclusions of Cruise Data

Nutrients and phytoplankton

The areas of highest nutrient levels are the western shelf, the wharf front and the station 6 area (Wooding Point). Phytoplankton biomass levels are not readily related to zones of high nutrient levels, and is consistent with the statistical data showing poor correlation between the two (Section 3.4.3). No doubt relatively rapid water movement accounts in part for this poor relationship, as water containing higher concentrations of nutrients may be dispersed before phytoplankton populations can substantially increase. Wind conditions are generally fairly high, class 2 to class 3, which, for example, is necessary to drive the Cockburn Sound wind driven model (Steedman and Craig, 1979). Tidal exchange averages 24 per cent, as noted earlier, and volume flux exceeded this during some of the cruises.

A problem could occur during any long periods of low wind activity (class 1 and 2) when nutrient resident time might increase, and this could result in a phytoplankton bloom. This would only last as long as the low wind conditions prevailed, after which phytoplankton would be dispersed and presumably flush out to the Sound. However, no such blooms were encountered in the present study.

The cessation of SOFP activities appeared to have little impact on nutrient levels in the wharf area, as did the reduction of TB operations in June. This was overshaddowed by the continued discharge of HC and the drain near ASPC.

Problem Areas

1. Middleton Beach. A band of relatively high concentration, on the maps, always links the PWD discharge with Middleton Beach and suggests that there may be a plume of water from the outfall to the beach irrespective of transient changes in wind direction.

3.4.7 (Cont'd)

Higher levels of nutrients at station 6 compared to station 15 indicate a nett accumulation of nutrients in that area. The highest levels of phytoplankton biomass encountered in the study have also been recorded in this zone. Although these levels are still low, the possibility that they may reach bloom conditions must be viewed with some concern as this area is a direct contact recreation site.

2. Wharf front. High levels of nutrients were present much of the time, resulting from the presence of several points of discharge. However, these nutrients appear to disperse quickly as high nutrient level areas are localised.

3. Western shallow shelf. High levels of nutrients are present much of the time, spread over a wide area, indicating a longer resident time of nutrients. This is consistent with the salinity distributions which also indicated a longer resident time of waters on the shelf to that of the deeper waters.

   The dominant influence in this area is the main drain discharge, which receives a major portion of its nutrient load from ASPC, on occasions. The drain's plume is visible over a wide area extending across the shelf to the Town Jetty from ASPC. The shallow shelf is also an area of high productivity, with beds of seagrass and macroalgae. The shoreline accumulates drifts of detached seagrass leaves, which decompose. Nutrient cycling is, therefore, important on the shelf; there is some evidence of this on the south eastern part of the shelf where there are no discharges, although high nutrient levels have been observed from time to time.

4. BACTERIOLOGICAL SURVEY

4.1 Introduction

An interim report on this survey was produced in June, 1979 by the Department of Conservation and Environment. This report will incorporate that information plus data collected since then.

The marine and estuarine water quality criteria for direct contact recreation, as proposed by the EPA's Marine and Estuarine Water Quality Criteria Working Group, includes parameters for chemicals and biological materials, faecal coliforms and faecal material (MEWQC Working Group 1980).

The median reading for open and unenclosed bathing and swimming areas is recommended not to exceed 150 organisms/100 mL, and/or in which not more than 20 per cent of samples ordinarily exceed 500/100 mL. Samples collected during the wettest quarterly interval may be omitted if users are not commonly exposed during that interval.

The median level of bacteriological contamination of waters used for mollusc harvesting and culture for food should not exceed 15 faecal coliforms/100 mL, and/or when not more than 20 per cent of samples ordinarily exceed 50/100 mL (MEWQC Working Group 1980).

The median level of contamination of waters used for mussel culture should not exceed 15 organisms/100 mL (MEWQC Working Group 1980).

There are no W.A. bacteriological standards for shellfish. However, the British and United States criteria can be taken as useful guidelines. In the United States, the current recommended wholesale market standard for shellfish is not more than 2.3 faecal coliforms/g.

BRITISH	*E coli* LEVELS	CLASSIFICATION
	Up to 5/g	Satisfactory
	6 - 15/g	Doubtful
	> 15/g	To be regarded with suspicion
U.S.	Up to 24/g	Acceptable
	> 24/g	Public health concern

Table 4.1: British and United States bacteriological standards for shellfish.

This survey was aimed at identifying problem areas with regard to public health risks for swimming, boating and taking of foodstuffs.

4.2 Methods

Water samples were collected directly into sterile bottles and kept in the dark at $4^{o}C$ until delivery to the State Health Laboratories, Perth. Delivery was effected 24 hours after collection.

Samples were analysed for faecal coliforms, *Vibro parahaemolyticus*, and *Salmonella*.

Mussels were collected at several sites where contamination was thought to be highest. These were sent for analysis with the water samples.

4.3 Data

Vibro parahaemolyticus was not identified from any of the samples in the survey.

4.3.1 Natural waters

Table 4.2 shows the faecal coliform counts for the natural waters.

Salmonella isolations are indicated by a superscript. Station 5 (Middleton Beach) is of interest from a direct contact recreation point of view, while the other sites are secondary recreation areas. Stations 60 to 109 are in the shipping area where public access is limited. Stations 58, 60, 73 to 149 were not included in the initial sampling programme due to limitations on analyses.

4.3.2 Mussels (Table 4.3)

With the exception of four samples all mussels were collected from the deep water and Town jetties as these sites had the largest specimens and most prolific numbers. Mussels from the deep water jetty were heavily contaminated for most of the time. Town jetty mussels are also contaminated to a lesser degree than the deep water jetty. It should be noted that although these levels are sometimes in the acceptable range, *Salmonella* serotypes have been isolated from the sample.

4.3.3 Industrial discharge

The five industries processing foodstuffs and waste were monitored for coliform counts, *Vibro* and *Salmonella* isolates. Table 4.4 shows that as expected PWD and TB have consistently high coliform counts and frequent *Salmonella* isolations. HC(w), HC(e) and SOFP also show consistently high coliform counts. The two HC factories showed *Salmonella* isolations on several occasions.

Table 4.5 lists the different *Salmonella* isolates identified from each of the effluents. As expected the greatest diversity exists in TB and PWD where the waste is derived from warm blooded animals and people. Note that *S. havana*, *S. adelaide* and *S. typhimurium* identified from the HC factories, which process fish and vegetables, also occur in the TB and PWD effluents.

4.4 Discussion

When compared with the proposed direct contact recreation criteria (refer to Section 4.1 and Table 4.2, the results of the sampling at Middleton Beach (station 5) revealed that only two out of eleven samples (18 per cent) exceeded the proposed median level, and none exceeded the proposed 80th percentile.

TABLE 4.2

FAECAL COLIFORM COUNTS (COLIFORMS/100 ML) IN NATURAL WATERS
Salmonella Serotypes indicated by superscript

DATE \ PR	5	6	15	25	37	58	60	61	63	65	67	73	99	103	106	109	126	145	149
31.01.79	43	460	460	9	11			0	9	15	43[3]								
28.02.79	460	N/R	N/R	N/R	23			0	240	240	9								
27.03.79	0	0	1100+	23	15			0	1100+	1100+	1100+								
01.05.79	0	0	15	93	93			0	15[1]	43	150[1]								
22.05.79	93	21	0	15	93			4	240	43	240								
19.06.79	0	1100+	0	0	43			15	1100[6]	150	150								
25.07.79	460[4]	N/R	N/R	150[5]	460[5]			4	23	15	15								
14.08.79	0	0	460[7]	15	0			15	21	0	0								
12.09.79	N/R	0	1100[7]	290	1100	0	93	15	150	20	7	0	43	9	15				
10.10.79	0	0	150	240[8]	43	N/R	240[8]	23[8,2]	93	240[8,2]	0	N/R	9[8]	4	9	0		0	0
06.11.79	0	N/R	N/R	93	240[2]	43	0	0	43	460[2]	240[2]	4	21	23	240[2]	43		240	
04.12.79	4	0	0	0	3	0	0	0	4	0	93	4	4	9	0	0	0	0	0

[1] *S. adelaide*
[2] *S. bovis morbificans*
[3] *S. havana*
[4] *S. isangi*
[5] *S. muenchen*
[6] *S. potsdam*
[7] *S. senftenberg*
[8] *S. typhimurium*

N/R No Result

TABLE 4.3

BACTERIA COUNTS AND *SALMONELLA* SEROTYPES ISOLATIONS FOR MUSSELS COLLECTED.
VIBRIO PARAHAEMOLYTICUS TESTS WERE NEGATIVE FOR ALL SAMPLES

Site	Counts per gram	31/01/79	27/02/79	27/03/79	01/05/79	21/05/79	19/06/79	24/07/79	14/08/79	10/09/79	10/10/79	05/11/79	04/12/79
Town Jetty	Coliforms	43	1100	4	230	90	23	90	21	2300		2	9
	E. coli	Nil	1100	4	40	4	4.3	90	7	230		1	4
	Salmonella Isolates	-	*saint paul*	*saint paul*	*livingstone* *havana* *adelaide*	-	*saint paul*	*havana*	*infantis*	*alsterdorf*			*bovismorbificans*
Deep Water Jetty	Coliforms	23	43	15	1500	90	430	900	40	46000		240	40
	E. coli	23	43	15	1500	90	430	400	15	4600		240	40
	Salmonella Isolates	*havana*	-	*saint paul*	*meleagrids* *havana* *adelaide*	*typhimurium*	*typhimurium*	+	-	*typhimurium*		*bovismorbificans*	*havana*

\+ *Salmonella* species isolated, no identification

PR 206		4 0 -						PR 58					40 4 *havana*
Wharf						9.3 4.3 -		PR 73					40 4 -

TABLE 4.4

FAECAL COLIFORM/100 ML AND *SALMONELLA* SEROTYPES
ISOLATED FROM INDUSTRIAL DISCHARGES

DATE	HC(w)	SOFP	TB	HC(e)	PWD
31.01.79	110000+ *havana* *isangi*	110000+ -	110000+ *havana* *adelaide* *typhimurium* *wandsbek*	43 -	110000+ *anatum* *muenchen* *typhimurium*
28.02.79	110000 *havana*	110000+ -	N/R	110000 -	N/R
27.03.79	110000+ *havana*	110000+ -	110000+ *saint paul*	110000+ *havana*	110000+ *saint paul* *muenchen* *livingstone*
01.05.79	110000+ *isangi*	150 -	110000+ *adelaide* *anatum*	460 *adelaide*	110000+ *typhimurium* *muenchen*
22.05.79	N/R N/R	N/R	N/R *adelaide* *potsdam* *typhimurium*	N/R	N/R
19.06.79	110000+ -	N/R	110000+ *havana*	110000+ *havana*	110000+ *muenchen*
25.07.79	N/R	N/R	N/R	110000+ -	110000 *typhimurium*
14.08.79	110000+ -	N/R	110000+ *havana*	110000+ -	110000+ -
12.09.79	110000+ *havana*	N/R	110000+ *muenchen*	24000 -	110000+ -
10.10.79	150 -	N/R	110000+ *bovis-morbificans*	110000+ -	110000+ *derby* *muenchen*
06.11.79	1100	N/R	110000+ *give* *bovis-morbificans*	1100 *havana* *isangi*	110000+ *typhimurium* *muenchen*
04.12.79	110000+ -	N/R	110000+ *orion*	2400 -	110000+ *typhimurium*

N/R no record - not isolated

TABLE 4.5

SALMONELLA SEROTYPES IN EACH DISCHARGE AND THE NUMBER OF TIMES THEY HAVE BEEN ISOLATED

EFFLUENT	HC(w)	SOFP	TB	HC(e)	PWD
TYPE	FISH CANNING	FISH PROCESSING	ABATTOIR	VEGETABLE PROCESSING	SEWAGE
Isolate	*havana* (4) *isangi* (2)	No isolations	*havana* (3) *adelaide* (3) *typhimurium* (2) *wandsbek* (1) *saint paul* (1) *anatum* (1) *potsdam* (1) *muenchen* (1) *bovis-morbificans* (2) *orion* (1) *give* (1)	*havana* (3) *adelaide* (1) *isangi* (1)	*anatum* (1) *muenchen* (6) *typhimurium* (5) *saint paul* (1) *livingstone* (1) *derby* (1)
Moore swabs	*isangi* *typhimurium* *havana*				

4.5 (Cont'd)
There does not appear to be a seasonal trend or a correlation with wind direction (refer to Table 2.1). Other factors such as water movement and industrial discharge volume are unknown. In addition the mean value for the sampling period was 96 faecal coliforms/100 mL. This is below the level recommended for swimming waters presented in Section 4.1.

Station 6 on occasions has high coliform counts. It is also an area of nutrient accumulation, apparently derived from sewage. The interim report highlighted the need for regular monitoring of Middleton Beach waters during summer. The further sampling has shown that this monitoring should be extended to all year.

The harbour waters are in general satisfactory but sometimes becoming slightly polluted. The waters in the wharf area are slightly polluted much of the time.

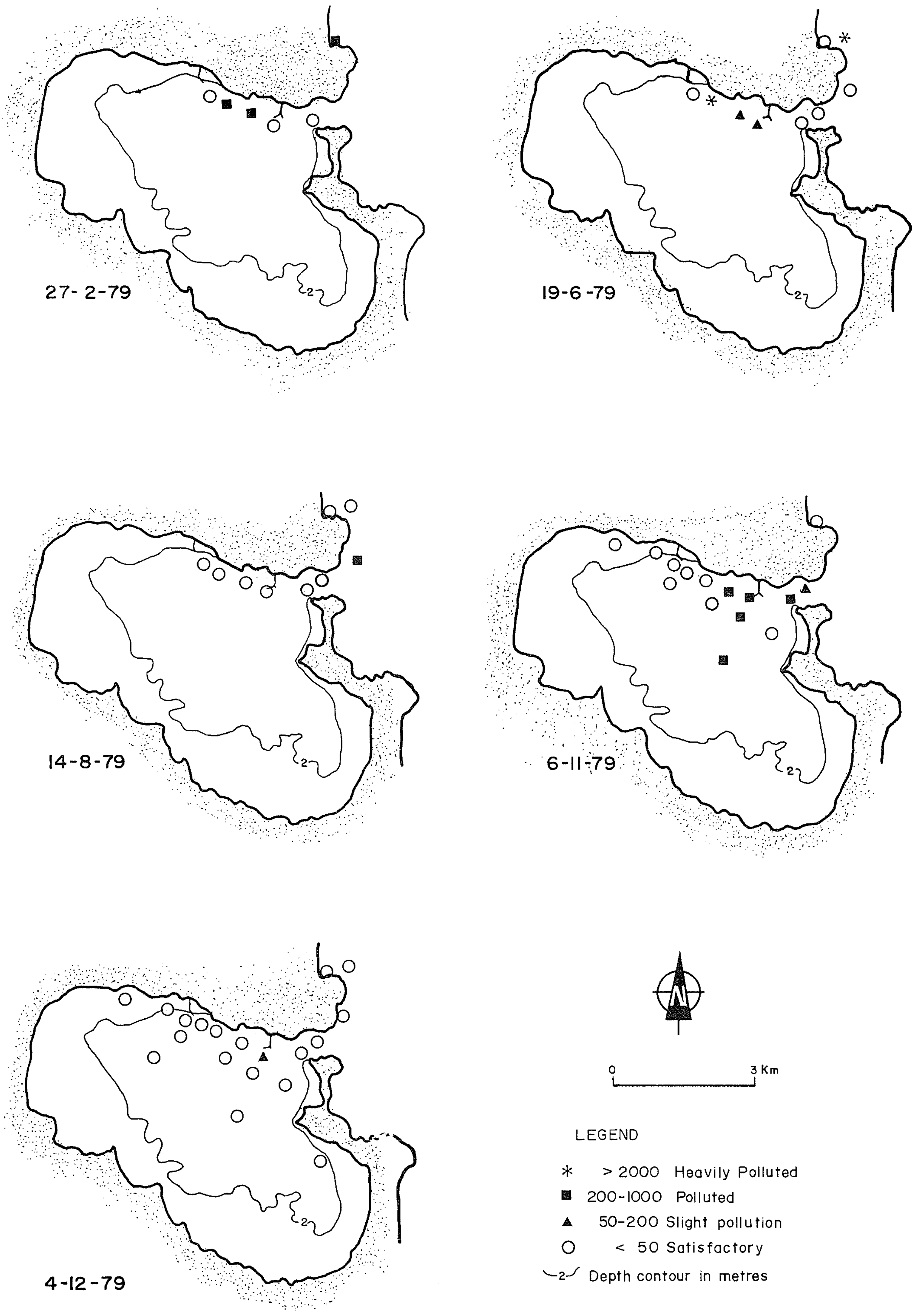
Figure 4.1 shows the bacteriological water quality for each of the cruises used in the SYMAP interpretation. These data do not give any indication of sewage intrusion into the harbour or of very significant movement of coliforms along the wharf area.

The results of the extended sampling programme; (6.11.79, 4.12.79) are also shown in Figure 4.1. The results of the monitoring at 6.11.79 show that industrial discharge can on occasions extend its influence well into the harbour. The conditions under which this occurs are not known.

The level of bacteriological contamination in mussels is high, which is to be expected as the waters in which they grow have coliform levels higher than the acceptable level of 15 coliforms/100 mL. Mussels should not be harvested and used for human consumption unless they are adequately cooked. This recommendation has already been made in the interim report.

Salmonella contamination
The levels of contamination and *Salmonella* serotypes isolated from mussels throughout the survey period are detailed in Table 4.3. At the Town Jetty site *Salmonella* comprising seven serotypes were isolated from eight (73 per cent) of the mussel samples, and at the deep water jetty five serotypes were identified in eight (73 per cent) positive samples. Multiple *Salmonella* serotype isolations were recorded from two samples. Altogether a total of 17 (65 per cent) mussel samples were contaminated with *Salmonella* and 21 isolations comprising nine serotypes were recorded.

S. havana, *S. typhimurium* and *S. saint-paul* were the dominant serotypes and of the nine serotypes detected in mussels, six serotypes including the three major strains were associated with nearby abattoir or industrial discharges. *S. typhimurium*, *S. livingstone* and *S. saint-paul* were also isolated from both mussels and sewage effluent. *Salmonella* input from abattoir and sewage outfalls has also been implicated as a primary source of *Salmonella* contamination in coastal waters and mussels in the Owen Anchorage area during an earlier survey conducted from March 1977 to April 1978 (Iveson 1979).



BACTERIOLOGICAL QUALITY OF HARBOUR WATERS - faecal coliforms/100ml

Figure 4·1

4.4 (Cont'd)
A surprising finding from the monitoring programme was the high faecal coliform readings that were consistently found from the fish and vegetable processing plant effluents (Table 4.4). In addition a number of *Salmonella* serotypes were regularly isolated from the two Hunt's canning plant effluents.

Epidemiologically these findings clearly indicate the presence of a significant health hazard and the need to site public recreation areas a safe distance from abattoir and sewage outfalls. A wide diversity of *Salmonella* serotypes are constantly discharged in these effluents including the major strains responsible for sporadic cases and outbreaks of food poisoning *Salmonellosis* in humans.

In this Study, *S. havana* was the major strain isolated from mussels and the serotype was also detected in nearby industrial discharges associated with fish canning, vegetable processing and abattoir operations. *S. havana* is classified as a major human pathogen throughout agricultural and urban areas of Western Australia. However, in the present survey, *S. havana* was not isolated from sewage at the coastal outfall site or implicated in cases of *Salmonellosis* among Albany residents or visitors, either during the survey period or in the previous 20 years since records of human cases began.

Records of the Public Health Enteric Diseases Unit which are included in Table 4.6 also revealed that prior to 1979 in a total of 109 laboratory confirmed cases of *Salmonellosis* in Albany, *S. typhimurium* was the major human pathogen and was responsible for 88 (64 per cent) of all laboratory confirmed *Salmonella* cases. However, no human cases due to *S. typhimurium* or any of the other 16 serotypes identified to date in Albany residents have been linked with aquatic based activities including consumption of local shellfish.

Coincidentally with the 1979 survey, a marked increase in *Salmonella* cases occurred in Albany and a total of 28 cases were diagnosed compared with only two cases in 1978. The upsurge in cases, particularly those involving *S. muenchen* which was isolated during 1979 for the first time in human residents in Albany, was not linked to a local epidemiological circumstance, but was associated with a major outbreak of food poisoning traced to the sale of infected poultry produced in the Perth metropolitan region. The increase in human cases was also reflected in the prevalence of this serotype in sewage at the outfall site close to Middleton Beach.

Seasonal analysis of human cases revealed that 21 (75 per cent) of the *Salmonella* infections occurred in Albany during the late summer early winter March-June period, an interval which does not coincide with the local seasonal vacation and peak tourist activities (Table 4.7). *Salmonella* contamination in mussels, abattoir effluents and sewage occurred throughout the year and no significant changes were noted during the monthly sampling runs.

It is well known that the vast majority of sporadic cases of human *Salmonellosis* are rarely traced to the source of the infection, and the absence of human cases associated with aquatic based recreational activities and the harvesting of shellfish from waters subjected to

TABLE 4.6

COMPARISON OF *SALMONELLA* SEROTYPES ISOLATED FROM HUMAN CASES IN ALBANY (1954-1979 INC) AND ISOLATIONS FROM EFFLUENTS, MUSSELS AND WATERS DURING THE 1979 SURVEY PERIOD

SEROTYPE	HUMAN CASES			EFFLUENTS						
	1978	1979	1954 to 1979	Fish Canning	Veg Pro-cess	Abatt oir	Sewage	Mussels	Sea Water	Totals
*S.adelaide**	.	.	1	.	1	3	.	2	2	9
S.alsterdorf	.	.	.	.	.	.	.	1	.	1
*S.anatum**	.	.	.	.	.	1	1	.	.	2
*S.bovis-morb.**	.	1	9	.	.	2	.	2	3	17
S.bredeney	.	.	1	.	.	.	.	.	.	1
S.chester	.	1	3	.	.	.	.	.	.	4
*S.derby**	.	1	3	.	.	.	1	.	.	5
*S.give**	.	.	1	.	.	1	.	.	.	2
*S.havana**	.	.	.	5	3	3	.	6	1	18
S.infantis	.	.	.	.	.	.	.	1	.	1
S.isangi	.	.	.	3	1	.	.	.	1	5
*S.livingstone**	.	.	.	.	.	.	1	1	.	2
S.meleagridis	.	.	2	.	.	.	.	1	.	3
S.muenchen	.	12	12	.	.	1	6	.	2	33
S.newport	.	.	5	.	.	.	.	.	.	5
S.orientalis	.	.	1	.	.	.	.	.	.	1
S.orion	.	.	0	.	.	1	.	.	.	1
S.para B/java	.	.	2	.	.	.	.	.	.	2
S.potsdam	.	.	1	.	.	1	.	.	1	3
S.richmond	.	.	1	.	.	.	.	.	.	1
*S.saint-paul**	.	1	1	.	.	1	1	4	.	8
*S.senftenberg**	.	.	.	.	.	.	.	.	2	2
S.thompson	.	.	1	.	.	.	.	.	.	1
S.typhi	.	.	4	.	.	.	.	.	.	4
*S.typhimurium**	2	12	88	1	.	2	5	3	5	118
S.wandsbek	.	.	.	.	.	1	.	.	.	1
S.species	.	.	1	.	.	.	.	.	.	1
TOTALS	2	28	137	9	5	17	15	21	17	251

Note: During 1976 *S.oranienburg* (11), *S.havana* (6) and *S.typhimurium* (1) were isolated from gull droppings and *S.saint-paul* (1) during the 1979 survey.

footnote: * prevalent in abattoir effluents and sewage (SHLS Annual Report, 1977)

TABLE 4.7

MONTHLY DISTRIBUTION OF HUMAN CASES AND SALMONELLA SEROTYPES ALBANY 1979

SALMONELLA SEROTYPES	Monthly Totals of Human Cases												TOTALS
	J	F	M	A	M	J	J	A	S	O	N	D	
S.bovis-morbif.	.	.	.	.	.	.	.	.	1	.	.	.	1
S.chester	.	1	.	.	.	.	.	.	.	.	.	.	1
S.derby	.	.	.	.	.	.	.	.	1	.	.	.	1
S.muenchen	.	1	4	5	1	1	.	.	.	.	.	.	12
S.saint-paul	.	.	1	.	.	.	.	.	.	.	.	.	1
S.typhimurium	.	.	3	2	2	2	.	.	1	.	1	1	12
TOTALS	0	2	8	7	3	3	0	0	3	0	1	1	28

4.4 (Cont'd)
contamination, does in no way detract from the need to maintain adequate standards and upgrade as necessary current waste disposal procedures, particularly in coastal areas subjected to the increasing pressures of public recreation.

In previous years, for example in 1958 (Public Health Report 1958), a number of typhoid fever cases in Perth were linked with swimming at a metropolitan beach site accidentally subjected to sewage contamination, and in 1967 estuarine mussels harvested in the Fremantle area and consumed without adequate cooking, were implicated as the source of *S. typhimurium* infection in two children admitted to hospital with severe gastroenteritis (Public Health Department Records 1967). More recently in the Owen Anchorage/Fremantle coastal area (Iveson 1979), attention has been drawn to the public health significance of the discovery of *Salmonella* infections in seagulls and their involvement in a chain of infection which included waste disposal sites, swimming pools, water storage facilities, and island breeding colonies. It was noted in the Cockburn Sound Environmental Study (Iveson, 1979) that infected carrier birds may be responsible for *Salmonella* contamination in mussels on beacons and buoys located out of range of the dispersal potential of contaminated abattoir effluents and sewage.

Numerous Silver gulls were observed on occasions at the Albany sampling stations. However, in the present survey bird investigations were limited to one sampling run comprising the collection of pools of bird droppings at five locations where birds congregated. *S. saint-paul*, a serotype also isolated from local mussels, abattoir effluents and sewage was recovered from one sample. In a previous study by the Enteric Diseases Unit (unreported) *S. havana*, *S. typhimurium* and *s. oranienburg* were isolated from 12 out of 13 pools of gull droppings collected at the Cheynes beach site close to Albany.

An interesting and as yet unexplained epidemiological finding during the present Princess Royal Harbour survey was the isolation on several occasions of *S. isangi*, a serotype not previously identified in Western Australia.

S. isangi was first isolated in January from the Albany fish canning discharges. Subsequent isolations were recorded from the same site in May and from the nearby vegetable processing factory in November. In July *S. isangi* was also isolated from seawater collected at the Middleton Beach swimming site. A single human infection was diagnosed during late January 1979, in a patient from Katanning. Apart from these isolations in Albany and Katanning no further *S. isangi* have been recorded either from humans, effluents, foodstuffs, livestock or wild animals in Western Australia.

5. GENERAL DISCUSSION AND CONCLUSIONS

5.1 Water Quality

Overall nutrient levels are low, with little seasonal variation. The levels are similar to those found in mesotrophic freshwaters and CSIRO data obtained from the 50 m station off Rottnest Island (Chiffings, 1979). This would suggest that the harbour is sufficiently well flushed to cope with present nutrient loads. Nitrogen-to-phosphorus ratios suggest that, of these nutrients, nitrogen is more likely to be limiting phytoplankton growth. Chlorophyll a levels are also low with little seasonal variation. Because of the low levels and restricted range of chlorophyll a and nutrients, all of the measured parameters (physical and chemical) accounted for only 46 per cent of the variance in chlorophyll a values.

The bacteriological quality (Section 4.1) of the harbour water, away from the shipping zone, is from satisfactory to slightly polluted. The bacteriological quality of the water in the wharf area is poor.

5.2 Industrial Discharge

Data from the Government Chemical Laboratories Report (1978) show that Borthwick's Abattoir and the main drain are the two most important nutrient inputs into the harbour. Although no data on nutrient loads are available the PWD outfall must also be considered important with respect to Middleton Beach.

With the exception of ASPC and AWM all the discharges are heavily loaded with faecal coliforms and 15 seroptyes of *Salmonella* were isolated. Forty six isolations were identified during the period of sampling (Table 4.7). These discharges are largely responsible for the poor bacteriological quality of some areas of the harbour and Sound. This is shown by the number of *Salmonella* serotypes derived from warm-blooded animals, which were isolated in the discharges and waters (Table 4.6).

5.3 Problem Areas

The location of the three major discharges creates three areas of concern.

(1) Middleton Beach; a primary contact recreation area where nutrient levels could result in phytoplankton levels reaching bloom condition under poor water mixing conditions, especially if discharge rates were raised. Occasional high faecal coliform levels occur and indicate the need for continuing monitoring.

(2) Wharf front; an area where public access is limited. Nutrients appear to disperse sufficiently rapidly before appreciable accumulation occurs in the water column. Bacteriologically this area is polluted, and the taking of mussels for consumption is not recommended as high levels of *E. coli* have been observed and *Salmonella* serotypes are regularly isolated.

(3) Western Shallow Shelf (extending from the Sailing Club around the flats to Town Jetty); the main drain near ASPC is the major nutrient source. The area is characterised by reduced water movement, higher nutrient levels and higher productivity. Chiffings (pers. comm., 1980) has observed beds of seagrass in

A.W. Chiffings, Department of Conservation and Environment.

5.3 (Cont'd)

the deeper areas of the wharf. The presence of macroalgae has been observed in the shallower areas in association with seagrasses, e.g. *Posidonia* and *Zostera*. Some accumulation of algae was observed on the shoreline at station 201 in November, 1979.

High nutrient levels over seagrass beds can result in their degradation and ultimate loss giving rise to erosion of the sediments on the shelf and loss of benthic life such as mussels and worms which live in these sediments (Cambridge, 1979).

Macroalgae could grow to nuisance proportions in this area where nutrients are higher and water movement is reduced. This will result in large 'drifts' of algae accumulating in the shallow water and shoreline, where it will decompose releasing unpleasant odours and leave a black ooze over the sandy bottom (McComb *et al*).

5.4 Water Movement

Estimates of water exchange with the Sound were based on tide data and the information extracted from the Government Chemical Laboratories report (1978). Viewed with the salinity data we can say that exchange with the ocean is sufficient to allow dispersal of nutrients in the deep water, with nutrients released on the shallow shelf accumulating to some degree before dispersal.

5.5 Conclusions

(1) Water movement is important for the understanding of nutrient dispersal from discharges and the ultimate fate of these nutrients in the harbour system. Little is known of this and it is recommended that a study of the currents and tidal influence on the harbour be carried out. This should include waters in King George Sound outside the harbour and adjacent to Middleton Beach.

Water movement within the harbour and the relationship between waters on the marginal shelf and those in the deeper regions need to be understood. It would also be useful to obtain an understanding of where harbour waters go after they enter King George Sound, and how much of the water expelled on an ebb tide returns to the harbour on the next flood tide.

(2) Industrial Discharge

(a) Effluent should not be released in shallow near-shore areas as poor dispersal allows nutrients to accumulate. If industries are to continue discharging into the harbour this should be done in the shipping area where there is minimum public contact and maximum dispersal of nutrients.

(b) Release of industrial discharge at King Point or near there should be treated with caution. Three considerations are, firstly, effluent accumulation at Middleton Beach causing a deterioration of water quality; secondly, some of the discharge may move back into the harbour on flood tides; and thirdly, releasing sewage effluent which is high in nitrogen, with other effluents which are high in phosphorus, could result in phytoplankton blooms.

5.5 (Cont'd)

(c) The possible extension of the PWD outfall farther into the Sound should be investigated, particularly with regard to water movement.

(d) Some discharges result in visual plumes consisting of suspended solids (Government Chemical Laboratories, 1978) which are unpleasant to look at, and physical contact is undesirable. Steps should be taken to reduce this. Plumes have been observed from Borthwicks and the PWD outfall during sampling.

(e) ASPC Discharge; the input of this industry into the main drain should be investigated to determine firstly how much of the nutrient levels observed at Elleker Road site are attributable to ASPC and how much comes from the catchment upstream, and secondly by what process the nutrients from ASPC find their way into the drain.

(3) Further Sampling

Some regular monitoring should be continued to maintain some confidence in the water quality of the harbour and Middleton Beach. Bacteriological monitoring of Middleton Beach appears essential.

Some intensive periods of sampling are required during conditions of low wind and water movement, both during winter and summer. From this we should be able to say whether phytoplankton can reach bloom conditions during these periods of low energy.

(4) Sediments

It has been said that nutrients accumulate at Wooding Point and on the Western shallow shelf. An analysis of the nutrient levels of sediments in these and similar areas, where the influence of industrial discharge is less, should give more information on whether nutrients accumulate long enough to be assimilated into the sediments. A heavy metal analysis of these sediments would also contribute to the information on discharge effects.

(5) Biological Survey

It would be useful to have more details about the benthic flora and fauna of the harbour. A list of at least the species dominant and a general assessment of the health of some organisms, could be made, and in particular the distribution of seagrasses carefully mapped for future reference, since it appears that loss of these plants provides a useful and important means of documenting a decline in water quality (Cambridge, 1979).

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The field assistance of various people from the Department of Conservation and Environment and the Botany Department, The University of Western Australia, is also acknowledged.

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APPENDIX 1.

REPORT ON EFFLUENT SAMPLES FROM ALBANY - JUNE 1979

by

N. Platell

Government Chemical Laboratories
Plain Street, Perth, Western Australia

GOVERNMENT CHEMICAL LABORATORIES

30 Plain St., Perth, Western Australia 6000.
Telephone: 325 5544

Address all correspondence to The Director

Director
Dept. of Conservation & Environment
BP House 1 Mount Street
PERTH WA 6000

Attention: Dr. R. Field

OUR REF

YOUR REF

ENQUIRIES TO

EFFLUENT SAMPLES FROM ALBANY - JUNE 1979

As arranged through Dr R. Field, Mr H.D. Cocke of these Laboratories accompanied your officers to Albany and collected effluent samples while your officers were engaged in their regular monitoring activities.

Due to permanent cessation of activities of the "Southern Ocean Fish Processers" and temporary cessation of activities of the "Albany Superphosphate Co", samples from these sources were not collected.

Where applicable, the collected samples were bulked for each industry, in an identical manner to that used in the quarterly monitoring programme between April 77 and January 78 and outlined in our Report of Investigation No. 19.

For ease of comparison, included with the current set of results are the average values obtained in the previous monitoring programme (previous values in brackets).

The most notable changes, which are not necessarily significant when due consideration is made for the type of sampling undertaken, occurred at Borthwicks where the flow rate was reduced because there was only one mutton chain in operation; and at Hunts at Short St where the effluent contained only about one tenth of the usual level of contaminants.

N. PLATELL
CHIEF
WATER DIVISION

30th July, 1979. DT

7

GOVERNMENT CHEMICAL LABORATORIE
30 Plain Street, Perth, Western Australia 6000
Telephone: 325 5544
Address all correspondence to the Director

Director
Dept. of Conservation & Environment
BP House 1 Mount Street
PERTH WA 6000

Attention: Dr R. Field

OUR REF:
YOUR REF:
ENQUIRIES TO:

30th July, 1979. DT

MATERIAL Ten samples of effluents from Albany, marked as below.

LAB No 83598-607/79

FROM WHOM RECEIVED AND DATE Dept. of Conservation & Environment on 22nd June, 1979.

RESULT OF EXAMINATION

Marks:

Borthwicks	9am	$40m^3/hr^*$
Borthwicks	3pm	$40m^3/hr^*$
Hunts Semaphore Pt No. 1	8am	$1.3m^3/hr$
Hunts Semaphore Pt No. 1	2.30pm	$0.45m^3/hr$
Hunts Semaphore Pt No. 2	2.30pm	$12m^3/hr$
Hunts Short Str	1.30pm	$16m^3/hr$
Albany Woollen Mills	2.30pm	$6m^3/hr^*$
Albany Woollen Mills	4.00pm	$6m^3/hr^*$
PWD Drain Elleker Rd	10.30am	$340m^3/hr$
PWD Drain Frenchman's Bay Rd	11.00am	$1500m^3/hr$

*These flow rates were assumed from information provided by the industry.

../2

Sample	Borthwicks	- - - Hunts - - - Semaphore	Short	Albany Woollen mills
Lab.No.	83598-99	83600-02	83603	83604-5
Flow rate m^3/hr	40* (190)	6.9 (10)	16 (18)	6 (6)
pH	6.7 (6.9)	6.9 (6.1)	7.1 (6.5)	7.0 (6.8)
		mg/l		
Suspended solids	960 (1040)	160 (240)	170 (1340)	170 (76)
Oil and grease	700 (780)	50 (44)	60 (890)	100 (29)
B.O.D.	1240 (2120)	410 (510)	180 (3190)	96(290)
Nitrogen, N (kjeldahl)	81 (106)	74 (62)	54 (570)	13 (17)
Phosphorus, P (total)	21	7.1	7.5	17

Sample	Elleker Rd drain	Frenchman's Bay Rd drain
Lab.No.	83606	83607
Flow rate m^3/hr	340	1500
pH	4.6 (4.7)	6.9 (6.5)
Colour APHA units	240 (300)	330 (290)
Turbidity APHA units	12 (16)	6 (12)
	mg/l	
Total soluble salts	890 (1030)	790 (850)
Nitrogen, N		
ammonia	3.1 (0.87)	1.0 (0.53)
nitrate	0.35(0.24)	0.67(0.32)
Phosphorus, P (total)	7.6 (6.8)	2.7 (2.9)
Fluoride, F	2.8 (3.5)	1.2 (1.8)

*This figure could not be measured due to the changed disposal system since 1978. The figure supplied by the Engineer appeared to be commensurate with the activity for that day.

N Platell

N. PLATELL
CHIEF
WATER DIVISION

APPENDIX 2

DATA TABLES

MONTHLY RAINFALL TOTALS FOR ALBANY AIRPORT 1979

(supplied by Meteorological Station, Albany)

MONTH	RAINFALL (mm)
January	15.2
February	41.0
March	38.6
April	20.6
May	128.0
June	100.0
July	114.2
August	112.0
September	89.4
October	68.2
November	61.6
December	13.2
TOTAL	802.0

PHYSICO - CHEMICAL DATA

Mean and (standard deviation) calculated by computing the mean of surface and bottom of each station and computing the mean for all stations in the group

SALINITY $^{o}/oo$ S			
Date	KGS	HS	HD
19.12.78 D	-	36.8 (0.1)	36.9 (0.1)
31.01.79 J	36.4 (0.4)	37.0 (0.4)	36.7 (0.1)
27.02.79 F	35.6 (0.8)	35.2 (1.1)	35.7 (0.1)
26.03.79 M	33.6 (0.2)	34.8 (0.3)	33.5 (0.3)
30.04.79 A	35.8 (0.3)	35.5 (0.1)	36.1 (0.2)
21.05.79 M	35.9 (0.0)	32.9 (1.1)	35.8 (0.2)
18.06.79 J	35.8 (0.1)	30.9 (5.8)	35.5 (0.1)
24.07.79 J	35.3 (0.5)	31.0 (5.6)	35.5 (0.2)
13.08.79 A	35.0 (0.3)	-	34.7 (0.4)
10.09.79 S	35.4 (0.1)	35.4	35.1 (0.2)
10.10.79 O	35.06 (0.05)	34.7	34.9 (0.1)
05.11.79 N	-	36.1 (0.7)	36.1 (0.1)
TEMPERATURE ^{o}C			
D	-	21.1 (1.6)	18.2 (0.2)
J	20.5 (0.4)	19.4 (0.2)	20.4 (0.1)
F	19.1 (0.2)	21.0 (0.9)	19.9 (0.2)
M	19.3 (0.4)	19.8 (0.2)	19.2 (0.2)
A	-	-	-
M	15.7 (0.3)	-	14.3 (0.7)
J	14.6 (0.4)	-	13.1 (0.4)
J	13.6	10.4	12.5 (0.5)
A	15.5 (0.3)	-	15.1 (0.3)
S	14.6 (0.3)	14.0	13.6 (0.5)
O	15.14 (0.5)	13.2	14.6 (0.5)
N	-	18.4 (0.2)	17.2 (0.5)
D	-	-	-

KGS = King George Sound
HS = Harbour Shallows
HD = Harbour Deep

SECCHI DISC DEPTHS IN METRES			
D	-	Too shallow < 0.5 m bottom always visible	1.5 (0.3)
J	4.6 (1.0)		2.9 (0.8)
F	1.4 (0.2)		2.0 (0.6)
M	3.5 (0.7)		2.7 (0.8)
A	8.2 (0.3)		4.4 (1.0)
M	5.1 (0.7)		3.3 (0.7)
J	6.6 (2.1)		4.3 (0.6)
J	2.3		2.7 (0.6)
A	6.7 (1.4)		4.6 (1.0)
S	4.6 (0.7)		3.9 (0.5)
O	4.0 (0.7)		2.7 (0.5)
N	-		2.6 (0.8)
D	8.1 (2.6)		4.0 (0.6)

THE MEAN AND (STANDARD ERROR) FOR EACH CRUISE

Calculated by computing the mean of surface and bottom sample for each station and computing the mean of all stations in each group (Concentration units = $\mu g L^{-1}$)

PO_4-P

	1 19/12/78	2 31/1/79	3 27/2	4 27/3	5 1/5	6 21/5	7 18/6	8 24/7	9 13/8	10 10/9	11 10/10	12 5/11	13 4/12
10	-	5.0 (1.0)	12.0 (4)	3.0 (0)	5.0 (0)	6.0 (4)	5.0 (0)	13 -	4 (0)	4 (0)	4 (0)	5 -	
6, 15	-	6 (1)	9 (1)	6 (1)	5 (1)	3 (1)	5 (1)	-	6 (1)	8 (3)	6 (1)	-	
Harbour	10 (1)	5 (1)	9 (1)	5 (1)	12 (2)	8 (3)	10 (2)	20 (5)	11 (2)	12 (2)	9 (1)	9 (2)	

ORGANIC P

	1	2	3	4	5	6	7	8	9	10	11	12	13
10	-	28 (11)	39 (12)	26 (1)	38 (1)	52 (10)	35 (3)	4 -	3 (0)	4 (0)	11 (0)	6 -	
6, 15	-	28 (6)	68 (9)	22 (2)	34 (8)	47 (14)	49 (4)	-	5 (1)	8 (1)	12 (1)	-	
Harbour	30 (2)	44 (6)	47 (7)	24 (2)	37 (2)	63 (5)	57 (5)	20 (15)	8 (1)	9 (1)	14 (1)	17 (3)	

NH_4-N

	1	2	3	4	5	6	7	8	9	10	11	12	13
10	-	14 (1)	23 (11)	13 (4)	20 (3)	2 (1)	19 (1)	23 -	6 (4)	32 (5)	12 (0)	11 -	
6, 15	-	19 (2)	34 (8)	14 (2)	22 (4)	3 (2)	56 (12)	-	18 (6)	52 (20)	25 (15)	-	
Harbour	21 (1)	18 (2)	26 (2)	15 (1)	28 (5)	13 (3)	20 (2)	26 (2)	11 (2)	32 (2)	17 (1)	12 (1)	

NO_3/NO_2-N

	1 19/12/78	2 31/1/79	3 27/2	4 27/3	5 1/5	6 21/5	7 18/6	8 24/7	9 13/8	10 10/9	11 10/10	12 5/11	13 4/12
10	-	2	3	4	4	2	3	4	2	3	3	2	
6, 15	-	4	5	6	3	3	4	-	3	5	3	-	
Harbour	9	2	4	4	5	4	6	7 (2)	4	5	3	2	
			SE < 1										

CHLOROPHYLL A

10	-	0.9	1.6	1.8	0.4	0.9	0.9	1.4	0.8	0.8	0.4	0.8	
6, 15	-	1.1	1.6	1.8	0.4	1.0	1.0	-	0.7	0.6	0.9	-	
Harbour	3.8	0.8	2.5	2.4	0.8	1.3	0.6	0.8	0.9	1.0	0.8	1.5	
			SE < 1.0										

APPENDIX 3

METHODS USED DURING THE
NUTRIENT ASSESSMENT OF THE
WATER QUALITY OF PRINCESS
ROYAL HARBOUR.

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1. INTRODUCTION

This Appendix gives details of the sampling and analytical methods used during the nutrient assessment of the Princess Royal Harbour. All of the laboratory sample preparation and analysis done during this segment of the Study are carried out in the Wetlands Study Group Laboratory at the Botany Department, The University of Western Australia. This group is led by Associate Professor A.J. McComb.

2. SAMPLE COLLECTION

All water samples, whether for nutrients and chlorophyll a, are collected using a plastic, five litre Niskin bottle made by BCJ Plastics.

Water samples for nutrient analysis are decanted into Whirlpacks (Nasco) and stored on wet or dry ice and kept frozen on return to the laboratory until analysis are to be carried out.

Chlorophyll a samples are filtered on site. Approximately two litres of water is filtered under low vacuum pressure through a 47 mm GFC filter. The filter is air dried by increasing the vacuum, removed with forceps and folded into quarters. The filter is then wrapped in another GFC filter and stored in manilla seed envelopes. The exact volume filtered is noted and all envelopes stored in air tight plastic bags on ice in the dark. On return to the laboratory, a desiccant is usually added and the filters stored frozen until required for analysis.

3. ANALYTICAL METHODS AND QUALITY CONTROL

This section deals briefly with each of the main techniques used, attention being given to reliability.

3.1 Sample Handling

On return to the laboratory samples are deep-frozen until analysed. Ammonia and reactive phosphate are determined within one or two days of collection, the remainder within two or three weeks.

Samples are thawed in a warm water bath just prior to analysis. The Whirlpacks are then shaken vigorously several times, slit open, and two aliquots transferred directly to reaction vessels.

3.2 Capability of Methods

3.2.1 Introduction

Here we consider the capabilities of some of the methods routinely in use in the laboratory. They are ammonium nitrogen, nitrate and nitrite nitrogen, kjeldahl nitrogen, phosphate phosphorus, total phosphorus, and chlorophyll a. Each method is discussed under the following headings:

1. Brief description of the principles of the technique.

2. Working range of the method without dilution of the sample. This is the range over which standards and absorbances are related linearly.

3.2.1 (Cont'd)

3. Recovery. A "spike" of known concentration is added to a sample and the amount "recovered", as determined by the method, noted. The recovery provides a qualitative estimate of the presence or absence of interfering substances. It does not enable the analyst to apply a correction factor to results of an analysis but it does give a basis for judging the applicability of the particular method to the samples being analysed. The parameters required are a blank, a range of standards, duplicate samples, and samples spiked with known amounts of the substance being measured. The spike should be added in sufficient quantity to overcome the limits or error of the method, but not allow the total in the sample to exceed the range of the standards. The blank absorbance should be subtracted from each of the determined values. A standard curve is then drawn, and from this the amount of substance present is calculated -

$$\text{present recovery} = \frac{SK - S}{K} \times 100$$

where K = known spike, S = unknown sample, and

SK = sample plus spike.

4. Precision. This is the reproducibility of a result with the method is repeated on a homogeneous sample under controlled conditions, regardless of whether or not the observed values are displaced from the true value as a result of a systematic or constant error present throughout the measurement. Assuming a normal distribution the standard deviation (σ) is a measure of precision.

$\pm\ \sigma$ = 68.27 per cent confidence

$\pm\ 2\sigma$ = 95.45 per cent confidence

$\pm\ 3\sigma$ = 99.7 per cent confidence

Precision can be expressed as $\pm\ 2\sigma$ of the mean of n replicates, but is sometimes as $x \pm \sigma \div \sqrt{n}$ (i.e. the standard error of the mean), or as per cent.

5. Detection Limit. The lower limit is governed by the precision of the method. The limit of detection should be taken as 3σ where σ is measured for amounts near to the detection limit itself. That is, the amount present should be just significantly different from a blank determination. However, both 2σ and σ are quoted in the literature (Anon. 1971; Strickland and Parsons, 1972), and so both are given here.

The following points should be borne in mind:

1. Our laboratory uses 1 cm path length cells.

2. Recoveries were done on duplicates of samples with standard deviations averaged over 6-10 samples.

3. Determination limits were done on three replicate samples taken from one station.

3.2.2 Determination of Ammonia

Ammonia reacts with cyanurate and phenol, catalysed by sodium nitroprusside, to form the indophenol blue compound, which is then detected colorimetrically. Sample size 100 mL, providing two replicates of 50 mL each (Dal Pont *et al*, 1974).

Working Range 7.0 - 960.0 μgL^{-1} - N

Recovery at 16.0 μgL^{-1}, 114 per cent
at 80.0 μgL^{-1}, 120 per cent

McGlynn (1974) reports 97 per cent recovery at 12.0 μgL^{-1} and 95 per cent recovery at 28 μgL^{-1} using the slightly different Solorzano method (Major *et al*, 1972).

Precision at 12.0 μgL^{-1} the precision (2σ) was 7.8 L^{-1}, over a range of 50 to 300 μgL^{-1}. McGlynn (1974) reported on the Solorzano method at 18.0 μgL^{-1}.

Direction Limit 2σ 4.6 μgL^{-1}

3σ 6.9 μgL^{-1}

3.2.3 Determination of Phosphorus

This method relies on the formation of a phosphomolybdate complex and its subsequent reduction to a highly coloured molybdenum blue by ascorbic acid. The blue colour is then detected colorimetrically (Major *et al*, 1972).

Sample size 40 mL, providing two replicates of 20 mL each.

Working Range 2.4 μgL^{-1} - 1000 μgL^{-1} PO_4 - P
Strickland and Parsons (1972) and Anon (1971) report 1.0 to 1300 μgL^{-1}.

Recovery For a range of concentrations from 6 to 150 μgL^{-1} the recovery was between 95 and 99 per cent.

Precision For a range 1 to 150 μgL^{-1} the precision (2σ) was 1.6 μgL^{-1}. Stickland and Parsons (1972) report a precision of 0.6 μgL^{-1} at 9.3 μgL^{-1} and 0.9 μgL^{-1} at 93 μgL^{-1}.

3.2.4 Determination of Nitrate and Nitrite

Nitrate is reduced to nitrite by a copper-cadmium reduction column. The nitrite then reacts with sulphanilamide under acidic conditions to form a diazo compound, which then couples with n-1 naphthylethylene-diamine dihydrochloride to form a reddish-purple azo dye which can be detected colorimetrically. This method has been adopted for the autoanalyser (Technicon method No. 158 - 81 W).

Sample size 10 mL providing two replicates of 5 mL each.

Working Range 2.7 μgL^{-1} - 500 μgL^{-1}

Technicon quote 1.4 - 2000 μgL^{-1}, and the USA EPA (anon, 1974) 50 - 10000 μgL^{-1}. The higher levels can be achieved by changing pump tubes and using shorter pathlength flow cells, but have not been required in our present work.

3.2.4 (Cont'd)

Recoveries

0 - 50 μgL^{-1} - 101 per cent

50 - 500 μgL^{-1} - 96 per cent

Precision

0 - 10 μgL^{-1} - (2σ) 1.8 μgL^{-1}

Detection Limit

2σ - 1.8 μgL^{-1}

3σ - 2.7 μgL^{-1}

Technical quote 1.4 μgL^{-1}

Column efficiency The ability of the reduction column to reduce all the NO_3^- to $NO_2^=$

$$\frac{\text{Reduced } NO_3\text{-N}}{\text{Reduced } NO_2\text{-N}}$$

0 - 50 μgL^{-1} - 95 per cent

50 - 500 μgL^{-1} - 99 per cent

3.2.5 Determination of Total Phosphorus

Organic phosphorus is mineralised with concentrated perchloric acid, then a total orthophosphate determination is done. The digestion is carried out in 25 x 200 mm test tubes heated in a block digestor (Anon, 1971; McGlynn, 1974) manufactured by Prototype Equipment, Murray Road, Welshpool.

Sample Size 40 mL, providing two replicates of 20 mL each

Working Range 15.6 μgL^{-1} - 1000 μgL^{-1} PO_4-P

Recovery at 50 μgL^{-1} - 90 per cent

at 50 - 250 μgL^{-1} - 98 per cent

Precision 2σ - 10.4 μgL^{-1}

3σ - 15.6 μgL^{-1}

The digestion step has increased the level of variability and accordingly the detection limit. Problems with variable heating in the block digestor lead to a range of normalities in the final digest, which sometimes exceeds the required range for optimal colour development resulting in inaccurate determinations.

3.2.6 Determination of Kjeldahl Nitrogen

Organic nitrogen is converted to NH_4^+ by digestion in concentrated H_2SO_4 in the presence of a mercury catalyst, using a block digestor. Prior to June 1978 the ammonia was recovered from an aliquot of digestate by distrillation, and determined colorimetrically using the cyanurate method (anon, 1971; Atkins, 1978).

The precision of this method was poor for the low levels of nitrogen encountered in the majority of samples handled by the laboratory. Since June 1978 the following Technicon Auto Analyser method has been adopted. An aliquot of digestate is put through the autoanalyser and the ammonia determined by a colourimetric method in which an emerald-green colour is formed by the reaction of ammonia, sodium salicylate, and sodium hypochlorite, catalysed by sodium nitroprusside (Technicon method No. 329 - 74 W/B). The reaction pH is critical and some problems have been encountered in balancing the acidity of the digests with the buffer used in the analyser. The problem is aggravated if the acidity of the digests varies too much because of uneven heating on the block digestor.

Sample size 40 mL, providing two replicates of 20 mL each.

There is no information for recoveries and precision to date. However, some preliminary detection limits have been worked out by digesting a range of standards from 0 to 1800 μgL^{-1} NH_4-N. This showed the lower end of the working range to be somewhere near 200 μgL^{-1}; the overriding problem is that the blank absorbance is too high in relation to the sample absorbance, so that at levels less than 600 μgL^{-1} the reproducability decreases as a result of this. The obvious solution is to digest a larger volume of sample and other steps are being taken to reduce the blank absorbance.

3.2.7 Determination of Chlorophyll a

A known volume of water is filtered through a GFC filter (pore size 1.2 μ). The filter is then stored in the dark in a deep freeze until the extraction can be done. The filter plus phytoplankton is then ground and extracted in 90 per cent acetone. The optical density of the extract is determined using the spectrophotometer. From this chlorophyll a and phaeophytin are calculated (Strickland and Parsons, 1972).

Working Range

This depends on the volume of water filtered.

Precision	at 20 μgL^{-1} chlorophyll a (2σ)	4.2 μgL^{-1}
	at 3 μgL^{-1} chlorophyll a	0.6 μgL^{-1}
	at 5 μgL^{-1} phaeophytin	2.8 μgL^{-1}
	at 0.5 μgL^{-1} phaeophytin	0.2 μgL^{-1}

3.3 Interlaboratory Comparison

3.3.1 Orthophosphate

Two sets of samples were collected in Whirlpacks; one set was analysed in the Botany Department, and the other sent to Mr. N. Dyson, CSIRO, Division of Fisheries and Oceanography, Marmion, Western Australia.

3.3.2 Nitrate

Similarly, two sets of samples (n=26) were collected and one set sent to each laboratory. For the range of concentration 1.4 to 12.0 μgL^{-1} the mean difference was 2.1 μgL^{-1}. Although this correlation was not entirely satisfactory, the techniques at the two laboratories differed, and the one at CSIRO was designed with a higher detection limit than that in use here.

3.3.3 Total Phosphorus

Comparison with Government Chemical Laboratories (Plain Street, Perth) gave the same result, 20.0 μgL^{-1}, for a single sample.

3.4 General Comments

A more complete programme of inter-laboratory comparison involving more than one other laboratory would be of great benefit to this laboratory and the research projects it supports.

The foregoing data on method performance are somewhat tentative, and more detailed analyses are being made. However, the detection limits and precision should not be compared too closely with those given in the literature. The laboratory is at present processing samples in batches of 50 and 100 and sometimes more, and this results in a reduction of precision. If necessary, detection limits and precision can be improved by handling samples in smaller batches and using longer path length cells. When designed sampling programmes attention must be given to the level of precision required to give validity to the data, with respect to trends and background noise.

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