CHAPTER 1: GENERAL INTRODUCTION

1.1 INTRODUCTION

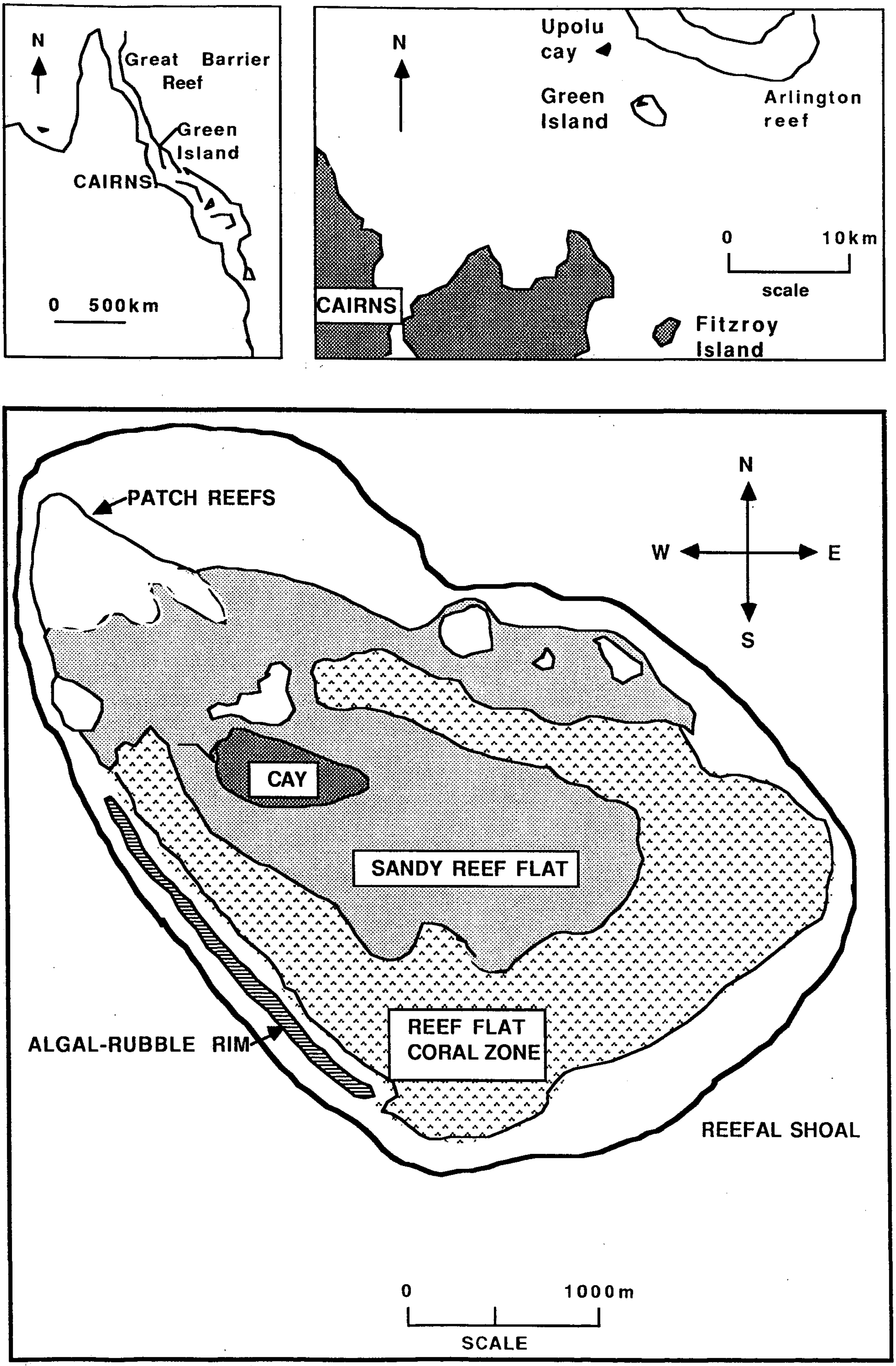
Concern has been expressed that anthropogenic influences ranging from riverine input carrying enhanced nutrient and sediment loads and agricultural fertilisers, to the more localised activities of tourist facilities (sewage discharge, dredging) has resulted in the degradation of inshore reefs in the Great Barrier Reef Marine Park (GBRMP). However, there is a lack of background information on the quantitative effect of waste water on Australian coral reef ecosystems. Case studies at Kaneohe Bay, Hawaii (Smith *et al.*, 1981) and Barbados (Tomascik and Sander, 1985) have demonstrated the deleterious effects of pollution and emphasized the importance of early detection and management to preserve the coral reefs. The most effective means of achieving some form of water quality control is through the setting of ambient water standards. If anthropogenic influences on ambient water quality are to be detected, accurate baseline levels of water quality parameters need to be determined. However, nutrients and a variety of related processes on reefs vary much more than is widely appreciated (Smith and Jokiel, 1975; Kinsey and Davies, 1979; Smith *et al.*, 1981; D'Elia, 1989) over a range of spatial and temporal scales. Recognising the complexity of coral reef systems, consideration of a range of large and local scale phenomena are required to adequately determine changes in water quality which are due to natural processeses and those that are anthopogenically induced. At a regional scale an understanding of the history of the water mass before it impinges upon the reef is necessary (river discharges, planktonic blooms and oceanic upwellings). At a reefal scale, a detailed understanding of the hydrological characteristics of the particular reef as well as the water residency and velocity is necessary. Other factors requiring consideration include nutrient flux between the benthos, sediments and sea water; nutrient input due to groundwater (Marsh, 1977) or terrestrial runoff; and water circulation patterns due to embayments. With regard to the input of anthropogenic material into receiving waters, or the effects of a development, it is difficult to generalise and predict the effects that changes in waste loadings may have on specific areas, or the cumulative effect over time.

Consequently, comprehensive, site specific baseline studies which determine the range of natural changes which occur over space and time are needed if realistic accceptable limits of change to the environment are to be defined.

The Great Barrier Reef Marine Park Authority (GBRMPA) recognises the need for an integrated research and monitoring programme on the effects of nutrients and siltation on the Great Barrier Reef (GBR). Such a programme has been discussed but its implementation is dependent on funding approval. A soundly based pilot study which facilitates the projection of optimal sampling designs is a necesssary pre-cursor to the implementation of such a large, costly, baseline or monitoring programme. A pilot study ensures the most powerful and cost effective design of a monitoring programme and minimises within sensible logistical constraints, the chances of making erroneous decisions about the presence or absence of environmental impacts (Mapstone *et al.*, 1989).

This pilot study was undertaken to examine the spatial and temporal variation in ambient levels of a range of water quality parameters around Green Island and to assess which ones best meet the requirements for assessing a change in the environment in a logistical and cost effective manner. The longer term objectives of studying Green Island was to collect baseline nutrient data so that comparisons can be made with the regional geographic studies and with data collected during re-development activities. Implicit is consideration of the consequences of changes in water quality on the patterns and processes on the surrounding coral reef.

Figure 1.1. Locality map of Green Island.



1.2 BACKGROUND INFORMATION

1.2.1 Study Area

Green Island (16°59'S 145°59'E) lies ca. 27 kilometres north east of Cairns (Figure 1.1). It is a vegetated sand cay surrounded by a lagoonal platform reef (Baxter, 1987). The cay lies towards the the north-west corner of the extensive reef flat and is composed mostly of sand and coralline rubble. It occupies an area of ca. 12 ha., the eastern 60 % of which is National Park. Six private leases are held on the western side of the cay. The largest of these is the site of the Coral Cay Hotel owned and operated by Great Adventures Pty. Previously it had been owned by Hayles Pty.

The reef itself occupies an area of 1200 ha. A shallow indistinct lagoon extends to the north of the cay (Green Island Management Committee,1980). The reef flat is generally at or near tidal datum, except to the north-west where there is a downslope dip. The windward flat is clearly divisible into coral and sand zones, with the latter more extensive on the leeward flat (Figure 1.1). Sea grass beds occur on the inshore flat to the north and north west of the cay. They are also widespread over the the reef flat to the east of the cay.

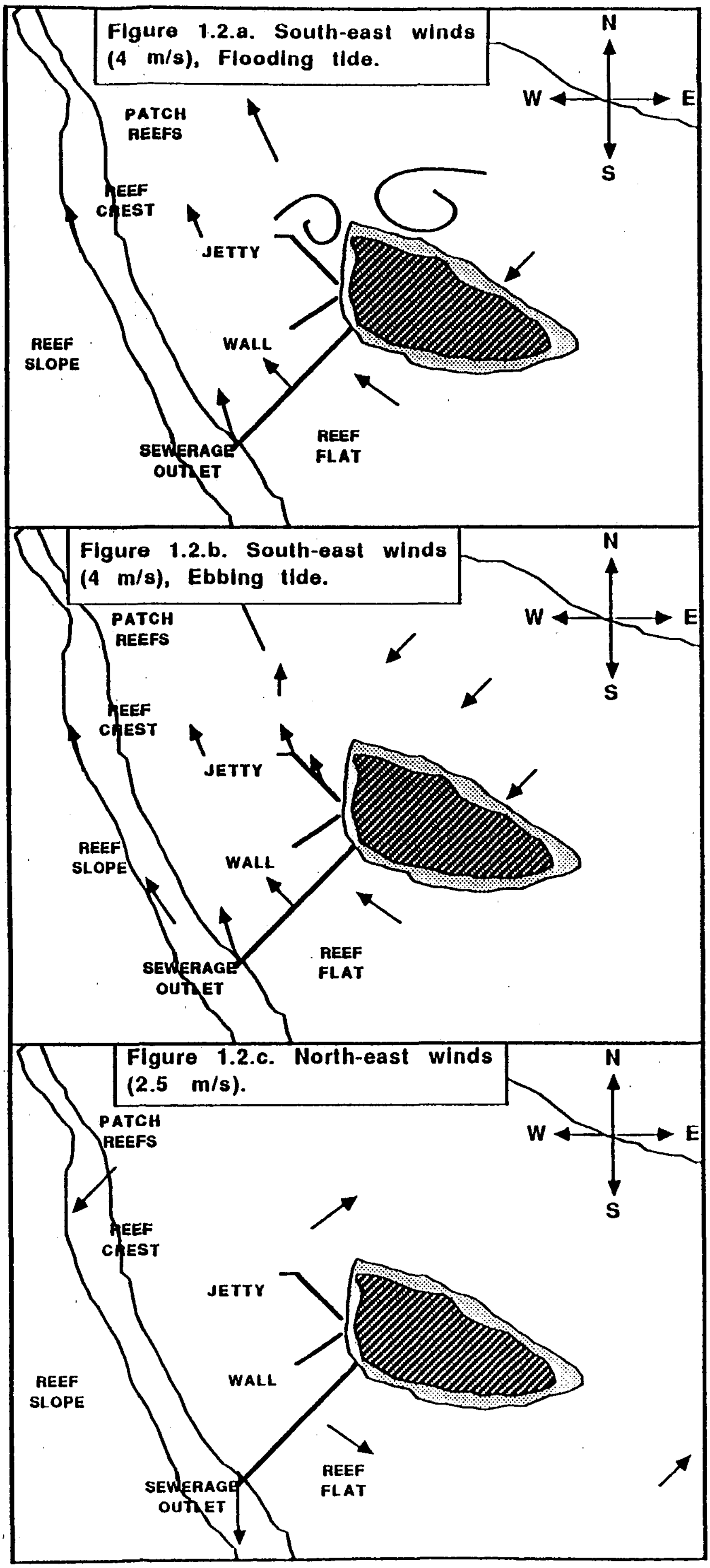
Green Island is zoned Marine National Park B within the Cairns Section of the Great Barrier Reef Marine Park. It has a Marine National Park Buffer Zone extending 500 metres out from the reef edge.

1.2.2 Hydrography and Hydrodynamics

The maximum tidal range is 3.1 metres with a spring tidal range of 1.7 metres. The lowest tides occur during the daylight in winter and at night during summer (Green Island Management Committee, 1980). Wolanski and Pickard (1985) and Black and Gay (1988) demonstrated seasonal and interannual fluctuations in currents were due to a local onshelf balance between winds and current in conjunction with fluctuations in Coral Sea circulation (Baxter, 1987).

On a local scale, van Woesik (1989) using Eulerian and Langrangian dye tracer studies, around the lee of the reef found that during north-east winds and a flooding tide the predominant residual current flow was spiralling around the island in an anticlockwise direction (Figure 1.2.c). During south-east winds and ebbing tide, currents flow towards the north-west, with a retention area in the lee of the reef (Figure 1.2.b.). A similar north-west flow occurs on the flooding tide with double spiralled eddies evident in the lee of the cay (Figure 1.2.a).

Figure 1.2. Local hydrodynamic patterns around Green Island over different weather and tide conditions (from van Woesik, 1989).



1.2.3 Anthropogenic Influences

Green Island has had a long history of human occupation and has clearly been subjected to increasing disturbance from human activity. Tourism has been heavy and has increased 5 fold since 1956 to ca. 150,000 visitors in 1978 (Baxter, 1987). In addition the reef has been subject to two major outbreaks of the crown of thorns starfish, *Acanthaster planci* in the last 25 years (1962-67, 1979-81). A combination of these events has modified the reefal environment, resulting in a greatly reduced hard coral cover. However, recovery in the form of diverse assemblages of *Acropora spp.* coral colonies has been observed along the south-west and north-east slopes (van Woesik and Fisk, *pers. obs.*, September 1989). The lee of the Island supports a high biomass of seagrass, whose presence has been attributed to anthropogenic factors (Kuchler 1978, van Woesik 1989).

1.2.4 Sewage Disposal

The Coral Cay Hotel and the public toilets are connected to a sewerage system (Green Island Management Report, 1986). Effluent is discharged from a detention tank through an outfall pipe made of perspex, located at the low water spring mark on the reef edge to the south west of the cay (Figure 2.1). Times of discharge are irregular as the system operates on a floating point discharge. The sewage is untreated apart from chlorination, with an average retention time of 2 hours (van Woesik, 1989) and an estimated mean discharge rate of 100 m^3/day (Bell, 1987). Water inlet and outlet pipes for the Marineland Melanesia aquarium system lie on the reef flat to the north of the cay (Fig. 1.1).

1.2.5 Re-development

With the recent change of ownership of the resort and the underwater observatory, a $25 million re-development has been proposed. This includes the upgrade of all facilties within the current lease boundaries, re-development of the cay beach and re-dredging of the harbour. To comply with GBRMPA requirements changes in the treatment of waste water are proposed with provision for the implementation of a secondary treatment plant.

1.3 GENERAL EXPERIMENTAL DESIGN

1.3.1 Rationale

Few water quality studies have been undertaken around Green Island, although at present a study of water quality on a transect from the Barron River mouth out to Green Island is in progress (Brady, *pers. comm.*). Water samples have been collected around Green Island as part of an ongoing project examining the effects of stress on corals (Rasmussen, *pers. comm.*). The preliminary results of the water movement studies undertaken as part of a multi-disciplinary study funded by GBRMPA suggested there is the potential for sewage effluent to be retained by eddies, which are in proximity to the areas of enhanced seagrass growth (van Woesik, 1989). In view of these results, the commonly held belief that sewage discharge has contributed to reef degradation, and the impending re-development of the resort, it was suggested that a detailed baseline study of the levels of nutrients around Green Island be undertaken. A necessary pre-cursor to such a study was a pilot study to determine the optimum allocation of sampling in a cost effective manner. The proposed baseline study is detailed in Appendix 1. As a number of other large water quality programmes are currently being proposed, such a pilot study is especially timely. The objectives for both the pilot and baseline studies are outlined below.

1.3.2 Objectives of Pilot Study

(1) To assess the variability of a range of water quality parameters at local spatial and small temporal scales around Green Island.

(2) To evaluate which parameters are of most use in assessing water quality.

(3) To design a sampling programme for the proposed baseline study, based on the results of this pilot study.

1.3.3 Overall objectives for the proposed baseline water quality study around Green Island.

(1) To collect baseline nutrient data around Green Island so that comparisons can be made with regional geographic studies and with data collected during marine re-development activities.

(2) To establish the spatial extent of nutrient enrichment resulting from the sewage discharge.

(3) To develop techniques which relate nutrient concentrations to biotic responses. i.e. the magnitude and spatial extent of benthic community change and primary productivity. (This will be carried out in conjunction with the proposed benthic monitoring programme (Fisk and van Woesik, 1989).

1.3.4 Sources of Variation

Due to a gamut of causes, water quality parameters are often spatially and temporally variable. To be able to detect differences which are due to anthropogenic activities, accurate baseline levels are firstly required which quantify natural ambient variation. The following potential sources of variability around Green Island were identified.

1. Depth variation.
2. Large scale variation between sampling sites.
3. Small scale variation between replicates.
4. Large temporal variation between seasons.
5. Diel variation.
6. Short term diurnal variation.
7. Tidal variation.
8. Large and small scale hydrodynamic processes (i.e. currents).
9. Prevailing wind and atmospheric conditions.
10. Topography of island and reef.
11. Mainland river runnoff.
12. Discharge from sewage outfall.
13. Biological blooms and other biological processes.
13. Sample handling error.
14. Sample analysis errors.

1.3.5 Constraints

While the study aims to measure 'baseline' levels, it should be noted that Green Island is already an 'impacted area' both from anthropogenic influences (i.e. sewage discharge and runoff) and other sources (*Acanthaster planci*). These effects have been compounded over time. The sampling undertaken during the pilot study was over a short duration with logistical and cost constraints limiting the number of sampling stations, replication levels and numbers of parameters that could be measured.

1.3.6 General Sampling Design

This pilot study was designed to measure the type and magnitude of spatial and temporal variation of a number of water quality parameters (mostly inorganic nutrients) around Green Island, over a range of scales. To such an end, 2 sub-programmes were undertaken:

(1) A study of temporal variation over one 24 hour period at two locations to assess the relative contribution of time, tidal phase and possibly sewage discharge to changes in water quality parameters. A study of between day (diel) variation was made on 3 consecutive days, sampling on the high tide.

(2) A study of spatial variation over a range of nested spatial scales.

These two studies are considered separately in the following two chapters.

1.4 GENERAL METHODS

1.4.1 Variables Measured

Nutrients:
- Nitrite **(NO_2)** + Nitrate **(NO_3)**
- Ammonium **(NH_4)**
- Orthophosphate **(PO_4)** (i.e Reactive Phosphorous)
- Total Nitrogen **(TN)**
- Total Phosphorous **(TP)**
- Particulate Nitrogen **(PN)**

Biological Parameters:
- Chlorophyll *a* **(Chl *a*)**
- Biological Oxygen Demand (5 days) **(BOD_5)**

Physico-Chemical Parameters:
- Suspended solids **(SS)**
- Clarity
- Dissolved oxygen **(DO)**
- Temperature

Physical conditions:
- Wind direction and speed
- Wave direction and height

1.4.2 Sample Collection

On each sampling occasion measurements of the following parameters were made in the following manner:

Weather Conditions:

Windspeed: Anemometer

Wind & wave direction: vane and compass

Wave height: visual estimation trough to peak.

Physical parameters:

Dissolved oxygen and temperature were measured at each site using a TDS Oxygen analyser (Model LC 182A). Water clarity was measured using a secchi disk.

Water Samples:

All samples were stored in sterile 'Whirlpacs' of various sizes. Samples for inorganic nutrients were collected in small (ca. 140 ml) whirlpacs, whilst samples for particulate nitrogen, and total nitrogen and phosphorous were stored in large (ca. 400ml) whirlpacs.

Surface samples were collected ca. 0.2m below the surface so as to ensure minimum collection of the surface film. Samples taken at depth were collected in a PVC van

Dorn sampler. Nutrient samples were then transferred to the whirlpacs and immediately stored on ice in 'eskys'. Upon return to the island samples were stored in a -20 °C freezer. Samples for Chlorophyll *a* and suspended sediment analysis were collected in containers and filtered at the *in situ* laboratory. The filters were frozen until completion of the analysis at the Australian Centre for Tropical Freshwater Research. BOD_5 samples were stored in the dark at ca. 20 °C for the 5 day period.

1.4.3 Site Selection

The existing knowledge of water movements around the island were used to guide site selection. Sampling sites were selected to quantify both the ambient levels of nutrients in waters around the island in areas not affected by the sewage discharge, and also the levels of nutrients in the area around the sewerage pipe.

1.4.4 Timing

The field work for this study was undertaken from the 2nd to the 4th of June 1989.

1.4.5 Weather Conditions

Conditions were typical for this time of the year, winds were south south- east and less than 10 knots. Sea conditions were calm, wave heights being under 0.3 metres. Swell was predominantly from the south (Table 1.1). Tidal attenuation was greatest on the 4th of June, with the onset of the new moon.

Table 1.1. Summary table of weather and tide conditions during the sampling period, 2nd to 4th of June 1989.

DATE	TIDAL PREDICTIONS		WIND CONDITIONS		SEA CONDITIONS	
	Time hours	Height metres	Direction degrees	Speed knts	Direction degrees	Height metres
2/6/89	0121	0.74	-	-	-	-
	0706	2.07	160	7	160	0.2
	1330	0.05	180	8	190	0.2
	2018	2.67	100	5	150	0.1
3/6/89	0211	0.74	170	6	170	0.1
	0753	1.96	170	7	190	0.1
	1412	0.00	180	9	180	0.3
	2103	2.72	-	-	-	-
4/6/89	0301	0.78	-	-	-	-
	0837	1.87	-	-	-	-

1.5 STATISTICAL ANALYSIS

1.5.1 Analysis of Variance

Multi-factorial analysis of variance (ANOVA) was used to test the significance of spatial and temporal factors of variability. Due to the number of sources of variation several models were applied. These are considered in detail in chapters 2 and 3. A factor was considered a significant source of variation if the probability of the assertion being wrong (Type I) was less than 5 % and was considered potentially significant for error probabilities of 5-10%. Assumptions of independence and homogeneity of variance were assessed using residual analysis. Where appropriate a Log (X) transformation was applied (Zar, 1984). Where significant results were found, *a posteriori* comparisons among means were made using Tukey's studentized range test.

1.5.2 Multi-variate Analysis

Techniques of clustering and ordination were used to examine patterns of nutrient composition between locations and over time periods in the 24 hour study. These techniques are not based the underlying normality assumptions and as a consequence lack a framework for hypothesis testing (Clarke and Green, 1988). They do however, allow a description of the data, and may reveal patterns not apparent using univariate statistics. Untransformed mean values of nitrite + nitrate, ammonium, and phosphate for locations and and time periods were used in the analysis. A Bray-Curtis similarity coefficient was used in quantify their relative similarity. For the cluster analysis an 'unweighted group mean' sorting strategy was used to classify the similarity matrix. Non metric multi-dimensional scaling (MDS), an ordination technique, constructs a similarity map based on rank order, where the distance between data points reflects their relative dissimilarity. A measure of 'confidence' in the results is given by a stress statistic.

1.5.3 Power Analysis

Where a factor was found not to be a significant source of variation, analyses of statistical power was used to estimate *a posteriori* the probability that the sampling design would detect a difference in nutrient concentration of a specified magnitude, if indeed it existed (Mapstone *et al.*, 1988). Procedures followed those of Cohen (1977). When analyses indicated that a factor did not constitute a significant source of variation, that factor and residual sources of variation were pooled. These were used as an estimate of variation for calculation of the power of other terms in the analyses. Secondly, estimates of spatial and temporal variation obtained from this study were used to estimate the power and sample size characteristics of the suggested monitoring programme based on the power/sample size tables in Cohen (1977).