Table 4. Parameter mean values in the pilot variability study

Parameter	Temporal Study	Spatial Study
Suspended solids (mg/l)	2.8	2.3
Nitrate (μg-at/l)	0.29	0.23
Nitrite (μg-at/l)	0.79	0.83
Ammonia (μg-at/l)	0.57	0.76
Orthophosphate (μg-at/l)	0.19	0.17

The results shown in Table 5 suggest that in this case the difference is small and there is good correspondence between the vertical and horizontal readings.

Table 5.

Site	Horizontal Value (m)	Vertical Value (m)
HS1	2.7	2.5
HS2	3.2	3.0
HS3	2.5	2.3
HS4	1.5	1.9

10. DISCUSSION

10.1 General Water Quality

The purpose of the baseline study was to gain a measure of the ambient, natural levels of a number of parameters in Nelly and Geoffrey Bays as possible future impact sites and Florence, Arthur and Picnic Bays as reference sites. Each of the parameters will be examined in turn and general comments made where appropriate.

10.1.1 Dissolved oxygen, salinity and temperature

Dissolved oxygen levels in the marine sites are uniformly high and show no changes with depth. There is also uniform salinity and little thermal

stratification, all consistent with the bay being well mixed. Dissolved oxygen levels in Gustav Creek are very variable as are salinity levels and detailed studies would probably show connections between salinity and dissolved oxygen and the salinity gradients set up by occasional saltwater entry into the Creek. Three samples of water collected in South, Central and North Geoffrey Bay around 4/1/89 by a member of the public after Gustav Creek had broken through the foredune were forwarded to GBRMPA and were analysed for salinity. It was stated that 'polluted' water had flowed from Nelly Bay around into Geoffrey Bay at the time of collection. The results (Table 6) show the considerable possible impact of contaminated water from Nelly Bay moving into Geoffrey Bay, at least under one set of weather conditions.

Table 6.

Site	Salinity (‰)
South Geoffrey Bay (near Bright Point)	5.0
Central Geoffrey Bay	5.9
Arcadia End of Geoffrey Bay	8.8

10.1.2 Nitrate and nitrite

Nitrate and nitrite values from the marine stations show no depth variability. The ranges and mean values for nitrate are considerably higher than those found in studies around the Whitsundays (Furnas et al., 1988), previously in Cleveland Bay (Walker and O'Donnel, 1981) and much higher than those found in shelf waters (Furnas and Mitchell, 1984; Furnas et al., 1988). However higher nitrate values have been found close to the coast (Brady, 1989) and on fringing reefs in the Whitsundays (Steven and van Woesik, 1989, Blake and Johnson, 1988).

The nitrite values are uniformly high and in many cases equal to or greater than the nitrate levels, at the surface as well as at depth. This is in contrast to all studies offshore where low or not detectable levels of nitrite were normally found (Furnas and Mitchell, 1984; Furnas et al.,

1988) and in reef lagoons where low levels were found (Furnas and Mitchell, 1988). Some elevated nitrite levels have been measured off Cairns (Brady, 1989) and in the Whitsundays (Blake and Johnson, 1988) but these have still been considerably lower than the mean values found in the present study. Further monitoring will concentrate on verifying these elevated, unexpected nitrite levels. Nitrate and nitrite levels in Gustav Creek are variable with high spot values of both nitrate and nitrite.

10.1.3 Ammonium

Ammonia values also show no obvious depth variability but the mean value found (0.49 μM) for all marine stations is significantly higher than found offshore in the Whitsundays (0.22 μM) or in shelf areas (0.12 μM and 0.15 μM) (see Table 1). High values have previously been noted around Hayman Island (ranging from 1.0 to 15 μM) and Hamilton Island (0.2 to 1.6 μM).

10.1.4 Total dissolved inorganic nitrogen (DIN)

The total DIN value has a mean of 2.24 μg-at N/l. This is very high compared to what is considered normal (or desirable) for healthy coral reefs (Bell et al., 1987). Bell et al. suggest that levels of DIN in excess of 1.1 μg-at N/l are undesirable for coral reef although their conclusions are based on Carribean data and we have little GBR data to verify this. Recent work in the Whitsundays (Blake and Johnson, 1988) has also found DIN levels of the magnitude and it may be that normally levels on fringing reefs are far higher than was recently believed. The high levels found in the present study can be interpreted in two ways. If indeed natural levels on the Magnetic Island reefs were once lower than now found then the reefs may be under stress at present DIN levels and any further anthropogenic increase in DIN levels must be prevented. Alternatively the Magnetic Island reefs may be surviving naturally at DIN levels higher than on the GBR main reefs or in the Carribean and some increase in DIN levels will not cause problems. Such is the case with GBR coastal coral reefs and sedimentation levels where tolerance to sediment and turbidity appear far higher than for offshore reefs.

10.1.5 Orthophosphate and total phosphorus

Levels of these nutrients (mean 0.19 μM) were generally similar to those found in other areas such as the Whitsundays (0.23 μM and 0.43 μM) in shelf

waters (0.16 and 0.16 μM) and in Cleveland Bay in the past (0.20 μM) (see Table 1). There was an appreciable difference between bottom samples and surface samples in both orthophosphate and total phosphorus values with greater levels at depth. Levels of total phosphorus were generally twice to eight times the dissolved inorganic phosphorus levels and this is similar to results found elsewhere (Furnas et al., 1988). The orthophosphate levels are just below levels suggested to be critical for coral (0.22 μM) (Bell et al., 1987) but this value seems low considering recent data on ambient levels on fringing reefs.

10.1.6 Silicate

Silicate levels (mean 3.7 μM) are higher than those found in shelf waters (1.06 and 0.93 M) and near the Whitsundays (1.72 μM) but the effects of runoff must be of great importance to silicate levels as any fresh water inputs could significantly affect silicate as shown by the relatively high levels found in Gustav Creek waters compared to the marine sites.

10.1.7 BOD_5

BOD_5 levels averaged 1.1 mg/l similar to average values found in unpolluted Carribean reefs (0.7 mg/l) (Bell et al., 1987). There is little comparable data from the GBR but traditional measurement of BOD levels as low as this, is fraught with difficulties.

10.1.8 Copper

Copper values appear to be far higher than those found in offshore (shelf) and reef waters and near Orpheus Island (generally 0.2 - 0.3 μg/l) (Denton and Burdon-Jones, 1986), but more comparable to other waters close to large metal smelting and refining industries, e.g. in the Mediterranean (levels with mean 1.2 μg/l) (Scoullos and Dassenakes, 1983) and in Australian harbours (Moran, 1984; Roy and Crawford, 1984).

This will complicate monitoring to detect elevated levels from anti-fouling paints but also suggests that the Magnetic Island fringing reefs are already living in waters containing copper levels considered by some authors to be above their recommended guideline for this metal (Bell et al., 1987).

10.1.9 Tri-(n-butyl) tin (TBT)

No TBT residues were detected at above 5 ng/l (the detection limit of the method) in the samples from this study, but there was evidence of the presence of methylated tin compounds presumably from natural sources. The present suggested tolerance levels in water for TBT are 5-10 ng/l (Goldberg, 1987) but with increasing evidence of effects at even lower levels than these viz. 2.5 ng/l (Bryan et al., 1986), these guidelines will be reduced. The analytical method used in this baseline study will be improved for the monitoring programme by use of more suitable sampling bottles (polycarbonate rather than polythene) and better trapping and detection such that the detection limit will be below 1 ng/l. TBT is not believed to occur naturally and the data from this study is as one would expect from an area with almost no moored boats.

10.1.10 Aromatic hydrocarbons

The levels were generally low and typical of relatively uncontaminated waters (Smith and Maher, 1984; Smith et al., 1987) but not open coastal waters. The regular boating and shipping activity around this side of Magnetic Island has probably contributed to these slightly elevated levels.

There is the possibility of some correlation between the aromatic hydrocarbon data and hydrocarbon degrader bacteria concentrations, particularly at S11 but the data is not extensive enough to draw statistically valid conclusions.

The hydrocarbon degrading bacteria levels (Table 7) are higher than levels previously found around Townsville (Saunders Beach and John Brewer Reef) (Larsen, 1986) particularly Site 11. However sediment grain size may affect measured numbers and further studies may confirm these results.

10.1.11 Coliform bacteria

Most samples with significant coliform levels were clustered around the north and central sections of Nelly Bay. Values also seemed to be higher after Gustav Creek had broken through the fore-dune and was discharging into Nelly Bay suggesting the positive coliform levels were linked to discharge from Gustav Creek. This also tends to confirm the findings of the variability study in this area. Samples from Florence and Arthur Bays

on the other hand were devoid of coliform bacteria. Gustav Creek is consistently contaminated with faecal coliform bacteria, both while flowing or not and this no doubt originates from the sewerage treatment works and incomplete septic action from urban septic tanks. Levels routinely exceed

Table 7. Hydrocarbon Degrading Bacteria (HDB) and Aromatic hydrocarbons (AH)

	Water /100 ml	Sediment /100 g	AH, Water $\mu g/l$ C.E.
Site 4			
23/12/88	1.6×10^2	1.6×10^5	
10/1/89		2.2×10^5	0.2
24/1/89	1.6×10^2		0.1
31/1/89	2.2×10^2	2.2×10^4	
16/2/89	5.1×10^3	1.6×10^5	
Site 6			
23/12/88	2.2×10^2	2.2×10^5	
10/1/89	5.1×10^3	9.2×10^5	0.1
24/1/89	1.6×10^3		0.3
31/1/89	1.6×10^2	5.1×10^4	
16/2/89	2.2×10^3	9.2×10^5	2.0
Site 9			
23/12/88	5.1×10^2	9.2×10^5	
10/1/89	5.1×10^3	9.2×10^5	0.1
24/1/89	1.6×10^3		0.3
31/1/89	1.6×10^2	2.2×10^5	
16/2/89		2.2×10^5	0.2
Site 11			
23/12/88		1.6×10^5	
10/1/89	1.6×10^4	5.1×10^5	0.1
24/1/89	1.6×10^5		0.5
31/1/89	2.2×10^2	6.0×10^6	
16/2/89	9.2×10^3	5.1×10^5	1.3

the Queensland guideline for primary contact water (zoo Faecal coliforms/100ml). If the expanded treatment plant discharges directly or indirectly into Gustav Creek even higher faecal matter levels can be expected in Gustav Creek and in the northern end of Nelly Bay i.e. inside the proposed marina and on the new swimming beaches.

10.2 Sediment/Turbidity

10.2.1 Levels

The mean values of suspended solids (non filterable residue) found in the water quality study and the sediment/turbidity study were similar (3.62 mg/l and 3.95 mg/l). These levels are within the ranges suggested to be background levels in the GBR viz. 6 mg/l (inner region) to 2 mg/l (outer region) (Bell et al., 1987) and far lower than levels found on the Daintree fringing reefs (mean 1093 mg/l) in March 1985 (Hopley, 1985 as cited in Hoyal, 1986) and in January, 1988 (mean 118.5 mg/l) (PER, August 1988). They can be compared also to previous measurements in Nelly Bay of 2.75 to 7.9 mg/l in February 1986 (Collins in PER, 1986) and in July and August, 1988 where higher values of between 35.0 and 115.6 mg/l were found (PER, August 1988).

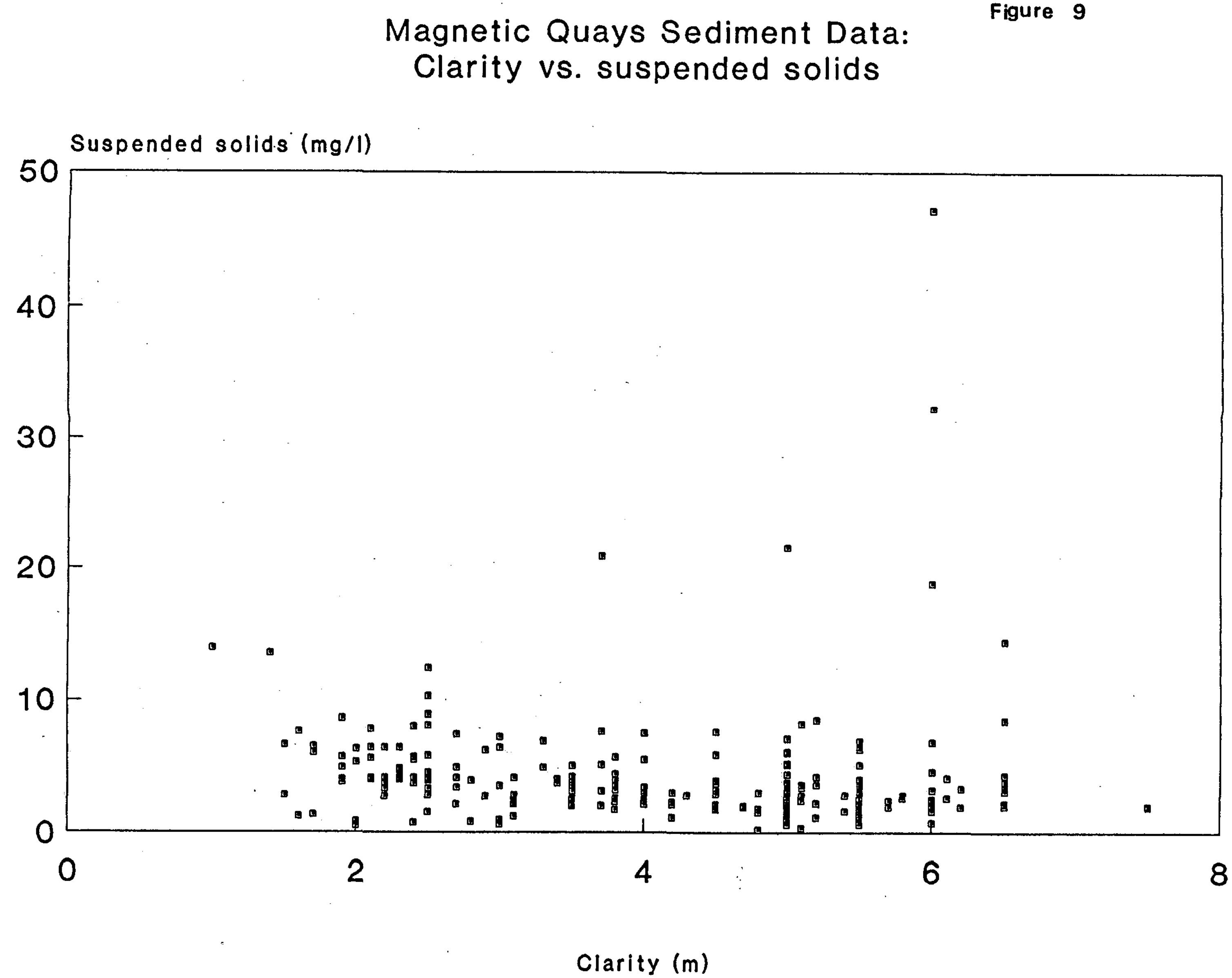
Tomascek and Sander (1985) suggest levels above 4 mg/l can cause reduction in coral growth but this data derives from Carribean reefs where natural sediment loadings may be far less than on the fringing reefs of Eastern Australia. On the Daintree reefs corals survive turbidity levels and sedimentation rates far higher than expected from overseas studies (Ayling and Ayling, 1987; Fisk and Harriott, 1987).

Results of sediment deposition measurements in the study areas are discussed in the biological monitoring report.

10.2.2 Secchi disc measurements, turbidity and suspended solids

As part of this study the relationship, if any, between Secchi disc readings and suspended solid levels was also investigated. Initially turbidity readings using a portable nephelometric turbidity meter were also included for comparison but early in the study it was decided this instrument was not giving and was probably not capable of giving accurate,

Figure 9


Magnetic Quays Sediment Data:
Clarity vs. suspended solids
Suspended solids (mg/l)
50
40
30
20
10
0
0
2
4
6
8
Clarity (m)

significant results at the turbidity levels found in Cleveland Bay waters. The measurement of Secchi disc depth (known also as clarity or transparency) is complicated in shallow water as the Secchi depth may often be greater than the total depth and so no vertical Secchi depth can be measured. Over one third of the readings in the sediment/turbidity study and over one half in the water quality study suffer this disadvantage.

Horizontal Secchi disc measurements can be made with two divers and may be relatable to vertical measurements under certain conditions, in particular a vertically homogeneous water column. However it appears from the present study that Secchi disc depth is not a good indicator of suspended solid concentrations particularly when wave action is resuspending bottom sediments and the water column is thus not homogeneous for sediment concentration. Figure 9 shows a plot of Secchi disc depths versus suspended solids for those samples taken where a true Secchi depth could be obtained. Manipulation of the data to only include surface samples does not dramatically improve the relationship although some relationship is then apparent. These results contrast with those from Walker's work (1982) where for open Cleveland Bay waters a relationship could be shown. The difference is likely to be in the degree of bottom resuspension and water column inhomogeneity in the shallower reef slope and reef flat waters compared to those of the deeper open bay. Secchi disc clarity is inversely related to wind speed but this is also complicated by total water depth, the relationship being stronger in shallower water. This is also governed by the fact that the suspended material in the water was generated primarily by bottom resuspension from wave turbulence.

10.3 Comparison of reef slope sites in all bays

The sites for the water quality and sediment/turbidity studies were initially chosen as 'impact' and 'control' sites with those in Nelly Bay and Geoffrey Bay being in the first category and those in Picnic, Arthur and Florence Bay in the second. The movement of water from Gustav Creek around Bright Point and into Geoffrey Bay on the occasion of the breakout of Gustav Creek through the foredune verified the selection of Geoffrey Bay sites as impact sites at least under some weather conditions.

Table 8 shows data from the reef slope sites in these two areas grouped together. Data from bottom and surface samples and from all five sampling occasions have been pooled and mean values and standard deviations listed.

Table 8. Comparison of Reef Slope Sites (averaged over all samples)

		SS	NO_2-N	NO_3-N	NH_3-N	DIN	PN	PO_4-P	TP	Sil.-Si	Chl_a	BOD_5	Cu	TC	FC'
		mg/l	µg-at/l								mg/l	mg/l	µg/l	org/100ml	org/100ml
Impact Area															
Nelly Bay North (S5)	$\bar{x}$	2.5	0.68	0.76	0.34	1.78	4.0	0.15	0.54	3.3	0.47	0.73	3.2	7.4	0.8
	SD	2.2	0.31	0.20	0.26		1.1	0.11	0.29	1.5	0.46	0.44	2.3	12	1.8
Nelly Bay Centre (S7)	$\bar{x}$	2.7	0.89	0.99	0.41	2.29	4.7	0.17	0.65	2.8	0.34	1.0	0.95	4.4	0
	SD	2.3	0.55	0.47	0.24		1.2	0.13	0.35	0.83	0.20	0.68	0.30	8.8	0
Nelly Bay South (S8)	$\bar{x}$	3.2	1.0	0.86	0.57	2.43	3.1	0.16	0.52	3.6	0.32	1.1	4.0	12	0
	SD	2.3	0.45	0.08	0.37		0.2	0.05	0.19	1.7	0.28	0.28	6.0	16	0
Geoffrey Bay North	$\bar{x}$	4.9	0.94	0.72	0.34	2.00	5.5	0.12	0.56	3.0	0.30	1.3	1.8	0.4	0
	SD	2.3	0.33	0.19	0.23		1.6	0.07	0.23	0.84	0.19	0.33	1.8	0.9	0
Control Area															
Picnic Bay (S10)	$\bar{x}$	6.6	1.0	0.86	0.43	2.29	4.7	0.24	0.89	3.3	1.1	0.93	2.3	0.4	0
	SD	5.6	1.2	0.09	0.36			0.15	0.58	0.10	0.59	0.54	3.5	0.9	0
Arthur Bay (S13)	$\bar{x}$	2.6	0.70	1.2	0.65	2.55	4.3	0.39	0.82	5.0	1.4	0.81	2.1	3.0	0
	SD	0.67	0.24	0.59	0.34		1.9	0.48	0.48	1.8	0.8	0.43	1.9	4.8	0
Florence Bay (S14)	$\bar{x}$	9.7	0.98	0.89	0.28	2.15	4.2	0.28	0.66	3.7	0.4	1.6	1.3	0	0
	SD	13.7	0.71	0.45	0.19		1.4	0.23	0.14	2.4	0.3	1.0	0.8	0	0

The data has not been statistically analysed although this will be done later. However some apparent differences can be noted by inspection.

While there appears to be some differences in suspended sediment mean values are so critically dependent on water depth and subsequent bottom resuspension that the results have to be treated with caution.

The most striking difference appears to be in phosphorus levels, both orthophosphate and total phosphorus, and in the chlorophyll-a values. In both cases the levels in the control areas are higher than in the impact areas by a factor of roughly two. The standard deviations in the means for these parameters, while only derived from a small data set, also strengthen this apparent difference.