CHAPTER 4: WATER QUALITY: COMPLIANCE ASSESSMENT

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Introduction

Probably the single most important indirect effect of tourist developments in the coral reef environment is that of a decline in local water quality (Saenger and Dutton, 1989). Sewage discharges, particularly if inappropriately sited or inadequately treated, are the most common sources of adverse effects on the biota (see review by Pastorok and Bilyard, 1985). Kaneohe Bay, Hawaii has been the site of the most detailed study of the effects of urban runoff and sewage on a coral reef ecosystem (Banner, 1974). In this bay, there was a drastic decline in the coral cover (particularly of *Porites compressa*) with heavy overgrowth by algae, such as *Dictyosphaeria cavernosa*. Immediately after resiting the sewage outfalls, some recovery was evident (Smith, 1977) and six years later the coral and macroalgal cover had returned to pre-discharge levels (Maragos et al, 1985).

In the Caribbean, where less than 10% of the sewage generated is treated, bacterial levels regularly exceed international standards for recreational contact waters (Barnes, 1973; Ward and Singh, 1987). In addition, the mat-forming alga *Cladophora prolifera* presently covers huge areas of in-shore waters although 25 years ago it was not reported (Bach and Josselyn, 1978; 1979; Lapointe and O'Connell, 1989). This alga, with a highly active alkaline phosphatase system and, thus, a high capacity to recycle organic phosphorus, can grow well in oligotrophic waters doubling its biomass every 100 days. However, with Nitrogen and/or Phosphorus enrichment, the biomass doubling time of this species is reduced to 14 days, allowing extensive mats to form which cause anoxia and a reduction in infaunal and epifaunal species diversity on decomposition (Lapointe and O'Connell, 1989).

Quite apart from the eutrophication effects described above, phosphate enrichment of coral reef waters may directly inhibit hard coral growth through phosphate inhibition of calcium carbonate deposition (Simkiss, 1964), an essential process of healthy coral growth.

As a condition of the GBRMPA permit and the permit under the *Environmental Protection (Sea Dumping) Act 1981*, the floating hotel resort was obliged to comply with set limits pertaining to water quality of the sewage plant effluent, the lagoonal water quality and the organic loads in the lagoonal sediments as defined in the environmental monitoring program (CCM, 1988). The results of the programs examining water quality are presented here.

Two sewage plants with a capacity of 15 cu.m. /hr treated all sewage and wastewater generated by the resort. Wastewaters were collected in a tank and treatment was started when levels reached a minimum treatment level. There were four stages of treatment:

a. Separation of sludge and wastewater. Initial plans were to incinerate sludge on-site, however, because of the mooring direction, soot from the incinerator fell back onto the boat, and the process consumed a lot of fuel. The sludge therefore was transferred by barge to the mainland for disposal;

b. Oxidation. Wastewater was treated by mixing oxygen and chlorine in the treatment plant. Throughout the life of the project there were major problems with low oxygen levels;

c. Disinfection. After oxidation with chlorine and oxygen, the wastewater passed through a whirl container where the action of the chlorine killed bacteria; and

d. Filtration and U.V. sterilization. Wastewater was filtered and treated by U.V. sterilizers, once they were functional in July 1988, at which point chlorination was no longer used.

Treated water was pumped on board a service barge and released at a designated location about 5 km from the resort.

Water quality monitoring objectives

The main objectives of the monitoring program for water quality of the sewage treatment plant effluent were:

a. to obtain water quality data on the treated effluent of sufficient reliability to satisfy the permit requirements of the GBRMPA and the requirements of the Sea Dumping permit (essentially this meant that treated wastewater should have a biological oxygen demand (BOD) of 20 mg/L; a non-filtrable residue (NFR) of 30 mg/L, an *E. coli* bacteria reading of no more than 200 organisms/100 ml of effluent, and a residual chlorine level of 2 mg/L); and

b. to provide sufficient data on effluent quality to enable the performance of the sewage treatment plant to be critically evaluated.

In addition to the program targeting the wastewater effluent, there was a second program concerned with general water quality in the vicinity of the resort. The objectives for the program monitoring lagoonal water quality were:

a. to obtain water quality data from John Brewer Reef lagoon, in the vicinity of the resort and its operation of sufficient reliability to satisfy the permit requirements of the GBRMPA; and

b. to provide sufficient data on water quality in the lagoon to enable the effect of the various resort-related activities to be critically evaluated.

In effect this meant measuring a number of water quality parameters, pre-resort, during the resort's operation, and post-resort. At the present time, no guideline values exist for estimating the water quality of reef waters.

Methods

Water quality monitoring for the Compliance Assessment Program was carried out from January to December 1988, and in July 1989. The first period covers the pre-resort and resort surveys and the latter was a post-resort survey.

Sewage effluent samples were tested every two weeks up until April 1988, and monthly thereafter. Samples were obtained from the terminal end of the transfer pipe at regular intervals during the transfer of the effluent to the barge and combined to produce a composite sample of the treated effluent. Mid-stream samples were taken in duplicate and were stored on ice until analysis.

All samples were collected in airtight sterile acid-rinsed bottles. Standard techniques (Standard Methods, 1981) were used for measurement of each of the parameters.

The following parameters were measured for the effluent samples, either on-site or in the laboratory:

five-day BOD
non-filtrable residue
free chlorine residue
total organic carbon (TOC)
salinity
E. coli concentrations
pH and dissolved oxygen
total phosphorus
ammonia-nitrogen
total nitrogen

For the lagoonal water sampling, samples were obtained from two fixed sites within the lagoon at monthly intervals. These sites were the resort station (R) and control station (C) (Figure 4). Lagoonal water quality was monitored during three periods, pre-resort (January 1988), during resort operations (July and December 1988), and after the resort was removed (July 1989). During these three periods, sampling was carried out over 24-hour periods to determine daily and tidal variation in each of the parameters measured.

All samples were analysed on-site or, alternatively, stored on ice and analysed as soon as they reached the laboratory.

The following parameters were measured:

dissolved inorganic nitrogen	salinity
ammonia	temperature
dissolved inorganic phosphate	dissolved oxygen
silica	free chlorine residue
chloroplyll *a*	*E. coli* bacteria
total organic carbon	BOD
dissolved organic carbon	

Results and conclusions

Wastewater treatment

Monitoring of the wastewater treatment plant showed that a number of technical problems existed and that during the commissioning phase (January to April 1988), the quality of the effluent did not reach the manufacturers specifications nor conform to the Sea Dumping permit requirements. Mean levels of BOD, suspended solids, *E. coli* and free residual chlorine for January - March 1988 were 57 mg/L, 70 mg/L, too numerous to count, and 0 respectively. Mean nutrient concentrations and TOCs for this period did not pose a problem: respective means were: 23 mg/L total Nitrogen; 5 mg/L total Phosphorus and 21 mg/L TOC.

The technical problems during commissioning included inadequate chlorination, poor UV disinfection, corrosion in holding tanks, the unexpected effects of flocculants in the wastewater, and the build-up of sludge in the holding tanks due to the incomplete operation of the resort's incinerator. By April, many of these technical problems had been overcome and good free chlorine levels and no *E. coli* were present in the effluent samples. Better operating procedures and the installation of an improved UV unit were undoubtedly responsible for improved disinfection. However, levels of BOD remained high and this was ascribed to:

a. the apparently high BODs of the flocculants from the desalination plant;

b. washings from the desalination plant which appeared to be contributing chemical oxygen demand (COD) to the effluent, and

c. build-up of iron in the holding tanks which exerted a high COD.

Based on the trends shown, it would seem that the following concentrations could be expected in the wastewater effluent without major operating changes:

Total Phosphorus	5-6 mg/L
Total Nitrogen	30-40 mg/L
Total Organic Carbon	30 mg/L
Suspended Solids	70-90 mg/L
BOD	50-70 mg/L
E. coli	nil N/100 mL

While these concentrations did not pose a significant problem for open ocean discharge, particularly with good initial dispersion, they were in breach of the Sea Dumping permit. Particular attention should be paid to the effects of the flocculants from the desalination plant on the BODs and total N levels in the wastewater.

Other aspects of the operating procedures that needed to be examined further included:

a. the diversion of effluent from the black water tank to the grey water tank when the oil and grease content exceeds 15 ppm;

b. the build-up of iron in the holding tanks from corrosion or the use of potassium permanganate; and

c. better aeration in the holding tanks and the adjustment of the pH to 8.0-8.5 to lessen sulphide generation.

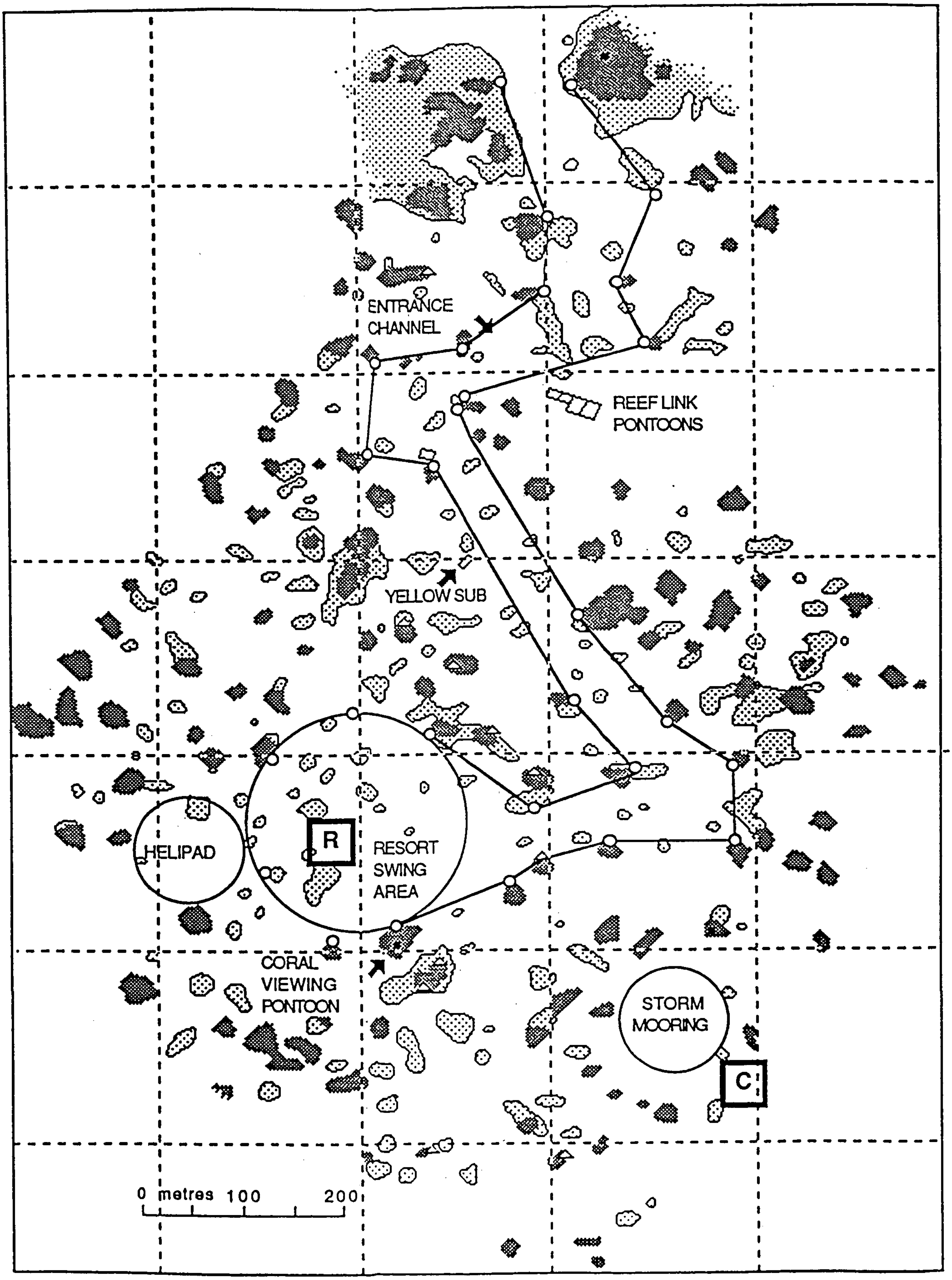

Figure 4. Resort swing circle (R) and control (C) sampling sites

The problem of the free residual chlorine concentration was a vexed one. The Sea Dumping permit required a free chlorine residual of 2 mg/L. Whether such a level was achievable without massive slug-dosing is questionable. Its desirability can certainly be questioned while adequate disinfection is being attained with UV irradiation.

A comparison of BOD and COD showed that there was no difference between the two, indicating that BOD for the sewage plant was very low (< 10 mg/L), while the value for COD was a result of the high levels of iron and sulphides present in the effluent. Overall efficiency of the operations ranged from 62% to 72%. The total amount of treated wastewater discharged at sea in 1988 was approximately 8052 tons, less than 0.07% of the wastewater discharged into Cleveland Bay from the population of the Townsville district. This is an extremely small quantity being discharged into an open sea environment with very great dilution factors.

Barnes (1973), in his analysis of Caribbean sewage effects, showed that with the increased use of package treatment plants, sewage effects can be minimised. However, a number of factors relating to the operation of package plants means that such systems do not operate to their full potential. These factors need to be considered in day-to-day management planning for tourist developments. They include:

a. fluctuating loads during peak and slack tourist seasons caused problems of overload at certain times, and an inadequate load to maintain the microbial populations within the plant at other times;

b. package plants often were operated by inexperienced personnel rather than by sanitary engineers, as a result of which, package plants were poorly maintained, and subject to frequent mechanical failure; and

c. virtually no monitoring of package plant function was undertaken.

Lagoonal water quality

The results of the lagoon monitoring indicated that there were no significant differences in any of the parameters between the resort and control sites (Table 4.1). One anomalous finding was the silica concentrations, which had increased significantly at both the resort and control sites during December 1988; but as no significant difference occurred between the resort and control sites, the increase must be due to a regional phenomenon such as an algal (silicoflagellate or diatom) bloom, rather than any effect due to the resort.

Only two effluents, the brine plume and some seawater coolant water, entered the lagoon from the hotel. Analysis of coolant seawater for nutrients established that this was not significantly different from lagoon water close to the resort. Sampling of the brine plume in April 1988 showed that this effluent contained appreciable levels of suspended solids (23 x seawater) and elevated levels of nutrients: phosphate (5 x seawater), nitrate (2.4 x seawater), silica (21 x seawater) and ammonia (60 x seawater).

On another occasion (30 June 1988), only silica was significantly higher than seawater (x 6). When these values were compared with concentrations measured in the swing circle station, it appeared that the brine plume did not significantly affect nutrient water quality in the vicinity of the resort. On one occasion (April, 1988), 15 MPN/100 mL *E. coli* were detected at the resort site and this was attributed to a visiting trawler.

The less intense monthly monitoring supports these findings and leads to the conclusion that prior to the placement of the resort, the lagoonal waters at John Brewer Reef were not significantly affected by human bacteria such as faecal coliforms and *E. coli*. Levels of organic matter in the lagoonal waters were low and comparable to other reef waters and no significant contamination of phosphorus and nitrogenous organic compounds was evident.

Monitoring results since the placement of the resort to December 1988 have shown that the activities of the resort have not significantly affected water quality parameters measured as part of this project, and the post-resort monitoring was consistent with this pattern.

Table 4.1. Mean water quality and nutrient data for John Brewer Reef (a) Pre-Resort, (b) Resort and (c) Post Resort

Mean Water Quality Data

	Temp (°C)	pH	O_2 (mg/L)	Susp Sed (mg/L)	Turbidity ((NTU)	BOD (mg/L)	TOC (mg/L)	DOC (mg/L)
(a) Pre-Resort (January 1988)								
Control Station	27.70 (11)	-	7.30 (4)	3.78 (20)	0.40 (11)	1.8 (10)	-	1.48 (9)
Swing Circle	27.55 (11)	-	7.48 (4)	3.62 (20)	0.35 (11)	1.8 (10)	-	1.68 (9)
(b) Resort (Febuary-December 1988)								
Control Station	25.92 (26)	8.25 (34)	7.77 (34)	2.64 (43)	0.26 (34)	0.54 (10)	0.98 (12)	0.68 (4)
Swing Circle	25.92 (32)	8.33 (34)	8.33 (43)	2.59 (42)	0.34 (34)	0.39 (6)	0.70 (12)	0.64 (4)
(c) Post-Resort (August 1988)								
Resort Station	20.80 (11)	-	8.72 (11)	3.06 (17)	-	-	-	-

Mean Nutrient Data

(a) Pre-Resort	PO_4 µM	NO_3 µM	NH_3 µM	Si µM	Chl *a* µg
(a) Pre-Resort					
Control Station	0.25 (21)	0.23 (21)	-	1.03 (21)	0.44 (22)
Swing Circle	0.29 (21)	0.48 (21)	-	0.99 (21)	0.30 (22)
(b) Resort	0.22 (39)	0.27 (39)	0.19 (36)	2.95 (21)	0.52 (43)
Swing Circle	0.24 (38)	0.26 (38)	0.19 (36)	2.97 (21)	0.58 (43)
(c) Post-Resort					
Swing Circle	0.12 (21)	0.28 (21)	-	0.93 (21)	0.16 (8)

Effect of *Trichodesmium* on water quality

Anomalous effects on nutrient water quality were found at John Brewer Reef during the presence of *Trichodesmium*, a blue-green algae which blooms prolifically in the Great Barrier Reef lagoon (Jones et al, 1982). This organism was present in the lagoon on 14 - 15 January 1988 and November - December 1988. During these occasions significant changes ($P < 0.001$) in dissolved phosphate, nitrate, ammonia, silica, chloroplyll *a,* pH and suspended sediment occurred (Jones, 1992). Suspended sediments and dissolved inorganic phosphate levels exceeded or were close to recent water quality tolerance levels derived for corals (Hawker and Connell, 1989).

Monitoring program design

The following recommendations were made for modification to an on-going program of routine water quality monitoring, had it continued.

a. Effluent disposal

- Operating procedures for the wastewater treatment plant should be examined with a view of improving the effluent standards; this includes reduction of sulphide generation and minimisation of corrosion of iron in the holding tank.
- Studies on the effect of flocculants on the BOD and total Nitrogen levels of the effluent should be investigated. The types of detergents and cleaning agents used should be critically examined to remove from use any that are phosphate-based.
- Delete the free chlorine requirement of 2 mg/L on the basis that UV disinfection is effective, and preferable to chlorination.
- Sludge, wastewater, and brine wastes should be returned to the mainland.
- Any effluent entering the lagoon should be monitored.
- Trace metals, oil and grease, and total Nitrogen and Phosphorus should be made every three months.
- The efficiency of the wastewater plant should be monitored every three months by the appropriate government agency.

b. Lagoonal water quality

- Comprehensive 24 hour monitoring should be carried out every three months. Visits should be intensive rather than cursory monthly visits.
- Specific activities should be labelled for critical examination.
- Any effluent entering the lagoon should be monitored for metals, nutrients and organics.
- In any reef water quality monitoring program specific attention should be given to assessing whether *Trichodesmium* is present since it has been established that this organism significantly affects water quality in the Great Barrier Reef Lagoon. Failure to take account of this organism can be detrimental to the developer.

An inherent problem with any monitoring program is that comparisons between 'impact' and 'control' sites provide data which can be criticised on statistical grounds. Claims are often made for random-block compartments distributed around 'impact' and 'control' sites. For seawater studies, such claims are not valid. Apart from being costly exercises, seawater is usually homogenous with most constituents lying within very narrow tolerance levels. A simple and inexpensive way is to correlate data for impact and control sites (Jones, 1991). Any deviations away from a significant correlation then can be investigated in detail.