WATER QUALITY MONITORING PROGRAM
AIRPORT CONSTRUCTION SITE
MOEN ISLAND, TRUK
TRUST TERRITORY OF THE PACIFIC ISLANDS
PART C
POST-CONSTRUCTION

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INTRODUCTION

Expansion of the Truk International Airport runway on Moen Island was begun in the summer of 1978 and completed in December 1981. The Part C Post-construction water quality (WQ) monitoring program was conducted in July 1982. In this program, the marine WQ stations used in the Part A and B programs were monitored over a 5-day period. Water quality analyses were used to assess post-construction WQ in relation to: 1) the Part A Pre-construction turbidity standard; 2) the TTPI WQ standards; 3) and Part B Construction WQ data and observations.

This study of water quality in the Part C Post-construction period was requested by the U.S. Navy in accordance with Contract No. N62742-78-C-0029, Part C. It was a portion of the third part of a three part environmental monitoring program which consisted of:

1. Part A. Pre-construction Monitoring Program

2. Part B. Construction Monitoring Program

3. Part C. Post-construction Monitoring Program

Each of these parts is further divided into two portions, a water (and, for Parts A and B, noise and air) quality monitoring program and a biological monitoring program. The biological monitoring program for Part C was undertaken by the Marine Laboratory of the University of Guam and is described in a separate report (Amesbury et al., 1982).

The Part A water quality monitoring program took place over a 3-month period in 1978 (Clayshulte et al., 1979). Eight water quality monitoring stations were established adjacent to the airport construction and dredge sites and ninth station was established as a control. The objectives of the Part A study were to determine baseline water quality and to develop turbidity limits to be used by the contracting agency to control changes caused by construction activity. The objectives of the Part B study were to monitor WQ in order to assess compliance with the Part A Pre-construction turbidity standard and the TTPI water quality standards.

Control of Truk International Airport was officially transferred to Truk State from the U.S. Navy (OICC) in December 1981. The completion of the Water and Energy Research Institute (WERI) Part B monitoring program coincided with this airport transfer. However, at the time of official transfer, all of the construction activities were not complete. Construction operations were still in progress in the Part C monitoring program. There were some clean up, restoration and finalizing construction operations in progress.

OBJECTIVES

The objectives of the Part C water quality monitoring program were to:

1. Determine the Post-construction marine WQ at stations established in the Part A monitoring program and a new station established for Part B monitoring.

2. Compare the data and observation obtained for the Part C monitoring with data from Parts A and B, and identify any changes in water quality.

METHODS

In order to evaluate the environmental impact during the construction period, water quality sampling stations were established and monitored over a three-month period, June to August 1978, as a portion of the Part A Pre-construction baseline monitoring program (Clayshulte et al., 1979). The sampling frequency, chemical and physical water quality parameters, and analytical techniques were designated by the contracting agency.

In additional to the nine Part A water quality stations, a new station (10) was established for the Part B monitoring program (Figure 1). Detailed descriptions and locations of the nine original stations were presented in the Part A report. The location of station 10 was described in the Part B report (Clayshulte and Zolan, 1982).

The water quality parameters and analytical techniques used in the Part C monitoring were the same as those used in Parts A and B of the monitoring program. The water quality parameters measured were pH, temperature, salinity, turbidity, dissolved oxygen (DO), total phosphorus (TP), and total Kjeldahl nitrogen (TKN). Additional chemical WQ parameters measured in the Part C monitoring were ortho-phosphorus ($P\text{-}PO_4$), ammonia-nitrogen (NH_3), total organic nitrogen (TON), nitrate- and nitrite-nitrogen ($NO_3\text{-}NO_2\text{-}N$), and total nitrogen (TN). The water column at each station was sampled at the surface (-1m) and bottom (+1m above substratum). Surface and bottom waters were analyzed for pH, temperature, salinity, turbidity and DO. The nutrient samples were from bottom water samples. Samples were taken between 0900 and 1400 hours with a PVC Van Dorn sampler. Temperature and salinity were measured in the field. Turbidity, pH, and DO were analyzed at the Truk Environmental Health Laboratory. The nutrient samples were frozen, transported in ice and analyzed at the WERI Laboratory in Guam.

Heavy metal samples were collected from bottom waters at each station. The samples were preserved with nitric acid and transported to WERI for analyses. The water sample from each station was analyzed for zinc (Zn), copper (Cu), lead (Pb), mercury (Hg), and arsenic (As).

Turbidity was nephelometrically measured at the Truk Environmental Health Laboratory with a Model 2100A Hach turbidimeter. Salinity was measured with a hand-held refractometer. The Azide-Winkler modification was used to detrmine DO (APHA, 1980). TP was analyzed by the persulfate digestion-ascorbic acid reduction method (APHA, 1980). TKN was determined by macro-digestion (500 ml sample), distillation, and nesslerization (APHA, 1980). Ortho-phosphorus was analyzed by the ascorbic acid reduction method

(APHA, 1980). Ammonia nitrogen was determined with the indophenol method (Cowan et al., 1978). Nitrate-nitrite-nitrogen was analyzed by the cadmium-reduction method (APHA, 1980). TN and TON were calculated quantitites based on the analyzed nitrogen components.

The TTPI water quality standards (TTPI, 1978) for nitrogen are in terms of total nitrogen. The samples in this study were analyzed using the total Kjeldahl nitrogen method which does not measure total nitrogen, since it does not measure nitrate- and nitrite-nitrogen. This is not a problem since the separate analyses of nitrate plus nitrite-nitrogen yielded very low concentrations.

Meteorological data including wind speed and direction, air temperature, total sunshine, barometric pressure and precipitation were obtained for the sampling day and previous 24-hour period from the U.S. Department of Commerce, National Weather Station, Moen Island, Truk. Water current directions were obtained at each monitoring station by measuring the movement of flourescein dye tracks (Figure 1).

RESULTS AND DISCUSSION

Some construction activities were still in progress, which affected lagoon water, when the Part C monitoring program was conducted. These construction activities involved work at sea level along the previous reef margin adjacent to station 5 and affected WQ around stations 5 and 6. There were three principal projects in progress which involved the former slurry settling lagoon:

a) removal of dredge discharge sediments and basalt rock from the reef margin zone west of station 5 and deposition of this material at the NE end of the runway;

b) recovery of the concrete dollose's which were stored along the reef margin during Part B construction and buried by dredge discharge material in a major storm. These dollose's were placed as needed along the runway breakwater complex;

c) removal of unusable dredged slurry sediments from the western end of the settling lagoon. These sdiments were too fine to be used as fill material. At the time of the Part C monitoring program, it was not known where these unusable sediments would be deposited.

Turbidity plumes which were directly attributable to the aforementioned construction activities along the reef margin between stations 5 and 6 affected WQ in the general area of station 6 . Turbidity plumes which originated from the new slurry lagoon affected WQ between stations 4 and 6 (Figure 1). These turbidity plumes were observed to extend to and beyond (northward) the control station (9). Outflow of water from the dredged lagoon (Figure 1) influenced WQ around stations 3 and 4, which were near the dredged channel entrances to the lagoon. Discharges of

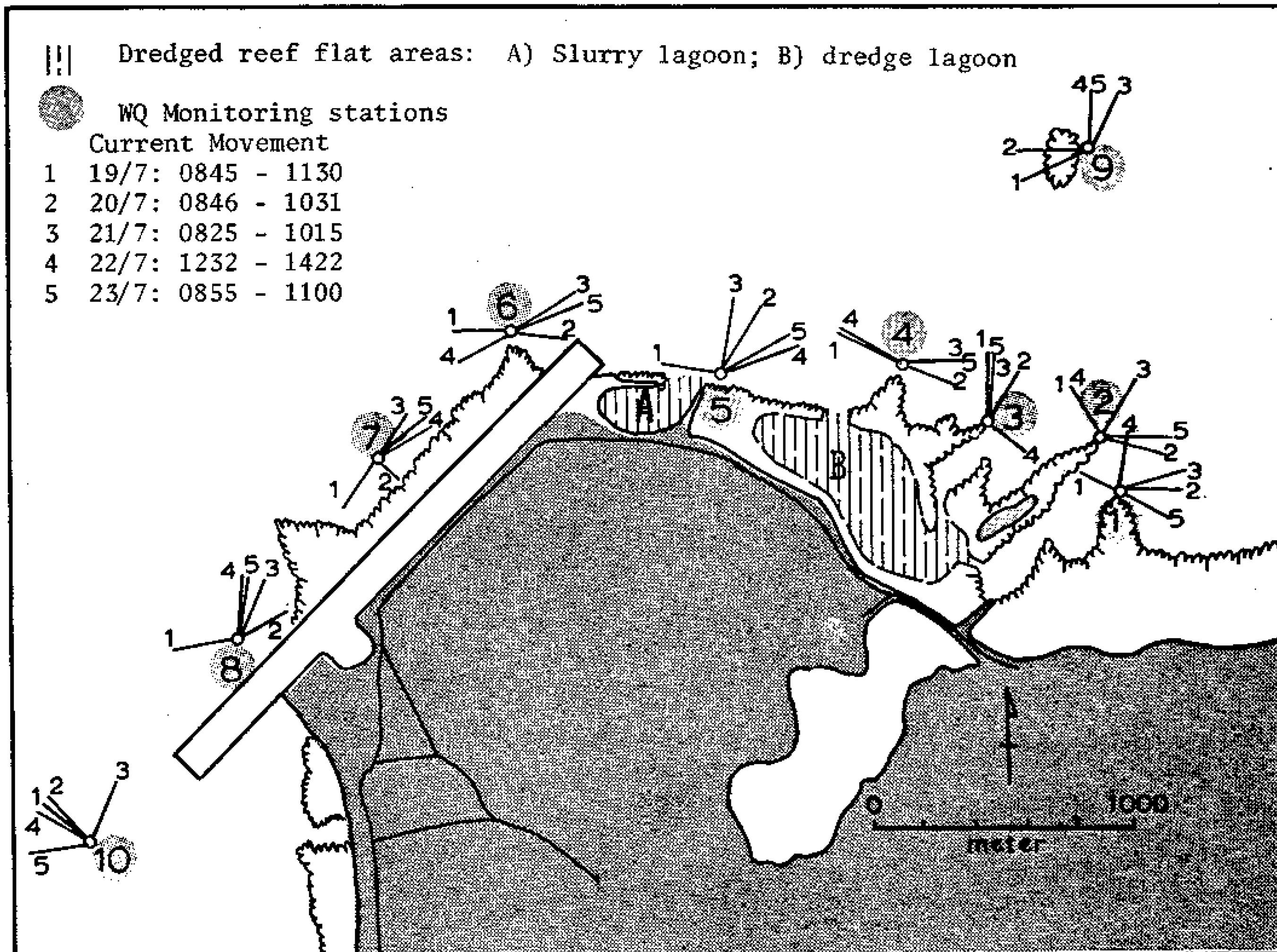

Figure 1. Water quality monitoring stations, water current movements, and dredged reef flat areas, Moen Island.

fuel/oil by boats anchored in the dredged lagoon were observed on surface waters at station 3 and 4. A particularly large discharge of fuel/oil on July 27, 1982, extended from station 3 to the control station.

Water Quality Standards

Physical and chemical water quality (WQ) parameters at the monitoring stations are evaluated and regulatd by the Part A Pre-construction turbidity standard ($\leq$2.0 NTU) and the TTPI marine water quality standards (TTPI, 1978). See Appendix C for the TTPI marine water quality standards for different classes of marine water. The construction site is class B water. The TTPI standards provide numerical limits for total phosphorus (TP), total nitrogen (TN), pH and dissolved oxygen (DO). The limits for temperature and salinity are "natural conditions" ±10 percent. A standard has not been established for TKN; however, the TN standard can be applied, since TKN is almost always the major total nitrogen component.

The physical and chemical WQ data for surface and bottom waters of each monitoring station are presented in Appendix A. Mean and standard deviation of WQ values (N = 5) for separate surface and bottom waters are included in the turbidity (Table A1), temperature (Table A2), pH (Table A3), salinity (Table A4), and dissolved oxygen (Table A5) tables. Table 1 presents the combined surface and bottom water mean (N = 10) for these WQ parameters. The TP, P-PO_4, NH_3, TKN and TON nutrient samples are from only bottom waters and the mean values (N = 5) presented in Tables A6, A7 and A8 are the same as those in Table 1. There are large standard deviations for the NH_3 (Table A7) and TKN (Table A8) analyses. Analyses of the TN (Table A8) and NO_3-NO_2 (Table A7) nitrogen components at WQ stations 6 and 9 are for an N = 5. The remaining WQ stations have a single analysis for these nitrogen components. The TN and NO_3-NO_2-N values in Table 1, except stations 6 and 9, represent a single value.

Mean turbidity values at stations 5 (surface water), 6 (surface and bottom waters) and 8 (surface water) exceeded the Part A standard of 2 NTU (Table 1). These high mean turbidities were a result of unusually high turbidity measurements taken on July 23, 1982 (Table A1). On this date, station 5 had the highest turbidities with values of 7.3 and 6.2 NTU for surface and bottom waters, respectively. The highest turbidity recorded for station 6 was 7.5 NTU on October 30, 1979 which was a Part B construction dredge spoil discharge period (Clayshulte and Zolan, 1982). Station 5 had turbidities of 5.5 and 4.5 NTU for surface and bottom waters, respectively, with a previous high turbidity of 5.9 NTU on September 25, 1980. Station 8 had turbidities of 4.9 and 3.0 NTU for surface and bottom waters, respectively, with a previous high turbidity of 10 NTU on September 25, 1980. These highly turbid waters at the runway WQ stations were caused by the prevalent meteorological conditions in conjunction with the accumulations of silty ooze deposited by Part B construction dredge filling operations. Lime muds deposited in the shallower waters around stations 5, 6, 7 and 8 were resuspended into the water column beginning on July 21, 1982 when the predominately southwesterly winds consistently exceeded 15 knots (Figure 2). These highly turbid lime mud plumes were

Table 1. Mean physical and chemical characteristics at water quality stations. Bottom depths are means (Table A9).

WQ STATION	Bottom Depth	Current Flow	Turbidity (NTU)	Temp. (°C)	pH	Salinity ‰	DO (mg/ℓ)	TP (mg/ℓ)	P-PO_4 (mg/ℓ)	NH_3 (mg/ℓ)	NO_3[2] (mg/ℓ)	TKN (mg/ℓ)	TN[2] (mg/ℓ)	TON (mg/ℓ)
1[1]	12.6	122	.94	27.6	8.23	33.7	5.5	.011	.005	.070	.003	.079	.091	.020
2	9.7	177	1.1	27.7	8.23	34.0	5.5	.008	.002	.048	.003	.151	.091	.103
3	13.0	33	1.1	27.8	8.22	33.9	5.6	.006	.003	.053	.071	.113	.184	.064
4	9.7	177	1.1	27.7	8.23	33.9	5.7	.008	.002	.060	.006	.063	.060	.006
5	8.0	90	1.9	27.7	8.21	34.1	5.8	.011	.002	.047	.003	.065	.116	.032
6	9.5	148	2.5	27.6	8.20	34.0	5.6	.012	.004	.059	.004	.342	.347	.292
7	9.7	101	1.5	27.8	8.21	34.0	5.6	.012	.003	.041	.003	.067	.003	.041
8	12.1	72	1.9	27.5	8.21	34.3	5.8	.013	.003	.071	.002	.085	.100	.041
9	9.7	253	.60	27.8	8.24	34.0	5.7	.017	.004	.046	.002	.073	.075	.039
10	16.2	240	.72	27.7	8.22	33.6	5.8	.016	.005	.076	.001	.104	.060	.045

[1]top - samples taken at -1m below surface.
bottom - samples taken at +1m above bottom.
[2]only station 6 and 9 are means (5 days), others single value.

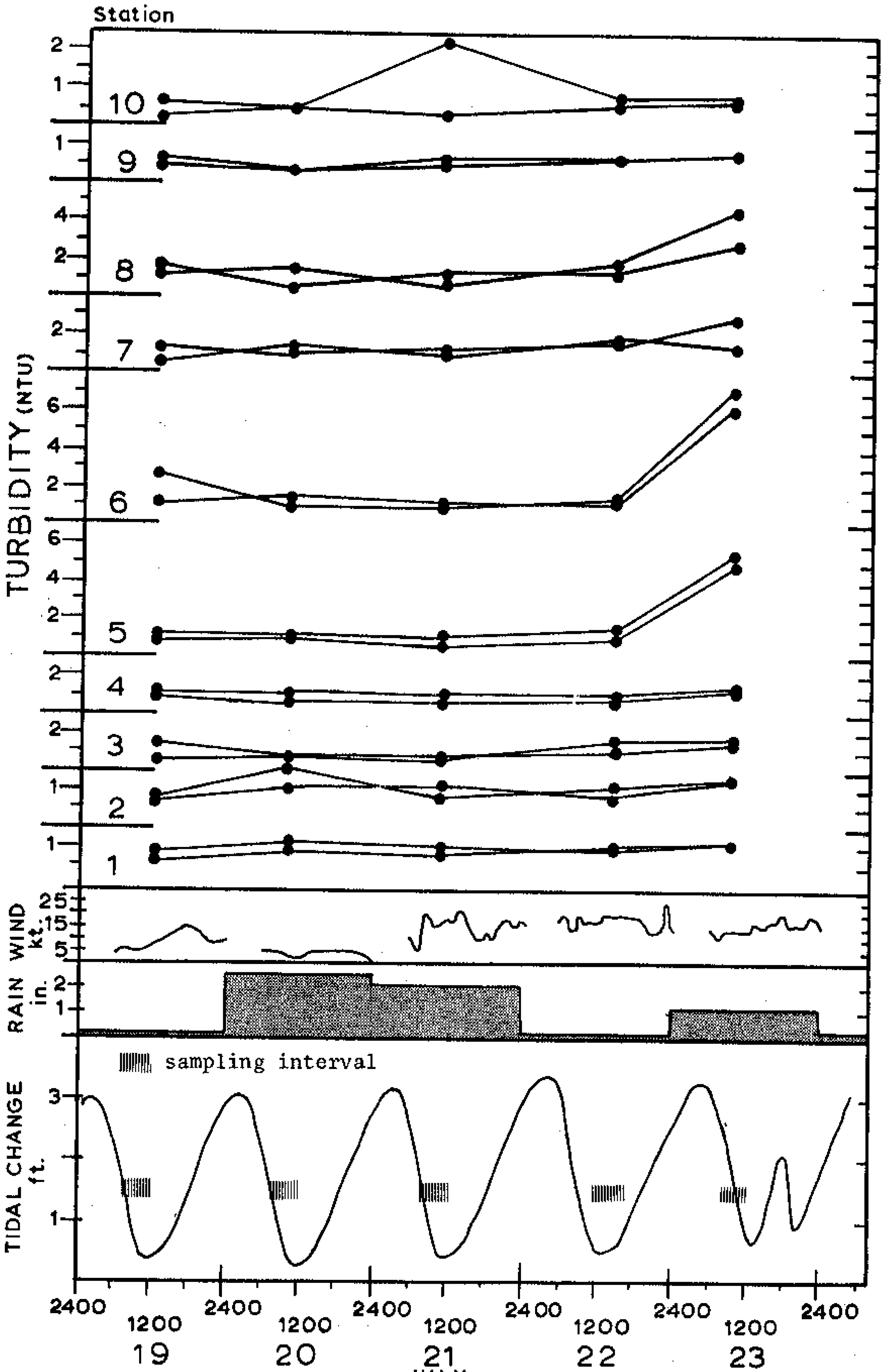

Figure 2. Monitoring station turbidities compared with meterological conditions.

transported toward the north to northeast by the prevalent water currents. These plumes were observed through July 29, 1982. In this time period, the plumes caused disruption in WQ extending to the control station 9.

The mean values of the other WQ parameters (TP, $P\text{-}PO_4$, TKN, DO, pH, salinity and temperature) from each monitoring station when compared with the TTPI class B marine water standards were within allowable limits (Table 1). Additionally, there were no exceedences of the standards for specific sampling dates for these parameters.

WQ Comparison with Parts A and B

Mean WQ values for turbidity, temperature, salinity, pH, dissolved oxygen, TKN and total phosphorus from Parts A, B and C of the WQ monitoring program are presented in Table 2.

The number of analyzed data sets were variable between the monitoring program parts. There were half as many WQ samples taken for nutrient analyses compared to the other WQ parameters. Dependent on the WQ parameter and WQ monitoring station, the number of data sets analyzed for each part were as follows: Part A had 5 to 19; Part B 37 to 79; and Part C had 5 to 10. The Part A and C monitoring trips were made in the summer months, while the Part B monitoring spanned a 40 month period with monthly sampling periods. The summer weather conditions for the Part A and Part C monitoring trips were quite different. Part A weather conditions were characterized by low winds, essentially calm lagoon waters and moderate rain shower activity (Clayshulte et al., 1979). Part C weather conditions were characterized by high winds (sustained winds to 36 knots during sampling), swells in excess in 1m and heavy rain shower activity with thunderstorms (Table 3).

As a result of the aforementioned considerations, discretion must be used in comparing the mean WQ parameter values for the three monitoring program parts. However, the Part B station 9 data can be used to define the long-term ambient WQ for natural lagoon waters. Part C mean WQ data for salinity, pH, TKN and TP are similar to Part B station 9 data (Table 2). These WQ parameters are also in reasonable agreement with Part A WQ data values. Part C station 6 TKN is higher compared with Parts A and B. Part C mean temperatures and dissolved oxygen values (DO) are significantly lower at all WQ stations compared with Parts A and B. The lower water temperatures and DO values are related to the tropical storm weather conditions. Lower water temperatures correspond to periods of heavy rainfall and lower DO is caused by reduced sunshine (Clayshulte and Zolan, 1982). Although temperature and DO values are lower for the Part C monitoring program, they are not indicative of environmental degradation and do not constitute a problem. Based on the 95 percent confidence intervals generated with the Part B mean data, Part C mean turbidities are significantly higher for WQ stations 1, 2, 3, 4, 5, 6, 7 and 9. Stations 8 and 10 have turbidities which are consistent with Part B means. The Part A mean turbidities are consistently less than the lower limit of the Part B 95 percent confidence intervals for the means.

Table 2. Comparison of mean water quality data for Parts A, B and C of the monitoring program.

MONITORING STATIONS*

WATER QUALITY PARAMETER	1 PARTS A	1 B	1 C	2 PARTS A	2 B	2 C	3 PARTS A	3 B	3 C	4 PARTS A	4 B	4 C	5 PARTS A	5 B	5 C
Turbidity (NTU)	.38	.64	.94	.40	.58	1.1	.50	.73	1.1	.41	.64	1.1	.36	1.0	1.9
Temperature (°C)	29.4	29.0	27.5	29.4	29.1	27.6	29.5	29.1	27.8	29.4	29.1	27.6	29.5	29.1	27.6
Salinity (⁰/₀₀)	33.6	33.7	33.7	33.9	33.7	33.9	33.8	33.6	33.9	33.8	33.7	33.9	33.4	33.7	34.0
pH	8.19	8.17	8.22	8.21	8.19	8.23	8.21	8.20	8.22	8.22	8.20	8.23	8.20	8.21	8.21
Dissolved Oxygen (mg/ℓ)	6.2	6.2	5.5	6.1	6.3	5.4	6.2	6.4	5.6	5.9	6.3	5.7	6.0	6.4	5.7
TKN ** (mg/ℓ)	0.11	0.15	0.08	0.07	0.15	0.15	0.07	0.18	0.11	0.03	0.13	0.06	0.12	0.13	0.06
Phosphorus (mg/ℓ)	.024	.011	.011	.021	.020	.008	.019	.012	.006	.023	.013	.008	.019	.011	.011
WATER QUALITY PARAMETER	**6 PARTS A**	**6 B**	**6 C**	**7 PARTS A**	**7 B**	**7 C**	**8 PARTS A**	**8 B**	**8 C**	**9 PARTS A**	**9 B**	**9 C**	**10 PARTS A**	**10 B**	**10 C**
Turbidity (NTU)	.34	1.2	2.4	.39	1.0	1.4	.43	1.5	1.8	.24	.43	.59	--	.97	.71
Temperature (°C)	29.5	29.1	27.6	29.3	29.0	27.7	29.3	29.0	27.5	29.6	29.0	27.7	--	29.0	27.6
Salinity (⁰/₀₀)	33.4	33.7	33.9	33.6	33.7	34.0	33.1	33.6	34.2	34.0	33.8	34.0	--	33.5	33.6
pH	8.20	8.21	8.20	8.19	8.21	8.21	8.20	8.21	8.21	8.22	8.23	8.24	--	8.21	8.22
Dissolved Oxygen (mg/ℓ)	6.1	6.4	5.6	6.0	6.3	5.6	6.0	6.3	5.7	6.4	6.4	5.6	--	6.3	5.7
TKN ** (mg/ℓ)	0.07	0.14	0.34	0.10	0.17	0.07	0.03	.016	0.08	0.05	.014	0.07	--	0.13	0.10
Phosphorus (mg/ℓ)	.024	.013	.012	.029	.015	.012	.020	.017	.013	.013	.011	.017	--	.012	.016

*surface and bottom waters combined

Table 3. Summary of weather data from NOAA weather station, Moen Island, and lagoon tidal changes. Water quality sampling was done on July 18-23, 1982.

DATE	TIME INTERVAL	WIND DIRECTION (degrees)	WIND SPEED (kts)	FASTEST WIND-24hr (dir.)kts	AIR TEMPERATURE (°F)	BAROMETRIC PRESSURE (in. Hg)	TOTAL SUNSHINE (min)	RAINFALL 24-hr (in.)	TIDAL CHANGE TIME (ft)	TIDAL CHANGE TIME (ft)	TIDE DURING SAMPLING
7-18	0800-1300	337	6	(N) 12	84.7	29.725	183	0.01	0201(2.8)	1029(0.5)	Fall*
7-19	0800-1300	100	6	(SW) 20	84.0	29.735	139	0.12	0233(3.0)	1053(0.4)	Fall
7-20	0800-1300	250	3	(W) 17	76.9	29.785	4	2.52	0306(3.1)	1122(0.3)	Fall
7-21	0800-1300	200	17	(SW) 36	77.9	29.805	0	2.40	0338(3.2)	1148(0.4)	Fall
7-22	1100-1600	210	19	(SW) 34	84.7	29.715	303	0.16	0410(3.2)	1214(0.5)	Neap
7-23	0800-1300	215	14	(SW) 36	82.3	29.785	87	1.47	0438(3.1)	1232(0.6)	Fall
7-24	24-hr	---	16.1	(SW) 32	81	--	384	0.20	0501(2.9)	1244(0.8)	--
7-25	24-hr	---	15.7	(SW) 23	85	--	511	0	0519(2.7)	1244(1.0)	--
7-26	24-hr	---	13.2	(SW) 19	85	--	392	0	0523(2.4)	1236(1.1)	--
7-27	24-hr	---	16.4	(SW) 25	83	--	46	0	0515(2.2)	1217(1.1)	--
7-28	24-hr	---	12.6	(SW) 23	82	--	510	0.25	0439(2.0)	1154(1.0)	--
7-29	24-hr	---	5.4	(SW) 17	84	--	536	0	0319(2.0)	1132(0.9)	--
7-30	24-hr	---	4.8	(NE) 17	80	--	83	.71	0154(2.1)	1101(0.8)	--

*reef flats and patchreef (station 9) exposed during sampling.

Total nitrogen (TN) is composed of several nitrogen species which include organic and ammonia nitrogen (= total Kjeldahl nitrogen) and nitrite-nitrate nitrogen. Nitrite-nitrogen is a readily convertable nitrogen species (to nitrate-nitrogen) and is generally measured at low levels in marine waters. Cowan and Clayshulte (1979) in a baseline study of marine water quality around Micronesian islands, including Truk lagoon, measured low levels of nitrite-nitrate nitrogen for near-shore waters and recorded similar results from previous studies. Ammonia- and organic-nitrogen concentrations are variable between different types of marine environmental systems. Marine waters near mangrove complexes or areas receiving flush from mangrove swamps tend to have higher organic-nitrogen concentrations, while fringing reef environments have more ammonia-nitrogen.

Nitrogen is an important nutrient of marine flora and it is often the limiting nutrient in marine waters. Therefore, the analyses of all nitrogen species can provide an assessement of the nitrogen cycle influence at WQ stations.

Nitrite-nitrate nitrogen concentrations were monitored daily at stations 6 and 9 and on a one time basis for the remaining stations (Table A7). The mean levels for this nitrogen species at station 6 and 9 were 0.004±.003 mg/ℓ and 0.002±.001 mg/ℓ, respectively. Station 3 had a high nitrite-nitrate nitrogen concentration of 0.071 mg/ℓ. This suggested that higher levels of this nitrogen species could occur, at WQ stations. However, based on the larger data base for stations 6 and 9 (Table 4), nitrite-nitrate nitrogen could be considered a minor TN component. It comprised 1.1% at station 6 and 2.7% at station 9 of the mean TN.

Organic - (TON) and ammonia-nitrogen (NH_3) were the major TN components (Table 5). These species comprised 98.6% at station 6 and 97.3% at station 9 of the mean TN. The ratio of TON to NH_3 was variable with stations 2, 3, and 6 having a greater quantity of TON and the remaining stations had more NH_3 (Table 5).

Total phosphorus (TP) is composed of a complex set of phosphorus species which have a wide range of oxidation states. The reactive or ortho phosphorus ($P\text{-}PO_4$) species is used by marine biota imetabolic processes. Phosphorus,like nitrogen is an essential nutrient for plant growth. As a result, $P\text{-}PO_4$ has the potential to become a limiting nutrient in marine biota growth. It has been shown that marine ecosystems can remain stable with very low concentrations of phosphorus, if these concentrations are reasonably constant (Barrett and Rosenberg, 1981). Large fluxes in nutrient levels cause by man-induced or natural pretabations can stress marine ecosystems. Stress in the ecosystem can be assessed by the ratio of nitrogen to phosphorus.

In a baseline marine WQ survey which included Truk Lagoon waters (Cowan and Clayshulte, 1980), the mean TP in class B water was 0.017 mg/ℓ with concentrations ranging from 0.003 to 0.094 mg/ℓ. The mean concentrations of $P\text{-}PO_4$ was 0.006 mg/ℓ with a range of 0 to 0.020 mg/ℓ.

Table 4. Comparison of nitrogen species at WQ Stations 6 and 9.

WQ Station	NO_3-NO_2 x(mg/ℓ)	%	NH_3 x(mg/ℓ)	%	TON x(mg/ℓ)	%	TKN x(mg/ℓ)	%	TN x(mg/r)
6	0.004	1.1	0.059	17.0	0.292	84.1	0.342	98.6	0.347
9	0.002	2.7	0.046	61.0	0.039	54.0	0.073	97.3	0.075

Table 5. Comparison of mean percent organic and ammonia-nitrogen components of total Kjeldahl nitrogen at WQ stations.

WQ Station	TON vs. TKN	NH_3 vs. TKN	Ratio TON/NH_3
1	25.3	92.4	3.7
2	68.2	31.8	-2.1
3	56.6	46.9	-1.2
4	9.5	95.2	10
5	49.2	72.3	1.5
6	85.4	17.2	-5.0
7	61.2	61.2	1.0
8	48.2	83.5	1.7
9	53.4	63.0	1.2
10	43.3	73.1	1.7
y	50.0	63.7	
+s.d.	21.2	25.5	

Their study showed that phosphorus was not a limiting nutrient in Truk lagoon waters under natural and slightly disturbed conditions. Mean TP at WQ stations in the Part C monitoring ranged from 0.006 (±.002) mg/ℓ at station 3 to 0.017 (±.002) mg/ℓ at station 9. The grand mean of all station was 0.012 (±.004) mg/ℓ. The percent $P\text{-}PO_4$ of TP measured at WQ stations was as follows:

STATION	Percent $P\text{-}PO_4$ to TP
1	26.7
2	25.0
3	50.0
4	25.0
5	18.2
6	33.3
7	25.0
8	23.1
9	25.5
10	31.2
mean±s.d.	28.1±8.8%

Nitrogen and phosphorus algal growth rate limitation can be evaluated by the ratio of total soluble inorganic nitrogen (TSIN = NO_3-N, NO_2-N and NH_3-N) to ortho-phosphate phosphorus ($P\text{-}PO_4$). The maximum TSIN/$P\text{-}PO_4$ mass ratio where nitrogen is the limiting nutrient is 15/1 (Specht, 1975). The TSIN/$P\text{-}PO_4$ mass ratios at WQ stations were as follows:

STATION	TSIN/$P\text{-}PO_4$
1	17/1
2	31/1
3	51/1
4	22/1
5	22/1
6	15.8/1
7	27.5/1
8	16.5/1
9	12/1
10	16.8/1

Nitrogen has been identified as the limiting nutrient in Truk Lagoon waters in previous studies (eg. Cowan and Clayshulte, 1980). Prior to construction activities, all of the WQ stations were measured to be nitrogen limited. The mean mass ratio of 12/1 at the control station (9) still showed nitrogen to be the limiting nutrient. However, at station 6 and at the remaining WQ stations (based on less data), phosphorus was measured as the limiting nutrient. The change in TSIN/P-PO_4 mass ratio indicates that the marine ecosystem is still being stressed by previous construction pertabations.

Natural sedimentation rates were determined at the WQ stations prior to dredge effluent discharges. Sediment fallout or "rain" ranged between 43 mℓ/m^2/day at the control station to 143 mℓ/m^2/day (station 4) to 18.8 g/m^2/day (station 5) with an organic content of 8.2 to 14.3 percent. The organic content of the lagoon sediments at WQ stations was about 3 percent. Dredge effluent discharges produced increased sedimentation rates with a 900 percent increase at station 6. There was no significant change in sediment "rain" at station 9 for the Part B Construction period. Part C Post-construction sedimentation rates were measured at stations 6 and 9. Station 6 sediment "rain" was still occurring at a rate of 256 mℓ/m^2/day. This was 200 percent over the initial natural conditions. Station 9 had a mean sediment "rain", based on 20 sedimentation traps, of 23.6 mℓ/m^2/day (12.5 g/m^2/day), which was consistent with both the Parts A and B measurements.

To maintain fine sand in the suspended sediment load, the average water current must be about 50 cm/sec. Water velocities, measured with drift drogues, at station 6 in 1978 (Pre-construction) ranged from 3 to 11 cm/sec; subsequent velocities, measured with dye tracks for both Parts A and B monitoring, have been in the same range. Only in periods of tropical storm induced heavy surf and wind, have current velocities been measured near 50 cm/sec. Therefore, most of the suspended load deposited along the WQ boundary is silt and clay sized particles. These silt and clay sized deposits are lime muds. Once these lime muds are deposited in the quieter and deeper lagoon water, they are difficult to remove by water currents.

In order to assess the volume of deposited mud resuspended by water currents, flat exposure plates were placed at station 6 from February to June, 1979. Accumulation of lime mud occurred at a rate of 15 mℓ/m^2/day. Therefore, most of the suspended sediment load "rained" onto station 6 was removed by currents. Visual inspection at this station during the sedimentation plate collection and at the conclusion of Part B monitoring (December, 1981), showed a 4-5 cm veneer of mud overlain on the lagoon sands. Pockets of mud were found with depths ranging to 20 cm. Analyses of the plate muds for grain size distribution showed 10-15% fine to very fine sands with the remainder as silts and clay. In Part C monitoring, visual inspection at this station showed an apparent decrease in veneered muds; but pockets of mud were still common throughout th area.

It was anticipated in the Part B monitoring that the resuspension of the shallow water lime muds would cause future disruption in WQ adjacent to the runway. However, the magnitude of the problem was not realized until the Part C monitoring. Turbidity plumes caused by resuspension of lime muds resulted in WQ degradation throughout the construction area.

In periods of intensified weather activity, resuspended of shallow water lime mud is easily accomplished by increased wind and surf conditions. It is highly likely that in the rainy season, which has frequent rainshower and thunderstorm activities, there will be some WQ degradation due to turbidity plumes.

Heavy Metals

Heavy metal concentrations at WQ monitoring stations were analyzed on a yearly basis between 1978 and 1982. Heavy metal concentrations for 1982 (Part C) were compared with 1978 (Part A) and 1981 (Part B) data (Table 6). The 1981 data was considered the most reliable Part B data set. The 1981 and 1982 analyses for arsenic (As), copper (Cu), lead (Pb) and zinc (Zn) used improved anlytical techniques which sould have more realistically assessed heavy metal concentrations. Heavy metal concentrations for As, Cu, Pb, and Zn were below the TTPI marine WQ standards (TTPI, 1978) and had values consistent with the 1981 data (Table 6). Arsenic was the only metal which was consistently below the marine WQ standards (10 μg/ℓ) for all 3 parts of the monitoring program. Concentrations of mercury (Hg) exceeded the TTPI marine WQ standards at stations 3, 4, 6, 8, 9 and 10. Hg is a difficult metal to analyze. The detection limit with available equipment and the TTPI WQ standard for Hg are the same at 0.1 μg/ℓ. In 1981 and 1982, only Hg standards were exceeded; but these values, which are low, were possible caused by stray contamination during the sampling or analysis. The very high 1979 Hg concentration (Part A Pre-construction) at station 8 was not seen in subsequent analysess in either the Part B or C monitoring program. Heavy metal contamination was not a WQ problem in the Part C monitoring program.

Meteorological and Hydrographic Effects

Table A9 presents water column depths for each sampling period and the visual clarity of the water column. The difference in depth between surface and bottom samples can inuflence measurements for most WQ parameters. Part B data analyses have shown that WQ stations with greater differences in depth between surface and bottom samples can have stratified water columns for specific WQ paramenters. Since differences in boat ancourage are unavoidable, there is a potential for variations in WQ as a result of sampling different portions of the water column. Surface and bottom samples for turbidity (Table A1), Ph (Table A3), salinity (A4) and DO (Table A5) show differences within the water column. Water temperatures (Table A2) are generally similar for surface and bottom water at each station.

Visual clarity correlated with turbidity measurements. Secchi measurements were dependent on water column depth. For shallow WQ stations, secchi readings could not be taken except in periods of extremely high turbidities. Secchi readings were obtainable on July 22, 1982 at WQ station 5, 6, 7, and 8.

Meteorological parameters (Figure 2; and Tables 3 and A10) and hydrographic conditions (Figure 2; and Tables 3, A9, and A11) were recorded

Table 6. Heavy metal concentrations (µg/ℓ) at water quality monitoring stations in 1978 (Part A), 1981 (Part B) and 1982 (Part C). The less than symbol (<) indicates metal concentrations were below detection limits. The 1978 analyses were made by the U.S. Navy Public Works, Fena Laboratory, Guam. The 1981 and 1982 analyses were made at WERI.

	ARSENIC (As)			COPPER (Cu)			LEAD (Pd)			MERCURY (Hg)			ZINC (Zn)		
WQ	Part A		PART C	PART A		PART C	PART A		PART C	PART A		PART C	PART A		PART C
STATION	1978	1981	1982	1978	1981	1982	1978	1981	1982	1978	1981	1982	1978	1981	1982
1	<10	1.2	1.0	<50	<1	3.0	<50	<1	<0.1	<1.0	<0.1	<0.1	<50	4	<10
2	<10	1.1	0.8	<50	<1	3.3	<50	1.7	0.3	<1.0	0.6	<0.1	<50	4	<10
3	<10	1.0	0.9	<50	<1	3.0	<50	<1	<0.1	<1.0	0.5	0.2	<50	5	<10
4	<10	1.4	0.9	<50	<1	2.8	<50	<1	0.3	<1.0	0.9	0.6	<50	4	<10
5	<10	1.2	1.1	<50	<1	2.5	<50	<1	0.3	<1.0	<0.1	<0.1	<50	4	<10
6	<10	1.2	0.9	<50	<1	1.2	<50	<1	0.9	5.0	<0.1	0.1	<50	4	<10
7	<10	1.8	0.9	<50	<1	0.3	<50	<1	0.2	<1.0	1.6	<0.1	<50	5	<10
8	<10	1.4	1.1	<50	2	0.3	<50	<1	0.3	29.0	0.7	0.8	<50	5	<10
9	<10	1.3	1.0	<50	<1	0.7	<50	1.0	0.3	<1.0	0.3	1.6	<50	11	<10
10	---	1.4	1.2	---	2	1.0	---	2.6	0.3	---	1.3	0.5	---	5	<10
WQ		10			10			10			0.1			20	
Standard		(µg/ℓ)			(µg/ℓ)			(µg/ℓ)			(µg/ℓ)			(µg/ℓ)	

for the Part C monitoring program. Appendix B presents a summary of major meteorological and hydrographic influences on WQ for the Part B monitoring program. Part C WQ was affected by the prevalent meteorological and hydrographic conditions. Wind direction and speed and water current movement affected turbidity (Figure 2). The wind speeds (in excess of 11 knots) for the prior day as well as direction (from the SW) helped to maximize turbidity levels. There was no apparent affect of precipitation on WQ station turbidities. The effect of tidal change could not be evaluated for the Part C monitoring since 4 of the data sets were taken on falling tides. However, the Part B analysis of WQ and tidal change showed limited correlation.

The dominantly southwest winds (Table A10) caused water currents to move toward the north to northeast (NE) (Table A11). Water movement toward the NE occurred only 7 percent of the time in the Part B monitoring. However, in the Part B monitoring program, water movement toward the NE produced higher turbidities. This trend was also evident for the Part C monitoring program. These NE water movements were observed to move turbidity plumes away from the runway toward the control station. (Table A11, Figure 1).

SUMMARY

The Part C Post-construction monitoring program showed a degradation of marine water quality (WQ) around the airport runway due to increased turbidity levels. These increased turbidities were attributed to past and ongoing construction operations. Accumlations of lime mud deposited in shallow waters adjacent to the runway were easily resuspended into the water column by tropical storm related wind and surf conditions. These turbidity plumes impacted large areas of lagoon water around the construction zone, including the off-shore control station. Winds originating from the southwest with speeds in excess of 11 knots appeared to maximize turbidities. Mean turbidity levels at stations 5, 6 and 8 exceeded the Part A standard of 2 NTU. Stations 2, 3, 4, 7 and 10 had turbidity exceedences for specific sample dates.

The Part C monitoring has shown large scale dredge and fill operations can cause long-term alternations in marine WQ. It can be anticipated that future resuspension of dredge deposited lime muds will occur in the vicinity of the runway as a result of normal tropical storm conditions.

The other physical and chemical WQ parameters, except the heavy metal mercury, analyzed at WQ stations were not in exceedence of the TTPI marine quality standards. Mean WQ data for salinity, pH, TKN and TP were consistent with Part B data and were not significantly different than the control station data. Station 6 TKN was higher than comparable data from Parts A and B. The TSIN/P-PO_4 mass ratios at all WQ stations except the control station (9) changed from nitrogen limited (Pre-construction) to phosphorus limited (Post-construction). This alteration in mass ratios indicated that the marine ecosystem was being stressed. Mean temperature and dissolved oxygen values were significantly lower compared with Parts A and B data. These lower values were a result of the prevalent weather conditions. The heavy metal concentrations for As, Cu, Pb, and Zn were below the TTPI marine WQ standards. Concentration of Hg exceeded the standards at stations 3, 4, 6, 8, 9 and 10, but were still at low levels, since the detection limit and standard are the same. Heavy metal contamination was not a WQ problem.

RECOMMENDATIONS

The high turbidities measured at WQ stations outside the designated WQ boundary constituted a degradation of lagoon water quality and a stressed ecosystem. These high turbidities were caused by resuspension of lime muds deposited in the shallow waters during dredge fill discharging operations. Stabilization of these lime mud deposits would reduce the risk of future WQ impairment in tropical storm periods. In order to determine the extent of lime mud depositions, an underwater survey should be conducted along the WQ boundary. Additionally, the marine sediments should be sampled and analyzed to determine the quantity of lime mud deposition. Since some construction operations were still in progress for the Part C monitoring program, it is recommended that a second post-construction monitoring program be conducted which measures marine turbidities at established WQ stations for a period of 5 days. The turbidity and marine sediment monitoring from this program could be used to more realistically ascertain the long-term impacts (or lack of impacts) of construction activities on lagoon waters surrounding the airport construction area. The nutrient levels, phosphorus and nitrogen, should be analyzed to determine if the post-construction TSIN/P-PO_4 mass ratios will convert back to the pre-construction levels.

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APPENDIX A

Water Quality Data

Table A1. Water quality: turbidity

PARAMETER: Turbidity, NTU

STATION		DATE					MEAN ± s.d.
		7-19	7-20	7-21	7-22	7-23	
1	TOP	0.90	1.2	1.0	0.95	1.2	1.0 ± .14
	SUB	0.59	0.85	0.75	1.0	1.2	0.88 ± .23
2	TOP	0.85	1.8	0.94	1.1	1.4	1.2 ± .39
	SUB	0.70	1.2	1.1	0.86	1.4	1.0 ± .28
3	TOP	0.70	0.78	0.94	1.1	1.4	0.98 ± .28
	SUB	1.3	0.70	0.72	1.5	1.8	1.2 ± .48
4	TOP	1.2	1.1	0.98	1.0	1.6	1.2 ± .25
	SUB	0.80	0.80	0.74	1.0	1.5	0.97 ± .31
5	TOP	1.2	1.2	1.1	1.4	5.5	2.1 ± 1.9
	SUB	0.98	1.1	0.78	1.01	4.5	1.7 ± 1.6
6	TOP	2.8	0.90	0.95	1.6	7.3	2.7 ± 2.7
	SUB	1.1	1.4	1.1	1.2	6.2	2.2 ± 2.2
7	TOP	1.2	1.0	1.1	1.6	3.2	1.6 ± .91
	SUB	0.70	1.5	0.94	1.9	1.5	1.3 ± .48
8	TOP	1.2	1.5	0.86	1.9	4.9	2.1 ± 1.6
	SUB	1.7	0.54	1.3	1.2	3.0	1.6 ± .91
9	TOP	0.45	0.45	0.50	0.60	0.81	0.56 ± .15
	SUB	0.68	0.45	0.58	0.67	0.78	0.63 ± .12
10	TOP	0.65	0.43	0.46	0.55	0.62	0.54 ± .10
	SUB	0.36	0.50	2.2	0.70	0.70	0.89 ± .75

Table A2. Water quality: temperature

PARAMETER: Temperature, °C

STATION		DATE 7-19	7-20	7-21	7-22	7-23	MEAN ± s.d.
1	TOP	29.2	27.0	27.0	28.0	27.0	27.6 ± 1.0
	SUB	29.0	27.0	27.0	28.0	26.5	27.5 ± 1.0
2	TOP	28.8	27.0	27.5	28.0	26.5	27.6 ± 0.9
	SUB	29.0	27.0	27.5	28.0	27.0	27.7 ± 0.8
3	TOP	29.0	27.0	27.5	28.0	27.5	27.8 ± 0.8
	SUB	29.0	27.0	27.5	28.0	27.5	27.8 ± 0.8
4	TOP	29.0	27.0	27.0	28.0	27.5	27.7 ± 0.8
	SUB	29.0	27.0	27.0	28.0	27.0	27.6 ± 0.9
5	TOP	29.0	27.0	27.0	28.0	27.5	27.7 ± 0.8
	SUB	28.9	26.5	27.5	28.0	27.0	27.6 ± 0.9
6	TOP	29.0	27.0	27.0	28.0	27.0	27.6 ± 0.9
	SUB	28.9	27.0	27.0	28.0	27.0	27.6 ± 0.9
7	TOP	28.9	27.0	27.5	28.0	27.0	27.7 ± 0.8
	SUB	29.0	28.0	27.0	28.0	27.0	27.8 ± 0.8
8	TOP	28.8	26.5	27.0	28.0	26.5	27.4 ± 1.0
	SUB	29.0	27.0	27.0	28.0	27.0	27.6 ± 0.9
9	TOP	29.2	28.0	27.0	28.0	27.5	27.9 ± 0.8
	SUB	29.1	27.0	27.0	28.0	27.0	27.6 ± 0.9
10	TOP	29.0	28.0	26.0	28.0	27.5	27.7 ± 1.1
	SUB	29.0	27.0	27.0	28.0	27.0	27.6 ± 0.9

Table A3. Water quality: pH.

PARAMETER: pH

STATION		DATE 7-19	7-20	7-21	7-22	7-23	MEAN ± s.d.
1	TOP	8.22	8.20	8.20	8.22	8.22	8.21 ± .01
	SUB	8.25	8.25	8.25	8.22	8.22	8.24 ± .02
2	TOP	8.22	8.21	8.28	8.20	8.22	8.23 ± .03
	SUB	8.26	8.25	8.22	8.22	8.20	8.23 ± .02
3	TOP	8.25	8.22	8.20	8.22	8.18	8.21 ± .03
	SUB	8.23	8.25	8.23	8.23	8.20	8.23 ± .02
4	TOP	8.25	8.25	8.20	8.23	8.18	8.22 ± .03
	SUB	8.28	8.28	8.20	8.18	8.25	8.24 ± .05
5	TOP	8.20	8.28	8.22	8.25	8.15	8.22 ± .05
	SUB	8.15	8.20	8.20	8.20	8.18	8.19 ± .02
6	TOP	8.15	8.33	8.19	8.18	8.15	8.20 ± .07
	SUB	8.18	8.25	8.21	8.19	8.12	8.19 ± .05
7	TOP	8.20	8.28	8.20	8.15	8.18	8.20 ± .05
	SUB	8.20	8.33	8.22	8.15	8.20	8.22 ± .07
8	TOP	8.17	8.30	8.25	8.20	8.12	8.21 ± .07
	SUB	8.21	8.28	8.25	8.18	8.15	8.21 ± .05
9	TOP	8.22	8.30	8.22	8.20	8.28	8.24 ± .04
	SUB	8.18	8.30	8.25	8.20	8.30	8.25 ± .06
10	TOP	8.18	8.28	8.25	8.18	8.28	8.23 ± .05
	SUB	8.22	8.20	8.20	8.12	8.28	8.20 ± .06

Table A4. Water quality: salinity

PARAMETER: Salinity, ‰

STATION		DATE 7-19	7-20	7-21	7-22	7-23	MEAN ± s.d.
1	TOP	34.4	32.8	32.2	34.4	33.3	33.4 ± 1.0
	SUB	35.0	33.3	33.3	34.4	34.4	34.1 ± 0.8
2	TOP	35.0	32.2	32.8	34.4	33.9	33.7 ± 1.1
	SUB	35.0	34.4	33.3	34.4	33.9	34.2 ± 0.6
3	TOP	35.0	32.8	32.8	33.9	34.4	33.8 ± 1.0
	SUB	34.4	33.9	33.3	34.4	34.4	34.1 ± 0.5
4	TOP	34.4	33.3	32.2	34.4	34.4	33.7 ± 1.0
	SUB	35.0	33.9	32.8	34.4	34.4	34.1 ± 0.8
5	TOP	35.0	33.3	33.3	34.4	34.4	34.1 ± 0.8
	SUB	34.4	33.3	33.3	34.4	34.4	34.0 ± 0.6
6	TOP	34.4	33.3	33.3	35.0	34.4	34.1 ± 0.8
	SUB	34.4	32.8	33.3	34.4	33.9	33.8 ± 0.7
7	TOP	34.4	33.3	32.8	34.4	34.4	33.9 ± 0.8
	SUB	35.0	33.9	33.3	34.4	34.4	34.2 ± 0.6
8	TOP	35.0	34.4	33.3	35.0	33.9	34.3 ± 0.7
	SUB	35.0	33.3	33.3	35.6	33.9	34.2 ± 1.0
9	TOP	35.0	32.2	33.3	34.4	35.0	34.0 ± 1.2
	SUB	34.4	33.3	33.3	34.4	34.4	34.0 ± 0.6
10	TOP	34.4	33.3	32.2	34.4	33.9	33.6 ± 0.9
	SUB	33.9	33.3	32.2	35.6	33.3	33.7 ± 1.2

Table A5. Water quality: dissolved oxygen

PARAMETER: Dissolved Oxygen (DO), mg/ℓ

STATION		DATE 7-19	7-20	7-21	7-22	7-23	MEAN ± s.d.
1	TOP	5.22	5.53	5.07	5.68	5.83	5.5 ± 0.3
	SUB	5.53	5.37	5.22	5.83	5.53	5.5 ± 0.2
2	TOP	5.22	5.37	5.07	5.68	5.68	5.4 ± 0.3
	SUB	5.37	5.53	5.37	5.83	5.53	5.5 ± 0.2
3	TOP	5.37	5.68	5.37	5.68	5.53	5.5 ± 0.2
	SUB	5.83	5.83	5.68	6.00	5.53	5.8 ± 0.2
4	TOP	5.68	6.00	5.68	5.68	5.83	5.8 ± 0.1
	SUB	5.53	5.37	5.53	5.83	5.53	5.6 ± 0.2
5	TOP	5.83	5.83	5.53	6.45	4.91	5.7 ± 0.6
	SUB	6.14	5.83	5.68	5.68	5.68	5.8 ± 0.2
6	TOP	5.68	5.83	5.37	6.00	5.37	5.7 ± 0.3
	SUB	5.68	5.37	5.53	5.68	5.37	5.5 ± 0.1
7	TOP	4.91	5.68	5.53	5.53	5.37	5.4 ± 0.3
	SUB	5.68	6.00	5.83	5.83	5.53	5.8 ± 0.2
8	TOP	5.83	5.83	6.14	5.53	5.83	5.8 ± 0.2
	SUB	6.00	5.68	5.53	5.83	5.37	5.7 ± 0.2
9	TOP	5.83	5.68	5.53	6.14	5.83	5.7 ± 0.3
	SUB	5.83	5.68	5.22	5.68	5.68	5.6 ± 0.2
10	TOP	5.83	5.83	5.53	6.00	5.53	5.7 ± 0.2
	SUB	5.68	5.83	6.14	5.68	5.68	5.8 ± 0.2

Table A6. Water quality: total and reactive phosphorus.

PARAMETER: Total Phosphorus (TP), mg/ℓ

STATION	DATE					MEAN ± s.d.
	7-19	7-20	7-21	7-22	7-23	
1 (-1m)	.006	.026	.008	.030	.004	.015 ± .012
2 (-1m)	.012	.007	.008	.005	.008	.008 ± .003
3 (-1m)	.007	.009	.005	.004	.004	.006 ± .002
4 (-1m)	.007	.007	.008	.008	.008	.008 ± .001
5 (-1m)	.009	.011	.015	.010	.008	.011 ± .002
6 (-1m)	.011	.013	.008	.013	.013	.012 ± .002
7 (-1m)	.010	.014	.010	.014	.013	.012 ± .002
8 (-1m)	.010	.013	.013	.013	.016	.013 ± .002
9 (-1m)	.015	.018	.017	.019	.014	.017 ± .002
10 (-1m)	.015	.015	.017	.017	.015	.016 ± .001

PARAMETER: Reactive Phosphorus ($P-PO_4$), mg/ℓ

STATION	DATE					MEAN ± s.d.
1 (-1m)	.002	.012	.003	.002	.002	.004 ± .004
2 (-1m)	.002	.003	.003	.002	.002	.002 ± .001
3 (-1m)	.002	.004	.003	.002	.002	.003 ± .001
4 (-1m)	.002	.003	.003	.002	.002	.002 ± .001
5 (-1m)	.001	.002	.004	.001	.002	.002 ± .001
6 (-1m)	.004	.005	.003	.003	.003	.004 ± .001
7 (-1m)	.003	.002	.003	.004	.002	.003 ± .001
8 (-1m)	.003	.003	.003	.002	.002	.003 ± .001
9 (-1m)	.003	.003	.005	.003	.004	.004 ± .001
10 (-1m)	.005	.005	.006	.004	.004	.005 ± .001

Table A7. Water quality: ammonia and nitrate-nitrite nitrogen.

PARAMETER: Ammonia Nitrogen (NH_3), mg/ℓ

STATION	DATE					MEAN ± s.d.
	7-19	7-20	7-21	7-22	7-23	
1 (-1m)	.059	.141	.048	.084	.031	.073 ± .043
2 (-1m)	.038	.059	.048	.038	.059	.048 ± .011
3 (-1m)	.059	.086	.052	.038	.031	.053 ± .021
4 (-1m)	.066	.072	.086	.038	.038	.060 ± .021
5 (-1m)	.031	.041	.093	.031	.041	.047 ± .026
6 (-1m)	.072	.076	.031	.048	.066	.059 ± .019
7 (-1m)	.038	.031	.048	.038	.052	.041 ± .008
8 (-1m)	.134	.031	.059	.100	.031	.071 ± .045
9 (-1m)	.031	.100	.031	.031	.038	.046 ± .030
10 (-1m)	.076	.055	.152	.031	.066	.076 ± .046

PARAMETER: Nitrate-Nitrite Nitrogen (NO_3 - NO_2), mg/ℓ

STATION	DATE					MEAN ± s.d.
	7-19	7-20	7-21	7-22	7-23	
1 (-1m)					.003	
2 (-1m)					.003	
3 (-1m)					.071	
4 (-1m)					.006	
5 (-1m)					.003	
6 (-1m)	.002	.010	.002	.003	.004	.004 ± .003
7 (-1m)					.003	
8 (-1m)					.002	
9 (-1m)	.000	.001	.002	.004	.002	
10 (-1m)					.001	.002 ± .001

Table A8. Water quality: Kjeldahl, total nitrogen and organic nitrogen.

PARAMETER: Total Kjeldahl Nitrogen (TKN), mg/ℓ

STATION	DATE					MEAN ± s.d.
	7-19	7-20	7-21	7-22	7-23	
1 (-1m)	.079	.069	.049	.108	.088	.079 ± .022
2 (-1m)	.088	.069	.329	.182	.088	.151 ± .109
3 (-1m)	.039	.290	.074	.049	.113	.113 ± .103
4 (-1m)	.069	.069	.074	.049	.054	.063 ± .011
5 (-1m)	.093	.069	.025	.025	.113	.065 ± .040
6 (-1m)	----	.069	.049	1.199	.049	.342 ± .572
7 (-1m)	.108	.005	.172	.049	.000	.067 ± .073
8 (-1m)	.039	.118	.108	.064	.098	.085 ± .033
9 (-1m)	.138	.069	.000	.098	.059	.073 ± .051
10 (-1m)	.054	.103	.098	.206	.059	.104 ± .061

PARAMETER: Total Nitrogen (TN), mg/ℓ

STATION	DATE					MEAN ± s.d.
	7-19	7-20	7-21	7-22	7-23	
1 (-1m)					.091	
2 (-1m)					.091	
3 (-1m)					.184	
4 (-1m)					.060	
5 (-1m)					.116	
6 (-1m)		.079	.051	1.202	.054	.347 ± .570
7 (-1m)					.003	
8 (-1m)					.100	
9 (-1m)	.138	.070	.002	.102	.061	.075 ± .051
10 (-1m)					.060	

PARAMETER: Organic Nitrogen (TON), mg/ℓ

STATION	DATE					MEAN ± s.d.
	7-19	7-20	7-21	7-22	7-23	
1 (-1m)	.020	.000*	.001	.024	.057	.020 ± .023
2 (-1m)	.050	.010	.281	.144	.029	.103 ± .112
3 (-1m)	.000	.204	.022	.011	.082	.064 ± .085
4 (-1m)	.003	.000	.000	.011	.016	.006 ± .007
5 (-1m)	.062	.028	.000	.000	.072	.032 ± .034
6 (-1m)	----	.000	.018	1.151	.000	.292 ± .573
7 (-1m)	.070	.000	.124	.011	.000	.041 ± .055
8 (-1m)	.000	.087	.049	.000	.067	.041 ± .039
9 (-1m)	.107	.000	.000	.067	.021	.039 ± .047
10 (-1m)	.000	.048	.000	.175	.000	.045 ± .076

*concentration of NH_3-N (Indophenol) was ≥ TKN concentration (nesslerization)

Table A9. Water quality: bottom depth and water clarity.

PARAMETER: Bottom Depth/Clarity

STATION	DATE 7-19	7-20	7-21	7-22	7-22	MEAN BOTTOM DEPTH
1 Depth	13.0	13.6	13.1	15.0	8.1	12.6
clarity	SM	SM	SM	C	SM	
2 Depth	8.8	9.9	11.3	10.2	8.1	9.7
clarity	SM	SM	SM	C	SM	
3 Depth	12.0	14.8	13.4	14.0	10.8	13.0
clarity	SM	SM	SM	M	SM	
4 Depth	8.0	14.1	8.6	7.6	10.2	9.7
clarity	C	C	SM	C	SM	
5 Depth	7.5	8.8	7.8	7.8	8.3	8.0
clarity	SM	C	SM	SM	S(3)	
6 Depth	8.2	11.2	7.2	14.0	6.8	9.5
clarity	M	C	C	M	S(2)	
7 Depth	10.5	7.9	10.4	9.7	10.2	9.7
clarity	M	SM	C	M	S(2)	
8 Depth	14.0	11.5	12.2	11.2	11.7	12.1
clarity	S(8)	SM	M	SM	S(3)	
9 Depth	9.5	12.1	9.1	9.4	8.3	9.7
clarity	C	SM	SM	C	SM	
10 Depth	16.2	15.0	16.2	16.5	17.1	16.2
clarity	C	C	M	C	C	

Clarity key:

C - clear
SM - slightly murky, bottom visible
M - murky, no visible bottom
S - secchi readings obtainable (value)

Table A10. Wind direction and speed at stations.

PARAMETER: Wind Direction and Speed (kts)

STATION		DATE 7-19	7-20	7-21	7-22	7-23
1	DIR	120	240	210	210	270
	SPEED	5	8	15	10	6
2	DIR	090	286	200	220	270
	SPEED	5	6	18	10	14
3	DIR	090	293	200	270	220
	SPEED	5	4	12	10	12
4	DIR	090	280	210	270	270
	SPEED	4	4	22	10	10
5	DIR	090	310	210	240	210
	SPEED	4	2	25-30	8	8
6	DIR	090	310	210	230	210
	SPEED	4	6	15	20	15
7	DIR	040	310	210	230	210
	SPEED	4-5	3	15	18	12
8	DIR	040	340	210	210	210
	SPEED	3	5-6	20	18	10
9	DIR	090	215	210	220	180
	SPEED	6	12	15	10	7
10	DIR	050	030	210	210	210
	SPEED	4-5	0-1	18	18	10

Table A11. Current flow directions and relative speeds at stations.

PARAMETER: Current Flow Direction, degrees

STATION		DATE 7-19	7-20	7-21	7-22	7-23
1	FLOW	305	090	075	010	130
	rs*	M	F	M	M	F
2	FLOW	330	105	030	330	090
	rs	F	F	F	F	F
3	FLOW	360	030	005	130	360
	rs	F	S	M	S	F
4	FLOW	294	090	110	300	090
	rs	F	S	F	M	F
5	FLOW	280	030	010	070	060
	rs	M	F	M	S	M
6	FLOW	270	100	060	240	070
	rs	F	F	F	F	F
7	FLOW	225	135	040	060	045
	rs	M	M	F	S	M
8	FLOW	260	060	025	005	010
	rs	S	M	F	F	F
9	FLOW	245	270	030	360	360
	rs	F	F	F	S	M
10	FLOW	305	310	025	300	260
	rs	M	S	M	S	F

*Relative speed:

S - slow
M - moderate
F - fast

APPENDIX B

Summary Part B Meteorological and Hydrographic Effects

Meteorological and hydrographic parameters (wind speed and direction, air temperature, precipitation, tidal phase and current direction) can influence WQ parameters. Quantitative analyses of Part B WQ parameters with meteorological and hydrographic parameters is summarized as follows:

1) Wind direction 24 hours prior to sampling could affect turbidity, temperature, DO and, to a lesser extent, salinity and TP. There is no correlation with pH or TP.

2) Wind direction at the time of sampling could affect temperature, salinity turbidity and, to a lesser extent, DO and TKN. There is no correlation with pH or TP.

3) The wind speed for the prior day can affect turbidity and temperature. Maximum turbidities occur with wind speeds in excess of 11 kts. Wind speeds for the day of sampling can affect turbidity and pH.

4) Maximum turbidities correlate with wind speeds for the prior day as well as wind direction.

5) Precipitation has limited affect on water quality parameters.

6) Water current flow significantly correlations with the wind direction.

7) Tidal change has limited influence on water quality. Turbidity, DO, salinity, TP and TKN are not affected by rising or falling tides.

8) Current flow direction can influence turbidity levels with water movement away from the fringing reefs and construction area has higher levels, while flow toward the land results in minimum turbidities.

9) There are seasonal changes in WQ parameters. Turbidity has the poorest long-term correlation.

10) Natural fluctuations in WQ caused by meteorological and hydrographic parameters can be greater than the man-induced changes.

APPENDIX C

Table C1. Trust Territory of the Pacific Islands (TTPI) marine water quality standards

PARAMETER	UNITS	CLASS AA	CLASS A	CLASS B
Total Coliform	#/100mℓ	<230		
Fecal Coliform	#/100mℓ		<400	<400
pH		Normal ±0.2	Normal ±0.2	Normal ±0.5
		[6.5 <pH <8.5]		
Total Nitrogen (TN)	mg/ℓ	≤0.40	≤0.75	≤1.50
		[Normal ±10%]		
Total Phosphorus (TP)	mg/ℓ	≤0.025	≤0.050	≤0.100
		[Normal ± 10%]		
TN/TP	--	[Normal ± 10%]		
Dissolved Oxygen (D.O.)	mg/ℓ	≥6.0 or 75% of saturation, whichever is greater	≥5.0	≥4.5
Total Dissolved Solids (TDS)	mg/ℓ	[Normal ± 10%]		
Salinity	o/oo	[Normal ± 10%]		
Temperature	°C	[Normal ± 0.9]		
Turbidity	NTU,JTU	Normal ±5%	Normal ±10%	Normal ±20%
Heavy Metals				
Arsenic	mg/ℓ	10	All marine water classes have same standard	
Copper		10		
Lead		10		
Mercury		0.1		
Zinc		20		