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

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LIST OF FIGURES

TABLE OF CONTENTS

Page

LIST OF TABLES

INTRODUCTION

Expansion of the Truk International Airport runway on Moen Island began in the summer of 1978. The Part B construction monitoring program began in September 1978 and continued through December 1981. The marine water surrounding the northeast fringing reef on Moen Island was monitored on a monthly basis. Water quality analyses were used to assess compliance with the Part A Pre-construction turbidity standard and the TTPI water quality standards.

The runway at the Truk airport was extended 430 m toward the southwest and 180 m toward the northeast and repositioned approximately 50 m northwest. This required placement of approximately 1.6×10^6 m^3 of fill material dredged from a fringing reef flat 1 to 2 km east of the runway (Fig. 1). Coral fill was obtained by a suction dredge and piped as a slurry to either primary settling lagoons at Metitiu Reef or directly discharged into lagoon waters adjacent to the runway. Additionally, some dredged coral fill was transported to construction areas in barges and placed by bucket crane. A protective embankment consisting of basalt boulders and manufactured concrete dolosse was placed around the runway to produce a seawall. The basaltic rock was obtained from the upland quarry at the northeast end of the runway. These embankment materials were placed by land-based heavy equipment and barges equipped with cranes.

This study of water quality in the Part B construction period was requested by the U. S. Navy in accordance with Contract No. N62742-78-C-0029, Part B. It is a portion of the second part of a three part environmental monitoring program which consists 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 B was undertaken by the Marine Laboratory of the University of Guam and is described in a separate report (Amesbury et al., 1981).

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 a ninth station was established, as a control. This control station was monitored to determine the trend in lagoonal water quality under natural existing conditions. The control station was selected so it would not be affected by dredge and fill operations, and yet be situated sufficiently close to the construction monitoring stations to have a characteristically similar water mass. 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 40 months of water quality monitoring conducted in conjunction with the Part B runway construction period provided a data base to evaluate the affect of dredge and fill operations on marine water quality. Additionally,

FILL AREA

DREDGE AREA

PROTECTIVE EMBANKMENT

c POU CHANNEL

P SEDIMENT PLUME GENERAL FLOW DIRECTION

s SLURRY SETTLING LAGOON AT METITIU

o1 WATER QUALITY MONITORING STATION

MANGROVE

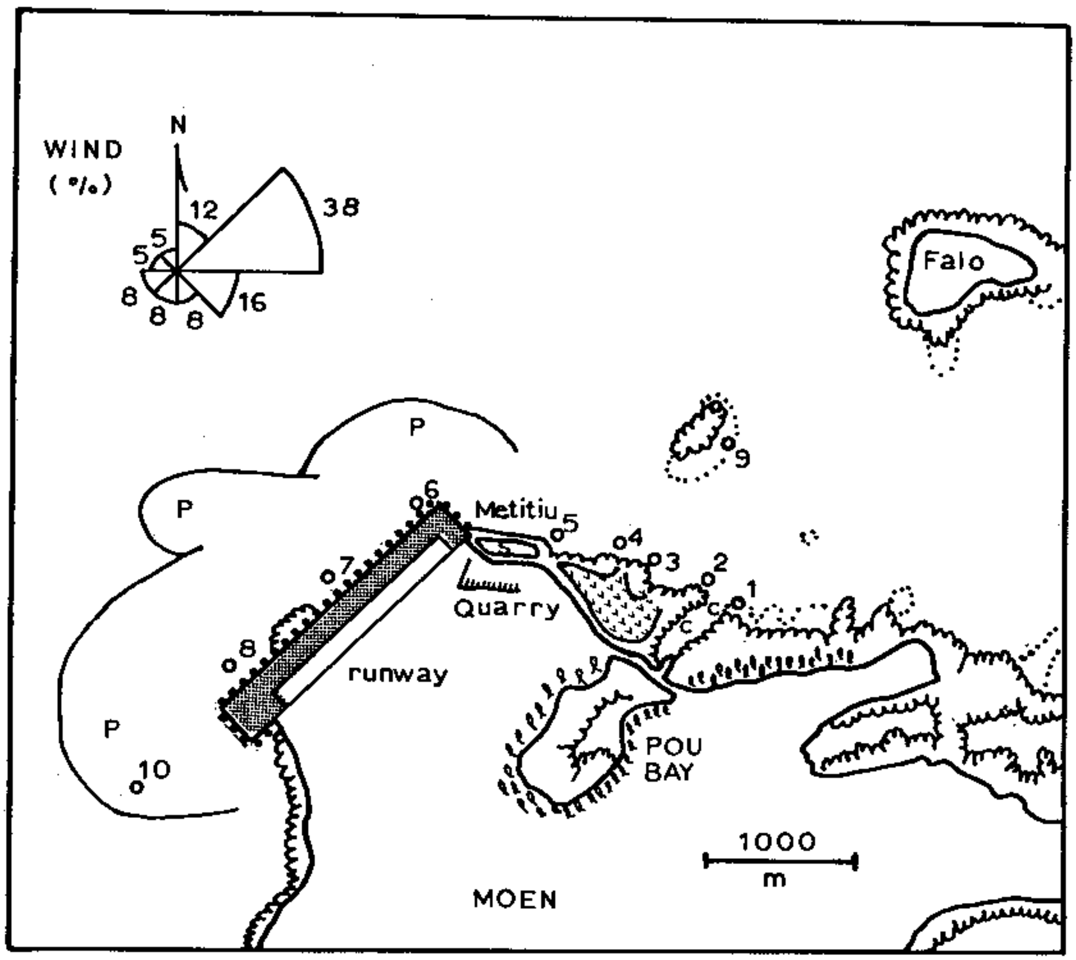

Figure 1. Airport construction site and water quality monitoring stations.

the control station monitoring assesses the effect of seasonality, meteorological, and hydrographic factors on selected physical and chemical water quality parameters.

OBJECTIVES

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

1. Determine the marine water quality at stations established in the Part A monitoring program and a new station established for Part B monitoring.
2. Report values in excess of the Part A turbidity standard to the contracting agency.

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 addition to the nine Part A water quality stations, a new station (10) was established for the Part B monitoring program. Detailed descriptions and locations of the 9 original stations were presented in the Part A report. New station 10 was established approximately 600 m lagoonward of the south-east end of the runway (Fig. 1). This station was not bouyed and samples were taken from a general area. The depth in this area varied from 20 to 25 m. Station 5 was relocated 50 m west when a basalt loading ramp was constructed which partially buried the original station. The original station was 68 m lagoonward of the reef margin at a depth of 9 m. The station was relocated approximately 80 m lagoonward of the reef margin at the depth of 10 m.

The water quality parameters and analytical techniques used in the Part B monitoring were the same as those used in the Part A monitoring program. The water quality parameters routinely measured were pH, temperature, salinity, turbidity, dissolved oxygen (DO), total phosphorus (TP), and total Kjeldahl nitrogen (TKN). The water column at each station was sampled at the surface (-1 m) and bottom (+1 m above substratum). Surface and bottom waters were analyzed for pH, temperature, salinity, turbidity and DO. The TP and TKN samples were from bottom water samples. Samples were mostly taken between 0900 and 1600 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 in December 1979, June 1980 and January 1981. The samples were preserved with nitric acid and transported to Guam for analyses. The December 1979 samples were analyzed by the U. S. Navy Public Works Center, Fena Laboratory. The 1980 and 1981 samples were analyzed at the WERI Laboratory. 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 YSI model 33 salinometer or hand-held refractometer. The Azide-Winkler modification was used to determine DO (APHA, 1975). TP was analyzed by the persulfate digestion-ascorbic acid reduction method (APHA, 1975). TKN was determined by macro-digestion (500 mℓ sample), distillation and nesslerization (APHA, 1975).

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 nitrite- or nitrate-nitrogen. This is not of concern since occasional 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 fluorescein dye tracks.

The water quality data were analyzed with a Statistical Package for the Social Sciences (SPSS) on an IBM 4332 computer. Input also included meteorological and hydrographic data from both the sampling day and the previous day. All statistical analyses were run with a 5 percent level of significance ($P \leq .05$).

RESULTS AND DISCUSSION

Comparison of Standards and Water Quality

Physical and chemical water quality parameters at the monitoring stations were evaluated by two different standards. The turbidity standard of ≤2.0 NTU was established in the Part A Pre-construction monitoring program. The other water quality parameters are regulated by the TTPI marine water quality standards. The TTPI standards provide numerical limits for TP; total nitrogen (TN), pH and DO. The limits for temperature and salinity are "natural conditions" ±10 percent. As previously mentioned, a standard has not been established for TKN, however, the TN standard can be applied, since TKN is the major total nitrogen component. Table 1 includes a summary of the water quality standards used in this study. Appendix A presents statistical summaries of water quality parameters (turbidity, A1; temperature, A2; dissolved oxygen, A3; salinity, A4; pH, A5; TKN, A6; TP, A7) for each monitoring station.

Mean values of the water quality parameters from each monitoring station when compared with the Part A turbidity standard and the TTPI class B marine water standards were within allowable limits (Table 1). Mean water quality, except turbidity, is consistent between monitoring stations. The control station (9) had slightly higher mean values for salinity, pH and DO. Station 1 had slightly lower mean pH and DO values. Mean turbidity values were significantly higher at monitoring stations (5, 6, 7, 8 and 10) adjacent

Table 1. Comparison of mean water quality at monitoring stations and the TTPI class B water quality standards.

Water Quality Parameters	T T P I Class B Standards	MONITORING STATIONS									
		1	2	3	4	5	6	7	8	9	10
Turbidity (NTU)	≤2.0*	0.64	0.58	0.73	0.64	1.0	1.2	1.0	1.5	0.43	0.97
Temperature (C°)	Normal±10%	29.0	29.1	29.1	29.1	29.1	29.1	29.0	29.0	29.0	29.0
Salinity (o/oo)	Normal±10%	33.7	33.7	33.6	33.7	33.7	33.7	33.7	33.6	33.8	33.5
pH	6.5≤pH≤8.5	8.17	8.19	8.20	8.20	8.21	8.21	8.21	8.21	8.23	8.21
Dissolved Oxygen (mg/ℓ)	≥4.5	6.24	6.27	6.37	6.29	6.42	6.36	6.29	6.26	6.40	6.32
Total Kjeldahl Nitrogen (mg/ℓ)	none**	0.15	0.15	0.18	0.13	0.13	0.14	0.17	0.16	0.14	0.13
Total Phosphorus (mg/ℓ)	≤0.100	0.011	0.020	0.012	0.013	0.011	0.013	0.015	0.017	0.011	0.012

*Part A pre-construction standard (Clayshulte et al., 1979).
TTPI Class B standard is normal ± 20%.

**There is no established standard for TKN.
TTPI Class B standard for TN is ≤1.5 mgN/ℓ.

Table 2. Turbidity (NTU) values in excess of the Part A turbidity standards. There were 776 turbidity measurements taken from surface and bottom waters for the Part B monitoring program.

DATE	STATION 2	3	5	6	7	8	10
4-3-79				2.3*			
7-6-79				5.0			
7-6-79				3.0*			
8-9-79			5.8				
9-5-79			2.2*	2.1*			
10-30-79				7.5		5.4*	
12-7-79	2.1*	2.2*		3.0			
1-2-80					3.6*	3.6	
1-3-80						2.6*	
1-31-80					4.5	7.4*	2.7
3-4-80		2.3					
5-8-80				2.1*	2.3		
5-8-80					2.1*		
5-28-80				2.2*			
8-7-80						4.3*	
8-29-80			2.2*				
9-25-80			5.9	4.7*		10*	
11-13-80						3.8	
11-13-80						8.4*	2.6*
12-18-80						2.6*	2.1*
4-9-81				2.4		7.0*	
6-18-81						3.0*	
7-10-81						2.1	
7-10-81						4.6*	
8-6-81				2.9		2.8	
8-6-81						5.6*	
9-4-81							14.5*

*subsurface turbidity sample; +1 m above substratum at stations 2, 3, 5, 6, 7 and 8; -20m depth at station 10.

Table 3. Percentage of samples exceeding the water quality standards and distribution of turbidity and phosphorus values.

	TURBIDITY (NTU)				TOTAL PHOSPHORUS (mg/ℓ)		
	>2.0	High 1.0-2.0	Mid 0.5-10	Low <.5	>0.10	High 0.05-0.09	Low <.05
STA 1	0	11.5	59.0	29.5	0	2.5	97.5
STA 2	1.3	5.1	53.9	39.7	5.0	0	95.0
STA 3	2.6	11.5	62.8	23.1	2.5	2.5	95.0
STA 4	0	18.0	43.5	38.5	4.9	0	95.1
STA 5	5.1	28.2	42.3	24.4	0	2.4	97.6
STA 6	13.9	27.9	48.1	10.1	2.8	0	97.2
STA 7	5.2	37.7	49.3	7.8	2.5	2.5	95.0
STA 8	16.9	32.5	31.1	19.5	4.8	0	95.2
STA 9	0	5.1	21.5	73.4	0	4.3	95.7
STA 10	5.4	17.6	50.0	27.0	0	4.6	95.4

to the construction area. Stations 6 and 8, which were near slurry discharge areas, had the highest mean turbidity levels at 1.2 and 1.5 NTU, respectively. The control station (9) had the lowest mean turbidity at 0.43 NTU and the lowest turbidity values for most sampling dates. However, station 9 mean turbidity was significantly higher in the Part B monitoring program compared with Part A. Only turbidity and phosphorus standards were found to be exceeded (Tables 2 and 3). Stations 2, 3, 4, 6, 7 and 8 had TP values in excess of the 0.1 mgP/ℓ TTPI class B marine water quality standard. Temperature, pH, salinity and dissolved oxygen were all found to be within the range of permissible limits (see Tables A1 to A7 in Appendix A). Total nitrogen values as approximated by the Kjeldahl nitrogen test also appear to fall within the TTPI standard. There were two values during the March 1978 sampling trip at stations 3 and 6 which may have exceeded the 1.5 mgN/ℓ standard with values of 1.8 and 2.0 mgTKN/ℓ. However, there was some question as to the accuracy of these test results.

Turbidity values in excess of the Part A turbidity standard (Table 2) occurred at the monitoring stations for specific sampling dates. Stations 6 and 8 had the greatest frequency of excessive turbidity readings (Table 3). Turbidity at stations 1, 4, and 9 (control) did not exceed 2.0 NTU. Stations 5, 7 and 10, which were near construction areas, exceeded the standards for 5 percent of the sampling periods. Station 3 exceeded the standards for 3 percent of the sampling periods. These higher turbidities occurred when barges containing dredged material were loaded near and transported across the station. One turbidity reading in excess of 2 NTU occurred at station 2 presumably as a result of natural flushing of marine water from Pou Bay.

Table 3 presents the ranges of turbidity for high intermediate and low values. Thirty percent of the turbidity values for stations 6 and 8, near slurry discharge areas were between 1.0 and 2.0 NTU. The control station (9) had 73% of its values below 0.5 NTU. Stations near the fringing reef (1, 2, 3 and 4), which were minimally affected by construction activities, had turbidity values ranging between 0.5 to 1.0 NTU 43 to 63 percent of the time. This indicates a background turbidity input into lagoon waters of roughly 0.5 NTU from the natural flushing of the fringing reef.

Water Quality Stratification

Physical and chemical water quality measurements were made for surface and subsurface water at each monitoring station to determine the uniformity of the water mass (Table A8). The difference in depth between surface and subsurface samples was about 6 to 7 m for stations 1, 3, 4, 5 and 9; 4 to 5 m for stations 2 and 6; 9 to 12 m for stations 7 and 8; and 15 to 20 m for station 10. In regards to overall water quality, there was no indication of continuous stratification of the water mass. Statistical analyses were generated by SPSS T-test comparisons on the surface and subsurface water at a 5 percent significance level. Stations 2, 4 and 8 had significantly different concentrations of specific water quality parameters between surface and subsurface waters. Stations 2 and 4 showed TP stratification with higher surface water concentrations. Stations 4 had TKN stratification with higher surface water concentration. Station 8 had higher subsurface turbidity levels. The high surface TP values at station 2 were possibly a result of nutrient enriched marine water flushing from Pou Bay.

Detailed Water Quality Analysis

Turbidity

Turbidity was identified in the Part A Pre-construction monitoring program as the water quality parameter which would probably be most effected by construction related operations. Stations 1, 2, 3, and 4 were established to monitor dredge operations and stations 5, 6, 7, 8 and 10 for slurry discharge operations. The suction dredge used to obtain coral-fill had an effective recovery system and did not generate sediment plumes. Dredge discharge operations, however, produced chronic sediment plumes. Slurry was directly discharged into lagoon water in the vicinity of stations 6 and 8. As a result, these areas had frequent and extensive sedimentation plumes on sampling dates concurrent with slurry discharge. Discharge plumes at station 6 were usually transported toward station 7 and station 8 discharge plumes moved toward station 10. Sediment plumes generated near station 5 were the result of turbid water overflow and man induced siphoning from the slurry settling lagoons.

To maintain fine sand in the suspended sediment load, the average water current must be about 50 cm/sec (Friedman and Sanders, 1978). Water velocities measured with drift drogues, at the stations in 1978, ranged from 3 to 11 cm/sec (Amesbury et al., 1978); subsequent velocities, measured with dye tracks, have been in the same range. In periods of heavy surf and wind, the current velocities have been measured near 50 cm/sec. Therefore, most of the suspended load in the sedimentation plumes at the monitoring stations 5, 6, 7, 8 and 10 have been silt and clay particles. The areas in the vicinity of stations 5, 6, 7 and 8 are covered with accumulations of silts and clays due to construction activities. These deposits, which are carbonates derived from a Holocene fringing reef, are lime muds. Once lime muds are deposited in quieter and deeper waters, they are difficult to remove by water currents (Friedman and Sanders, 1978). Lime muds deposited in shallower waters around the monitoring stations (5, 6, 7 and 8) can be resuspended into the water column in periods of heavy surf. These shallow water muds can potentially cause future degradation of water quality adjacent to the runway.

Turbidity characteristics for each monitoring station are presented in Table A1 of Appendix A. Trends in turbidities at the station can be seen when values are plotted aginst time (Fig. 2). A progression of increased turbidities occurred between stations 5, 6, 7 and 8 from 1979 to 1981. These increased turbidities were related to locations of discharge and filling operations along the runway. Turbidity levels remained seasonally constant at the control station (9) with occasional higher turbidities (<1.0 NTU) in storm periods. There were no differences in turbidity levels between stations for the first six months of monitoring, since there were no major dredge slurry discharges at this time. Stations 5 and 6 had significant increases in turbidity levels beginning in March 1979 (Fig. 2). Station 3 began showing increased turbidity levels by March 1980. Station 8 had the highest turbidity levels between March 1981 to August 1981. In this time period, turbidity levels at stations 5, 6 and 7 had slightly decreased. In the final sampling period between September 1981 to December 1981, there was no significant diffierences between the monitoring stations. Therefore, at the completion

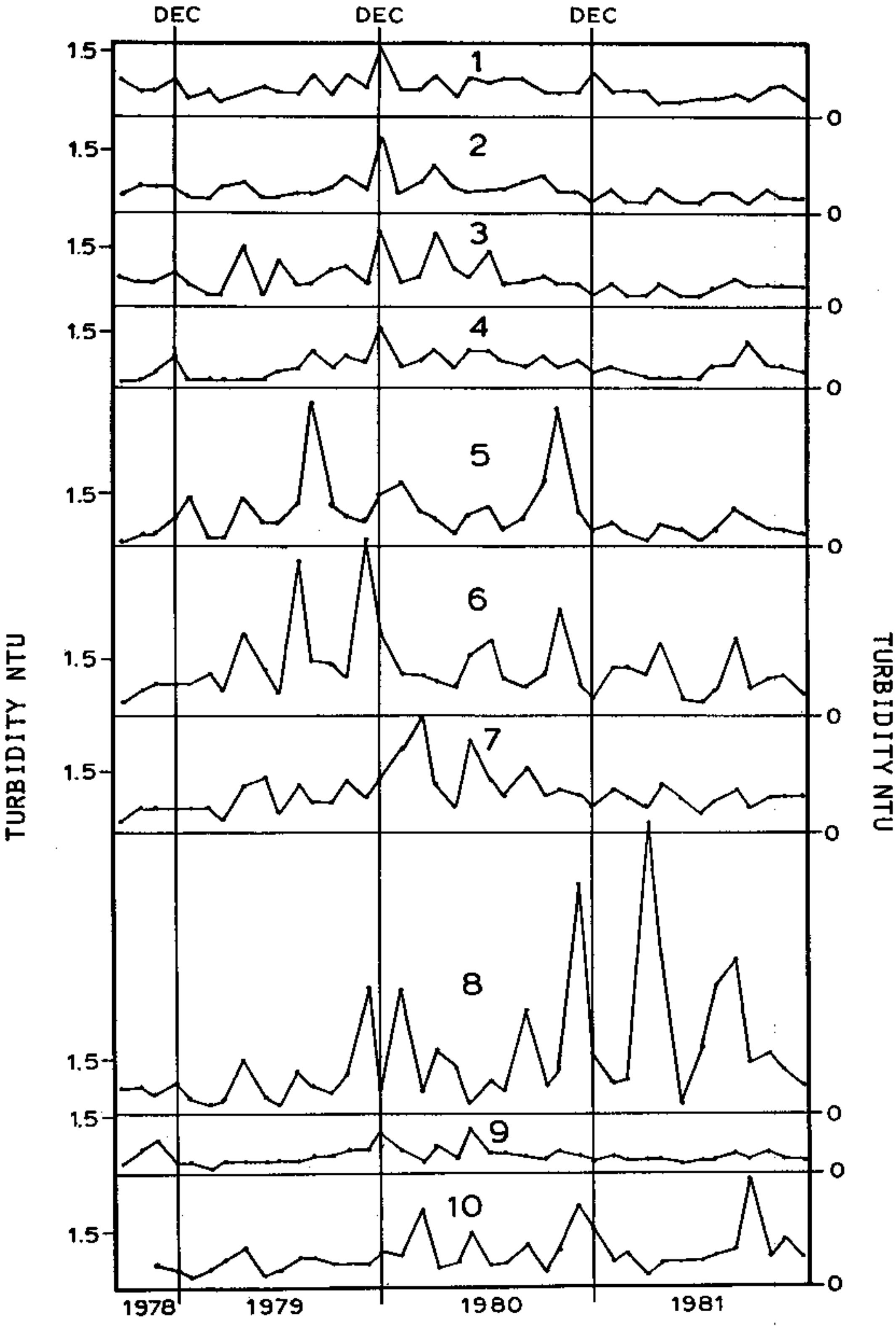

Figure 2. Turbidity at water quality monitoring stations from September 1978 to December 1981.

of major dredge slurry discharging and embankment construction, turbidity levels began to decrease at those stations impacted by construction operations. However, the turbidity levels in the last sampling period (December, 1981) at these stations were higher compared with the Part A monitoring program values.

Temperature

Temperature characteristics at each monitoring station are presented in Table A2 of the Appendix. Temperature showed no statistically significant difference between stations for either surface or subsurface waters. A cyclic trend in temperature was observed at all the stations (Fig. 3). The temperature maximums occurred from September to November (rainy season) and minimums from February to April (dry season).

Dissolved Oxygen

DO characteristics at each monitoring station are presented in Table A3 of the Appendix. There is a slight cyclic trend in the DO data (Fig. 4). DO tended to increase when the temperatures were at minimum. Salinity and temperature influence DO saturation in seawater; at a constant salinity decreases in temperature cause an increase in the DO saturation concentration. At constant temperatures, decreases in salinity cause an increase in the DO saturation concentration. The variation in sample collection times precluded having good correlation between temperature and DO. The mean late morning DO at the monitoring stations was usually at saturation.

Salinity

Salinity characteristics at each monitoring station are presented in Table A4 of the Appendix. There was no statistical difference in salinity between stations when analyzing for a combined water mass. Salinity was usually very similar between stations for a sampling period (Fig. 5). The data show a slight cyclic trend (Fig. 5). Salinity was measured with a hand-held refractometer which requires the sampling technician to make an optical reading. There is a possibility for technician error, which may account for the anomalous 1981 salinity data (Fig. 5). Salinity tended to increase in the time period from March to June and decrease from August to November (rainy season). The increased salinities occurred primarily in the dry season.

pH

pH characteristics at each monitoring station are presented in Table A5 of the Appendix. There was no distinct seasonal trend in pH data from the monitoring stations (Fig. 6). There was good correlation between stations for a sampling period (Fig. 6). However station 2 had statistically lower pH concentrations and station 9, primarily surface water, had statistically higher pH concentrations. There was no apparent correlation between pH concentrations and construction operations.

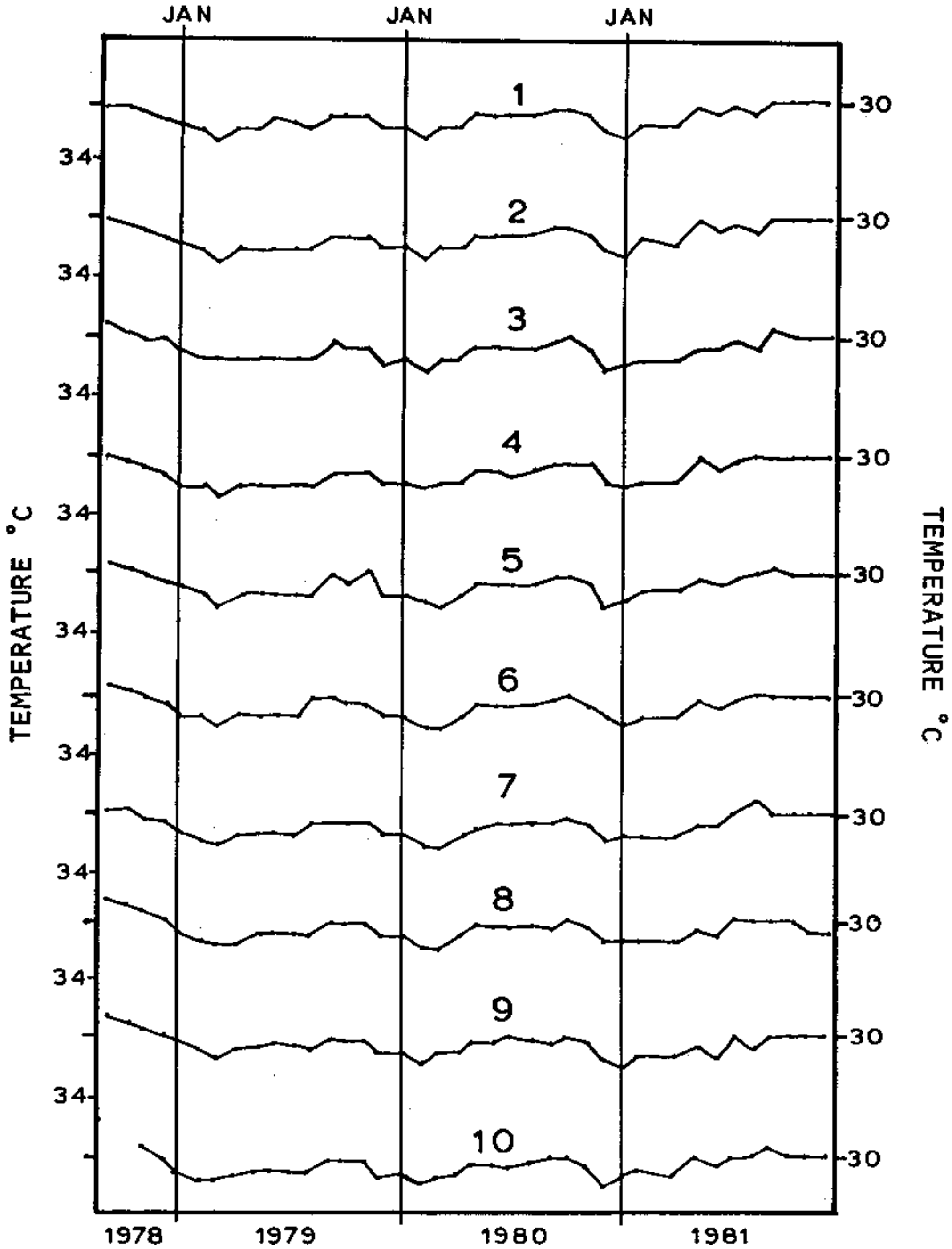

Figure 3. Temperature at water quality monitoring stations from September 1978 to December 1981.

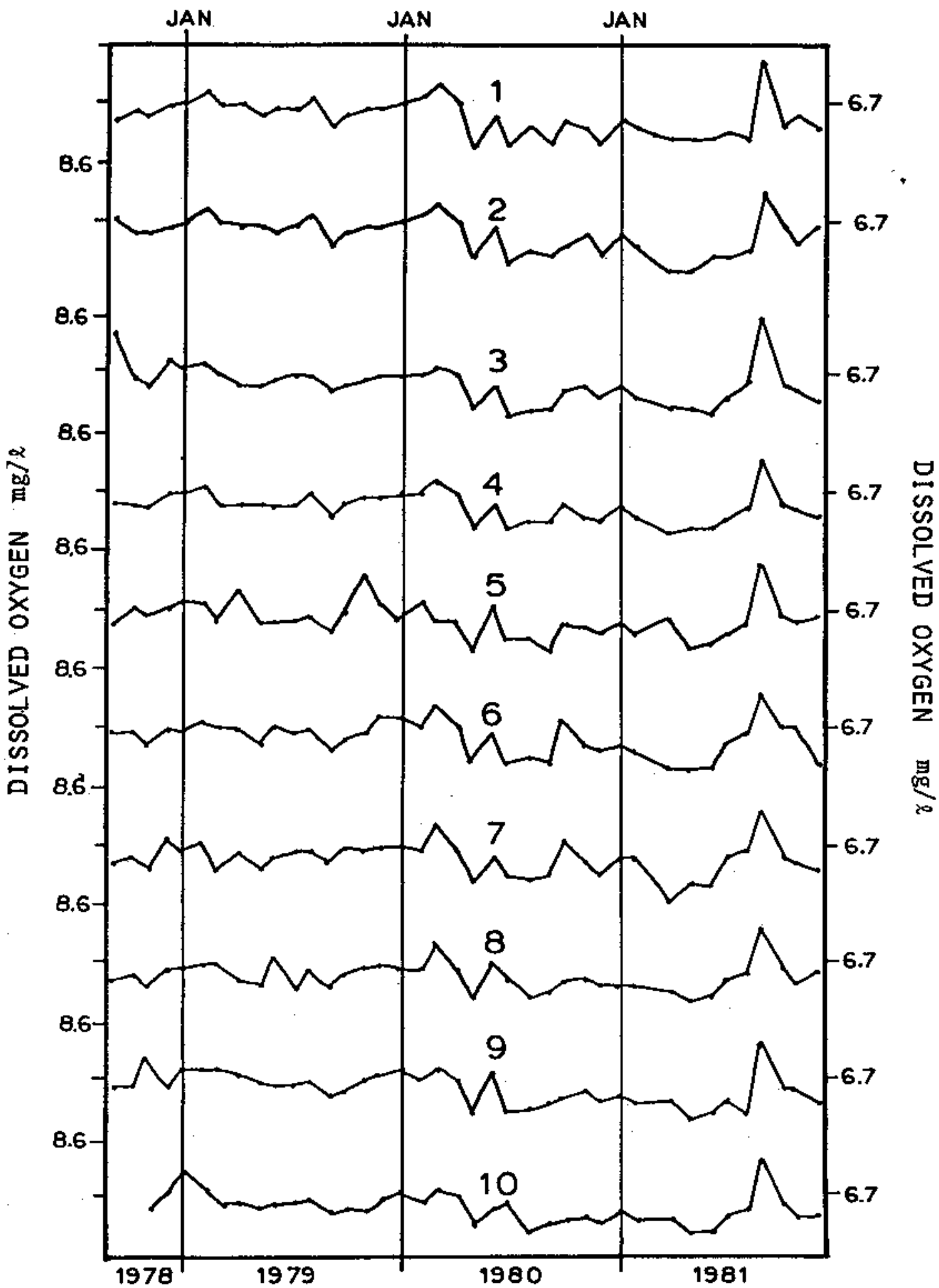

Figure 4. Dissolved oxygen at water quality monitoring stations from September 1978 to December 1981.

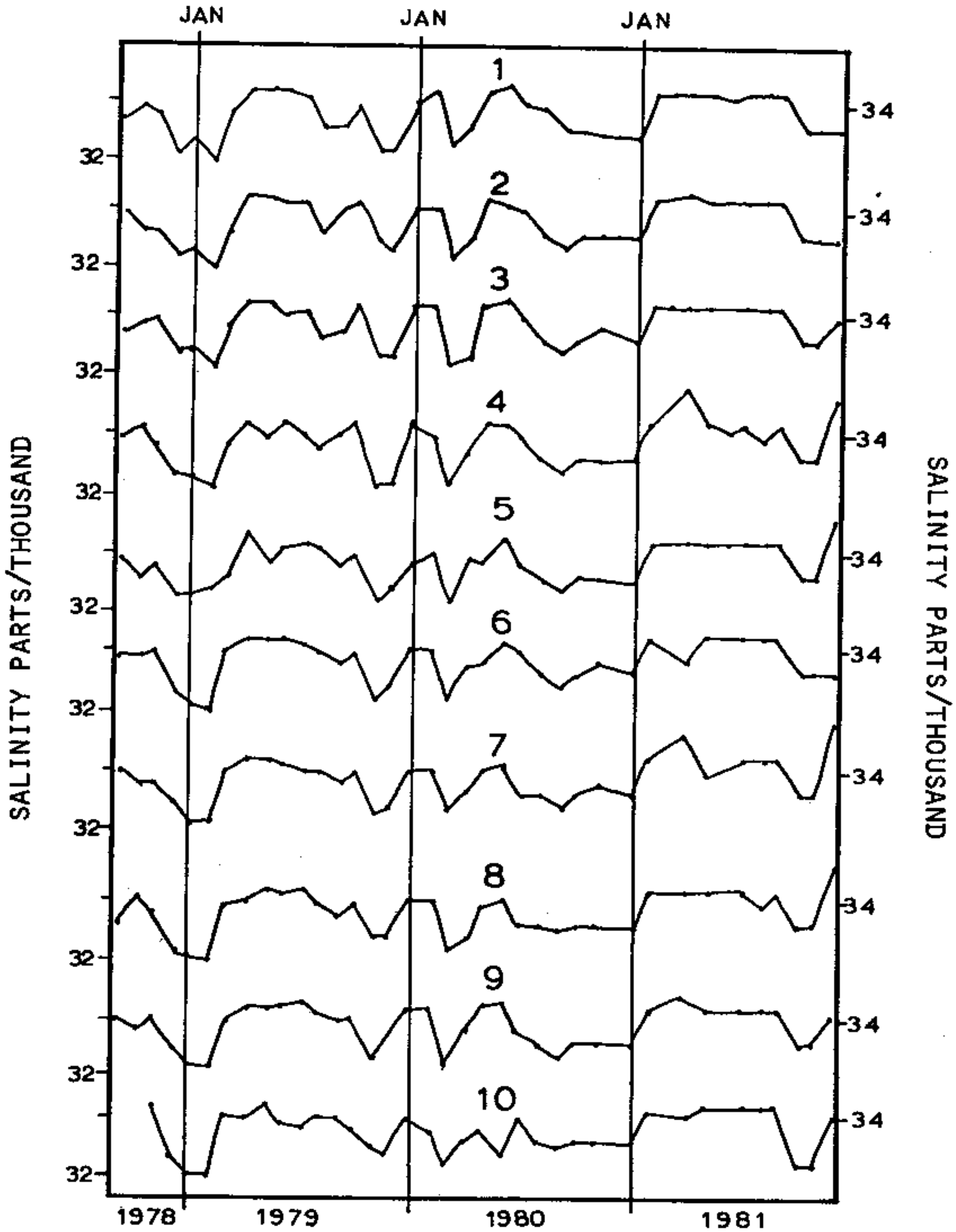

Figure 5. Salinity at water quality monitoring stations from September 1978 to December 1981.

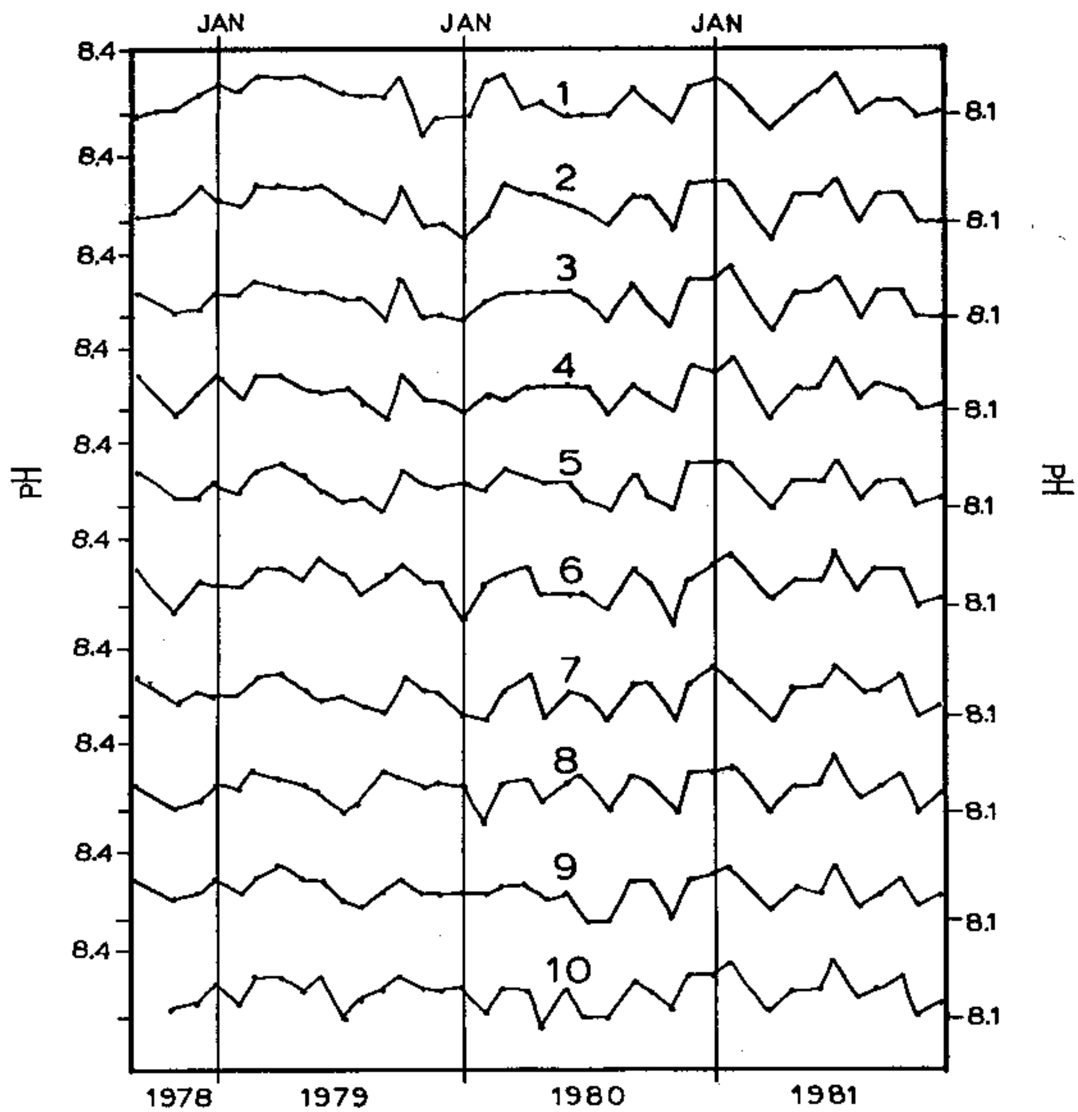

Figure 6. pH at water quality monitoring stations from September 1978 to December 1981.

Total Kjeldahl Nitrogen

TKN characteristics at each monitoring station are presented in Table A6 of the Appendix. Stations 6 and 9 (control) were sampled at both surface and subsurface for most of the sampling periods. The remaining stations were sampled primarily in subsurface waters with only 5 to 10 samplings for surface waters. TKN showed no characteristic trends and there was poor correlation between stations for a given sampling date (Fig. 7). The TKN analysis has proven to be a poor method for measuring nitrogen levels less than 0.30 mg/ℓ in natural seawater.

Total Phosphorus

TP characteristics at each monitoring station are presented in Table A7 of the Appendix. Stations 6 and 9 (control) were sampled at both surface and subsurface for most of the sampling periods. The remaining stations were sampled primarily in subsurface waters with only 7 to 11 surface samples.

TP concentrations were generally low with rare high values (Figs. 8a and 8b). There was no apparent seasonal trend in TP levels (Figs. 8a and 8b). At stations 6 and 9 orthophosphate-phosphorus (PO_4-P) levels were monitored. The mean values of PO_4-P at both stations were 0.003 mg/ℓ or about 40% of the TP.

Heavy Metals

The monitoring stations were analyzed for heavy metal concentrations in 1978, 1979, 1980 and 1981 (Table 4). Arsenic (As) was the only metal which was consistently below the TTPI marine water quality standard of 10 μg/ℓ. Concentrations of Copper (Cu), and lead (Pb) were substantially above the TTPI marine water quality standards in the 1979 analysis. These samples may have been contaminated since the 1980 and 1981 analyses sets had Cu and Pb metal concentrations below the standards. Zinc (Zn) had high concentrations in 1979 at stations 4 and 9 (control). These samples may also have been contaminated. The 1981 analyses for As, Cu, Pb and Zn used improved analytical techniques, which should have more realistically assessed heavy metal concentrations in the waters at the monitoring stations. Mercury (Hg) is a difficult metal to analyze. The detection limit with available equipment and the marine water quality standard for Hg are the same at 0.1 μg/ℓ. In 1981, only mercury standards were exceeded; but, these values were probably caused by stray contamination during the sampling or analysis. The mercury standard was exceeded in 1979, 1980 and 1981. The very high 1978 Hg concentration (Part A Pre-construction) at station 8 was not seen in subsequent analysis in the Part B monitoring program. The Hg concentrations recorded for the 1980 and 1981 analysis are probably too high, due to technical limitations in the sensitivity obtainable with the mercury hydride generation system. Heavy metal contamination is not seen as a water quality problem.

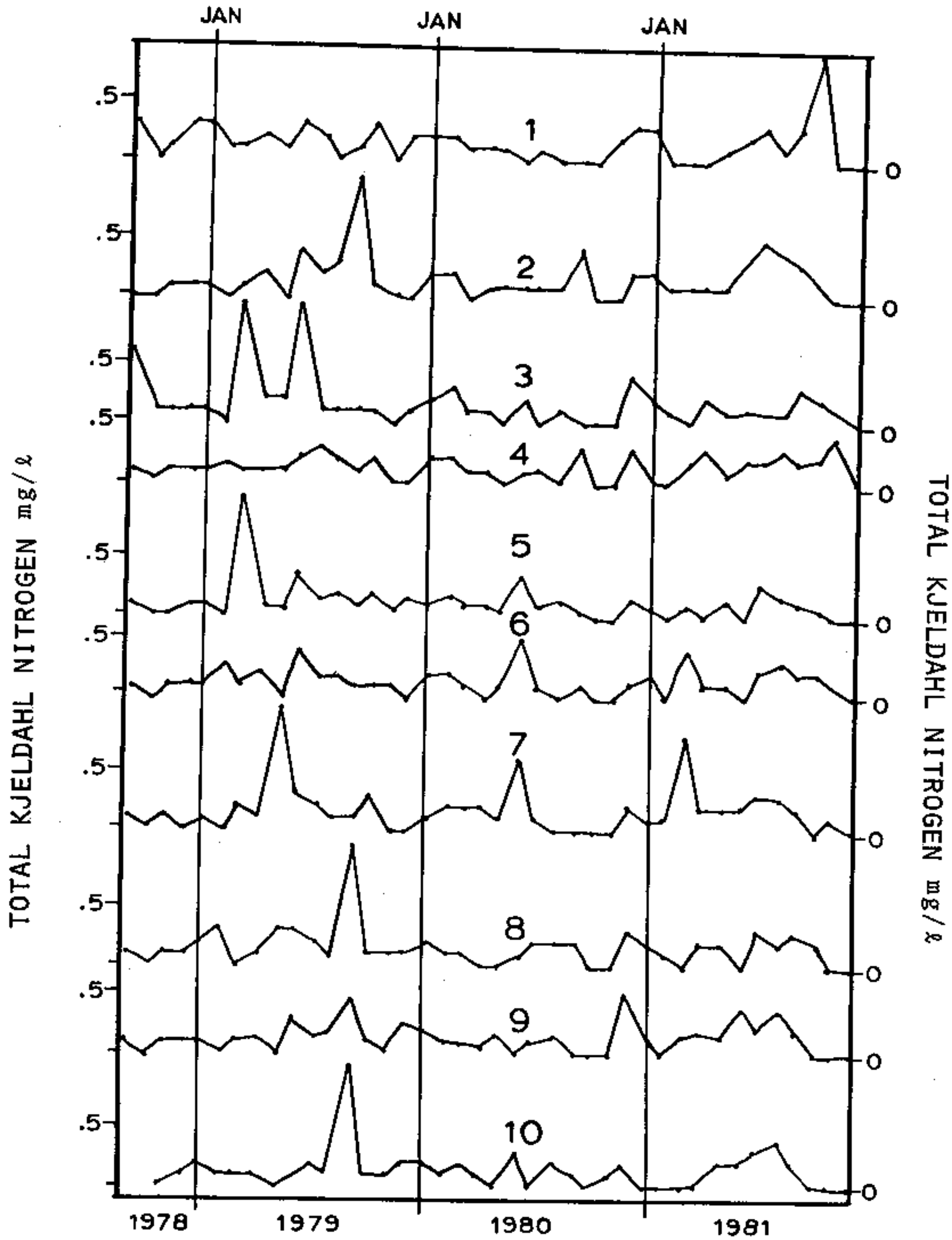

Figure 7. Total Kjeldahl nitrogen at water quality monitoring stations from September 1978 to December 1981.

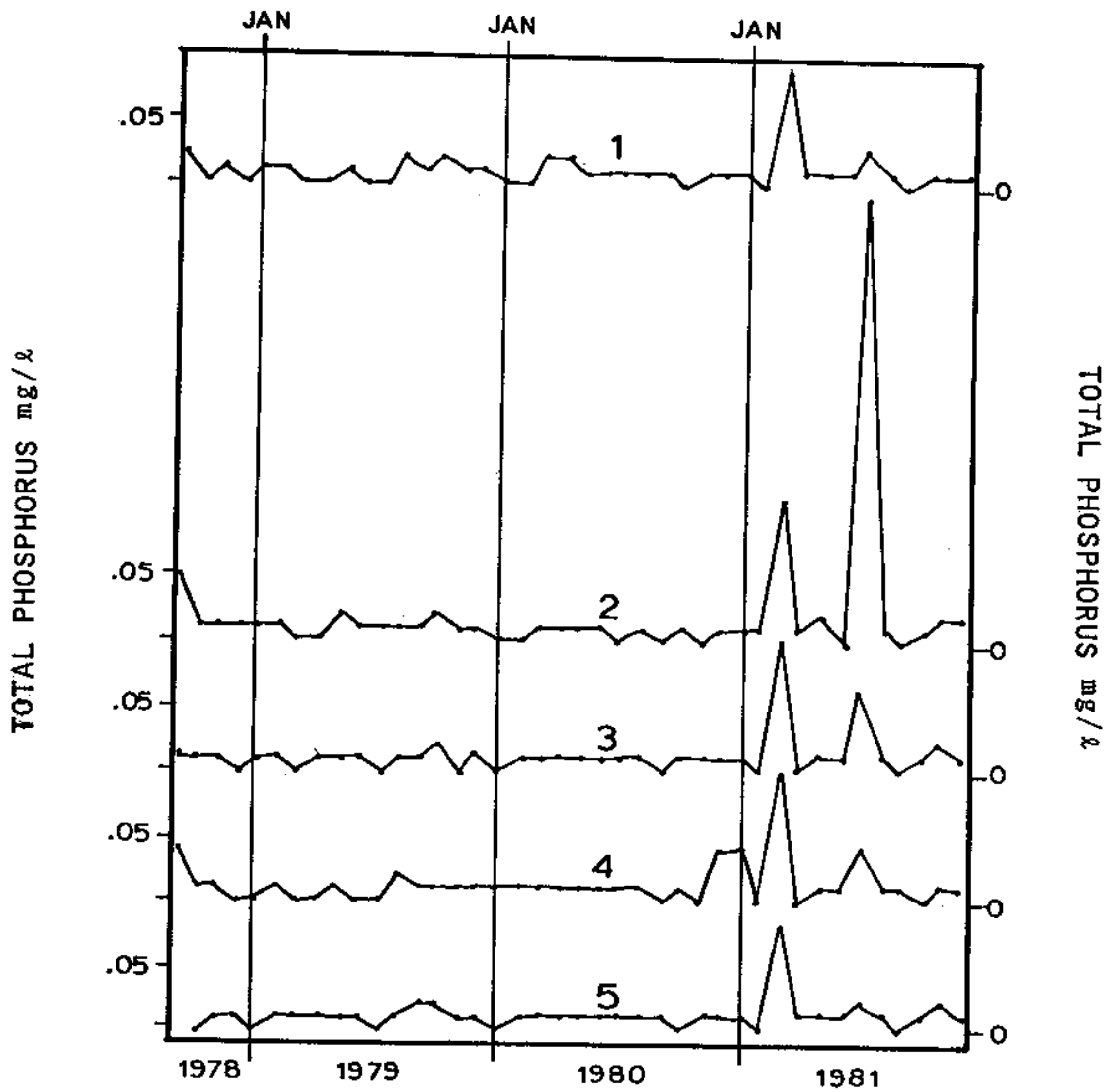

Figure 8a. Total phosphorus at water quality monitoring stations (1 to 5) from September 1978 to December 1981.

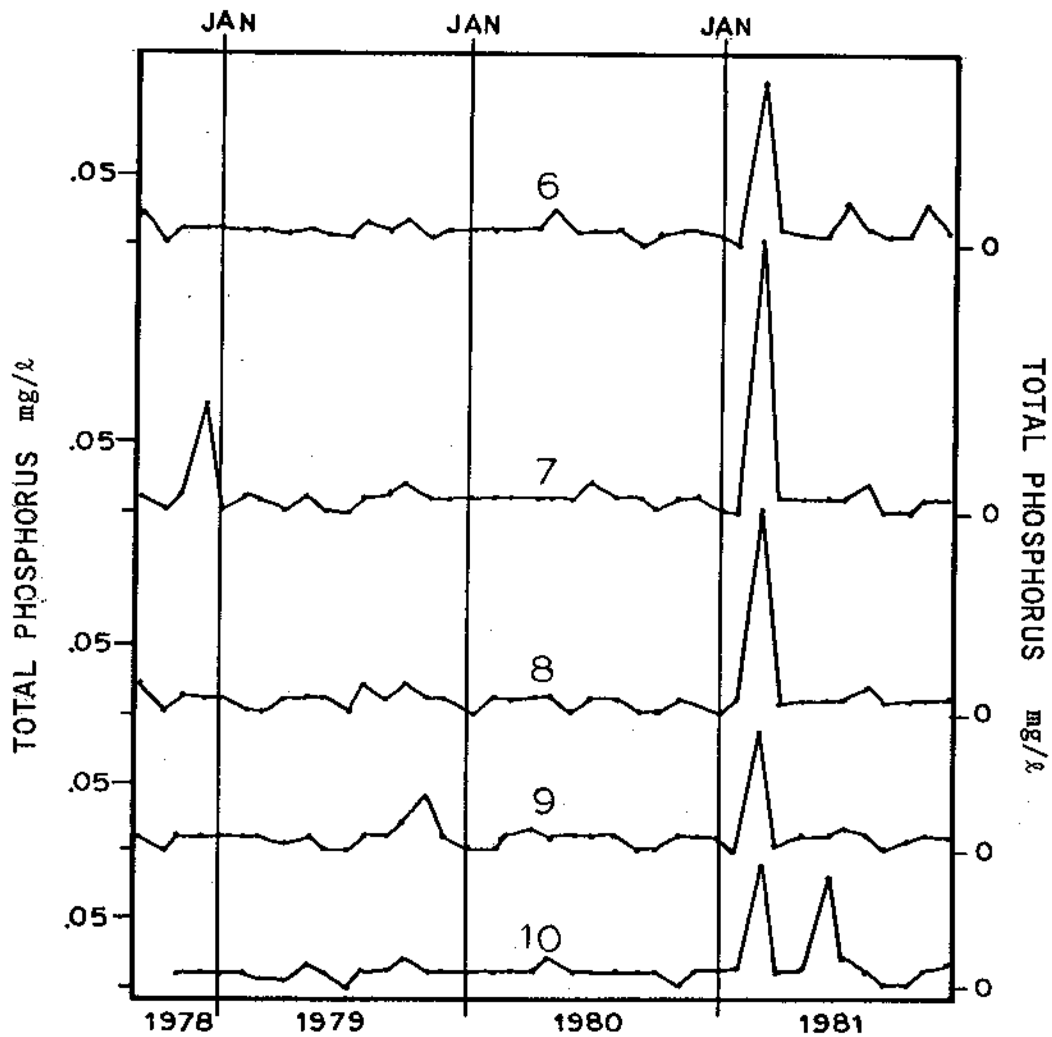

Figure 8b. Total phosphorus at water quality monitoring stations (6 to 10) from September 1978 to December 1981.

Table 4. Heavy metal concentrations (µg/ℓ) at water quality monitoring stations in 1978 (Part A), 1979, 1980, and 1981. The 1978 and 1979 analyses were made by the U.S. Navy Public Works, Fena Laboratory, Guam. The 1980 and 1981 analyses were made at WERI. The less than symbol (<) indicates metal concentrations were below detection limits.

	ARSENIC (As)				COPPER (Cu)				LEAD (Pb)				MERCURY (Hg)				ZINC (Zn)			
	1978	1979	1980	1981	1978	1979	1980	1981	1978	1979	1980	1981	1978	1979	1980	1981	1978	1979	1980	1981
STA 1	<10	<1.2	<2	1.2	<50	26	1.7	<1	<50	210	5.5	<1	<1.0	.4	2.4	<0.1	<50	10	<10	4
STA 2	<10	<1.2	<2	1.1	<50	26	1.0	<1	<50	210	4.8	1.7	<1.0	<.3	0.4	0.6	<50	10	<10	4
STA 3	<10	<1.2	<2	1.0	<50	25	<0.7	<1	<50	210	4.9	<1	<1.0	.4	<0.1	0.5	<50	6	<10	5
STA 4	<10	<1.2	<2	1.4	<50	32	<0.7	<1	<50	220	4.2	<1	<1.0	.6	<0.1	0.9	<50	50	<10	4
STA 5	<10	<1.2	<2	1.2	<50	25	0.8	<1	<50	170	3.8	<1	<1.0	.5	0.1	<0.1	<50	6	<10	4
STA 6	<10	<1.2	<2	1.2	<50	30	0.8	<1	<50	220	4.4	<1	5.0	.5	<0.1	<0.1	<50	10	<10	4
STA 7	<10	<1.2	<2	1.8	<50	26	0.8	<1	<50	170	4.1	<1	<1.0	.7	0.1	1.6	<50	5	<10	5
STA 8	<10	<1.2	<2	1.4	<50	30	0.8	2	<50	170	4.0	<1	29.0	.6	0.4	0.7	<50	5	<10	5
STA 9	<10	<1.2	<2	1.3	<50	50	0.8	<1	<50	180	4.9	1.0	<1.0	.3	0.4	0.3	<50	180	<10	11
STA 10	--	<1.2	<2	1.4	--	33	1.0	2	--	180	4.9	2.6	--	1.0	0.2	1.3	--	6	<10	5
Water Quality Standard	10 (µg/ℓ)				10 (µg/ℓ)				10 (µg/ℓ)				0.1 (µg/ℓ)				20 (µg/ℓ)*			

* TTPI Marine Water Quality Standards list the zinc standard at 0.02 µg/ℓ, however this is believed to be a misprint and should read as 0.02 mg/ℓ.

Meteorological and Hydrographic Effects

Meteorological and hydrographic parameters (wind speed and direction, air temperature, precipitation, tidal phase and current direction) can greatly influence water quality parameters. For construction impact studies, it is desirable to separate the water quality effects of construction activities from those caused by natural forces. Without this type of analysis, construction activities may appear to affect chemical and physical water quality to a greater extent than they actually do. Unfortunately, little tropical research has been done in the past to develop a methodology by which these effects can be separated.

Appendix B presents the results of statistical analyses which were used to analyze the relationships between water quality parameters and natural forces (wind speed and direction, precipitation, sunshine, tidal phase, current direction). Meteorological factors at the time the samples were collected as well as 24 hours prior to sampling were considered. This analysis was preliminary in nature and does not identify cause and effect relationships. It does, however, identify those water quality parameters which were effected in a statistically significant manner by natural forces. No analyses were made to indicate the magnitudes of the significant effects because the data base was inadequate for this purpose (monitoring program not designed for the purpose).

Temperature, salinity and DO were affected by wind direction for both prior day and day of sampling winds. Minimum salinities occurred with a SSW or SSE wind and maximum values with a ESE or NNE wind. Minimum temperatures, for the day of sampling, occurred with the SSW wind and maximum values with WSW wind. Wind speed affected temperature and pH. Maximum wind speed (>20 kts) resulted in minimum temperatures, while moderately high speeds (11-20 kts) correlated with maximum temperatures. pH values are lowest in periods of low wind (>3 kts) and highest with moderately high speeds (11-20 kts). Station salinities, particularly in surface waters, were significantly reduced when rainfall occurred prior to sampling. Water currents affected temperature and, to a lesser extent, DO, pH and salinity. Tidal change affected temperature (stations 5 and 6) and pH (stations 2, 3, 4 and 5). TP and TKN had poor correlations with meteorological and hydrographic factors.

SUMMARY

The Part B monitoring program has shown large scale dredge and fill operations in marine waters can cause significant changes in water quality. Increased turbidities are the dominant alteration of water quality which can be attributed to construction operations. Although other water quality parameters (i.e. temperature, pH, DO, salinity, TP, TKN) show statistically significant differences between stations near construction operations and non-construction related stations, these fluctuations cannot be wholly attributed to construction operations. Many of these fluctuations are temporal changes caused by meteorological and hydrographic influences which overshadow man-induced perturbations.

Mean turbidity levels at all monitoring stations were below the established turbidity standard of ≤2 NTU. However, 5% of all turbidity measurements were in excess of this standard. Stations 6 and 8, located near slurry discharges, accounted for 63% of the excess turbidity values. Additional construction related turbidities exceeding the standard occurred at stations 3, 5, 7 and 10. There were no seasonal turbidity trends at any of the monitoring stations. Turbidities at the control station were generally (73 percent) below 0.5 NTU with only 5 percent of the turbidities in excess of 1.0 NTU. These higher values were usually related to storm conditions. A few meteorological characteristics (wind direction and velocity, and precipitation) and current direction affected turbidity. This was particularly evident at monitoring stations not associated with construction operations. Turbidities were significantly affected by wind direction and velocity for both the time of sampling and prior day. Tidal change did not influence turbidity at any of the monitoring stations. Current direction at stations 1 and 2 correlated with turbidity levels, primarily resulting from the outflow current of Pou Bay.

Temperature, salinity, pH, DO and TN, TP are regulated by TTPI marine water quality standards for class B waters. Temperature, salinity, pH, DO did not exceed the TTPI water quality standards. Concentrations in excess of the TTPI standard for TP (0.1 mg/ℓ) occurred at stations 2, 3, 4, 6, 7 and 8. Station 2 had the highest TP levels with a surface water mean of 0.059 mgP/ℓ, which was significantly higher than the other monitoring stations. These high values were attributed to the nutrient enriched waters flowing from Pou Bay. There were two TKN values which exceeded the TTPI standard for for TN. There were generally low TKN levels at the stations (<0.2 mgTKN/ℓ), which showed poor correlations between stations for a given sampling date.

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APPENDIX A
Water Quality Data

Table A1. Turbidity at water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE MINIMUM	RANGE MAXIMUM	95% CONFIDENCE INTERVAL
1TOP	39	.61	.29	.30	1.7	.51 - .70
2TOP	39	.57	.32	.19	1.7	.47 - .68
3TOP	39	.74	.45	.28	2.3	.59 - .88
4TOP	39	.65	.33	.19	1.5	.54 - .75
5TOP	39	1.1	1.2	.29	5.9	.7 - 1.5
6TOP	40	1.3	1.4	.25	7.5	.9 - 1.7
7TOP	39	1.1	.7	.35	4.5	.8 - 1.3
8TOP	39	1.1	.8	.29	3.8	.8 - 1.3
9TOP	40	.43	.23	.13	1.2	.35 - .51
10TOP	37	.77	.48	.20	2.7	.61 - .93
1SUB	39	.68	.27	.31	1.8	.59 - .77
2SUB	39	.59	.30	.29	2.1	.49 - .69
3SUB	39	.72	.42	.26	2.2	.58 - .85
4SUB	39	.64	.37	.27	1.9	.52 - .76
5SUB	39	.93	.51	.32	2.2	.76 - 1.1
6SUB	39	1.1	.8	.25	4.7	.9 - 1.4
7SUB	38	1.0	.6	.30	3.6	.8 - 1.2
8SUB	38	1.9	2.0	.36	8.4	1.2 - 2.5
9SUB	39	.44	.18	.24	1.0	.37 - .50
10SUB	37	1.2	2.3	.30	14.5	.4 - 1.9
1T/S	78	.64	.28	.30	1.8	.58 - .71
2T/S	78	.58	.31	.19	2.1	.51 - .65
3T/S	78	.73	.43	.26	2.3	.63 - .82
4T/S	78	.64	.35	.19	1.9	.56 - .72
5T/S	78	1.0	.9	.29	5.9	.8 - 1.2
6T/S	79	1.2	1.1	.25	7.5	1.0 - 1.5
7T/S	77	1.0	.6	.30	4.5	.9 - 1.2
8T/S	77	1.5	1.5	.29	8.4	1.1 - 1.8
9T/S	79	.43	.21	.13	1.2	.39 - .48
10T/S	74	.97	1.7	.20	14.5	.58 - 1.4

Table A2. Temperature at water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE MINIMUM	RANGE MAXIMUM	95% CONFIDENCE INTERVAL
1TOP	38	29.1	.7	27.8	30.2	28.8 - 29.3
2TOP	39	29.1	.7	27.8	30.8	28.9 - 29.3
3TOP	39	29.2	.8	27.9	31.6	28.9 - 29.4
4TOP	39	29.1	.7	27.5	30.2	28.8 - 29.3
5TOP	39	29.2	.8	27.5	30.5	28.9 - 29.4
6TOP	39	29.1	.8	27.8	30.6	28.9 - 29.4
7TOP	38	29.1	.8	27.6	31.3	28.8 - 29.3
8TOP	38	29.0	.7	27.7	30.7	28.8 - 29.3
9TOP	39	29.0	.7	27.8	30.4	28.8 - 29.2
10TOP	37	29.0	.8	27.8	30.7	28.7 - 29.2
1SUB	38	29.0	.6	28.0	30.0	28.8 - 29.2
2SUB	38	29.0	.6	27.8	29.9	28.8 - 29.2
3SUB	38	29.0	.7	27.9	30.4	28.8 - 29.2
4SUB	38	29.0	.8	27.5	31.2	28.8 - 29.3
5SUB	37	29.0	.7	27.8	30.2	28.8 - 29.2
6SUB	38	29.0	.7	27.8	30.0	28.8 - 29.2
7SUB	38	29.0	.7	27.7	30.2	28.7 - 29.2
8SUB	37	28.9	.7	27.7	30.2	28.7 - 29.2
9SUB	38	29.0	.7	27.3	30.5	28.8 - 29.3
10SUB	36	28.9	.8	27.7	30.9	28.7 - 29.2
1T/S	76	29.0	.7	27.8	30.2	28.9 - 29.2
2T/S	77	29.1	.7	27.8	30.8	28.9 - 29.2
3T/S	77	29.1	.7	27.9	31.6	28.9 - 29.3
4T/S	77	29.1	.7	27.5	31.2	28.9 - 29.2
5T/S	76	29.1	.7	27.5	30.5	28.9 - 29.3
6T/S	77	29.1	.7	27.8	30.6	28.9 - 29.2
7T/S	76	29.0	.8	27.6	31.3	28.8 - 29.2
8T/S	75	29.0	.7	27.7	30.7	28.8 - 29.2
9T/S	77	29.0	.7	27.3	30.5	28.9 - 29.2
10T/S	73	29.0	.8	27.7	30.9	28.8 - 29.1

Table A3. Dissolved oxygen at water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE		95% CONFIDENCE INTERVAL
				MINIMUM	MAXIMUM	
1TOP	38	6.24	.61	5.02	7.99	6.04 - 6.44
2TOP	38	6.25	.65	4.56	7.63	6.04 - 6.47
3TOP	38	6.48	.79	5.20	9.47	6.22 - 6.73
4TOP	38	6.35	.71	5.46	9.31	6.12 - 6.58
5TOP	39	6.51	.81	5.00	8.60	6.25 - 6.77
6TOP	39	6.40	.63	5.17	7.98	6.20 - 6.60
7TOP	39	6.27	.59	4.56	7.71	6.08 - 6.45
8TOP	39	6.28	.53	5.27	7.98	6.11 - 6.45
9TOP	38	6.49	.62	5.39	7.89	6.29 - 6.69
10TOP	37	6.34	.59	5.47	8.31	6.14 - 6.54
1SUB	38	6.25	.63	4.87	8.07	6.04 - 6.46
2SUB	39	6.28	.54	5.10	7.67	6.10 - 6.46
3SUB	38	6.27	.61	5.05	8.07	6.07 - 6.47
4SUB	38	6.22	.52	5.32	7.90	6.05 - 6.39
5SUB	38	6.34	.64	5.40	8.17	6.13 - 6.55
6SUB	38	6.32	.64	5.14	7.94	6.11 - 6.53
7SUB	37	6.32	.55	5.32	7.76	6.13 - 6.49
8SUB	38	6.24	.53	5.38	7.80	6.07 - 6.42
9SUB	38	6.31	.68	4.10	8.03	6.09 - 6.53
10SUB	37	6.31	.53	5.33	7.69	6.13 - 6.48
1T/S	76	6.24	.62	4.87	8.07	6.10 - 6.38
2T/S	77	6.27	.59	4.56	7.67	6.13 - 6.40
3T/S	76	6.37	.71	5.05	9.47	6.21 - 6.53
4T/S	76	6.29	.62	5.32	9.31	6.14 - 6.43
5T/S	77	6.42	.73	5.00	8.60	6.26 - 6.59
6T/S	77	6.36	.63	5.14	7.98	6.22 - 6.50
7T/S	76	6.29	.56	4.56	7.76	6.16 - 6.42
8T/S	77	6.26	.52	5.27	7.98	6.14 - 6.38
9T/S	76	6.40	.65	4.10	8.03	6.25 - 6.55
10T/S	74	6.32	.56	5.33	8.31	6.19 - 6.45

Table A4. Salinity at water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE MINIMUM	RANGE MAXIMUM	95% CONFIDENCE INTERVAL
1TOP	38	33.6	.8	32.0	35.0	33.4 - 33.9
2TOP	37	33.7	.7	32.1	35.0	33.4 - 33.9
3TOP	37	33.7	.7	32.2	35.0	33.5 - 33.9
4TOP	37	33.7	.8	32.0	35.5	33.4 - 34.0
5TOP	38	33.7	.7	32.5	35.5	33.4 - 34.0
6TOP	37	33.7	.7	32.2	34.4	33.4 - 33.9
7TOP	37	33.7	.8	32.2	36.1	33.5 - 34.0
8TOP	37	33.7	.8	32.0	35.5	33.4 - 33.9
9TOP	37	33.8	.7	32.2	35.0	33.6 - 34.0
10TOP	35	33.6	.8	31.9	35.0	33.3 - 33.8
1SUB	38	33.7	.7	32.2	34.4	33.5 - 33.9
2SUB	37	33.6	.7	32.0	34.4	33.4 - 33.8
3SUB	37	33.7	.7	32.5	34.7	33.4 - 33.9
4SUB	38	33.8	.7	32.5	35.5	33.5 - 34.0
5SUB	37	33.7	.8	32.5	35.0	33.5 - 34.0
6SUB	37	33.7	.7	32.2	34.5	33.4 - 33.9
7SUB	37	33.7	.7	32.2	35.5	33.5 - 34.0
8SUB	37	33.6	.7	32.0	35.0	33.4 - 33.9
9SUB	36	33.9	.7	32.4	35.0	33.6 - 34.1
10SUB	35	33.5	.7	32.0	35.0	33.3 - 33.8
1T/S	76	33.7	.7	32.0	35.0	33.5 - 33.8
2T/S	74	33.6	.7	32.0	35.0	33.5 - 33.8
3T/S	74	33.7	.7	32.2	35.0	33.5 - 33.8
4T/S	75	33.7	.8	32.0	35.5	33.6 - 33.9
5T/S	75	33.7	.7	32.5	35.5	33.5 - 33.9
6T/S	74	33.7	.7	32.2	34.5	33.5 - 33.8
7T/S	74	33.7	.7	32.2	36.1	33.6 - 33.9
8T/S	74	33.6	.7	32.0	35.5	33.5 - 33.8
9T/S	73	33.8	.7	32.2	35.0	33.7 - 34.0
10T/S	70	33.5	.7	31.9	35.0	33.4 - 33.7

Table A5. pH at water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE		95% CONFIDENCE INTERVAL
				MINIMUM	MAXIMUM	
1TOP	37	8.16	.08	8.00	8.30	8.13 - 8.19
2TOP	37	8.19	.08	8.00	8.30	8.16 - 8.21
3TOP	37	8.20	.07	8.05	8.32	8.17 - 8.22
4TOP	37	8.20	.07	8.08	8.33	8.18 - 8.22
5TOP	37	8.21	.07	8.09	8.34	8.19 - 8.24
6TOP	38	8.22	.07	8.01	8.33	8.19 - 8.24
7TOP	38	8.20	.08	8.00	8.36	8.18 - 8.23
8TOP	38	8.20	.07	8.10	8.35	8.18 - 8.23
9TOP	38	8.24	.06	8.11	8.37	8.22 - 8.26
10TOP	37	8.21	.08	8.00	8.34	8.18 - 8.23
1SUB	38	8.19	.08	8.03	8.30	8.16 - 8.21
2SUB	38	8.20	.08	8.00	8.30	8.17 - 8.22
3SUB	38	8.20	.08	8.05	8.32	8.17 - 8.22
4SUB	38	8.20	.08	8.05	8.34	8.18 - 8.23
5SUB	38	8.21	.07	8.05	8.33	8.19 - 8.24
6SUB	37	8.21	.08	8.00	8.34	8.18 - 8.24
7SUB	37	8.21	.07	8.03	8.35	8.19 - 8.24
8SUB	38	8.21	.07	8.00	8.34	8.19 - 8.23
9SUB	37	8.23	.08	8.10	8.37	8.21 - 8.25
10SUB	37	8.21	.07	8.09	8.36	8.19 - 8.23
1T/S	75	8.17	.08	8.00	8.30	8.16 - 8.19
2T/S	75	8.19	.08	8.00	8.30	8.17 - 8.21
3T/S	75	8.20	.07	8.05	8.32	8.18 - 8.21
4T/S	75	8.20	.07	8.05	8.34	8.18 - 8.22
5T/S	75	8.21	.07	8.05	8.34	8.19 - 8.23
6T/S	75	8.21	.08	8.00	8.34	8.20 - 8.23
7T/S	75	8.21	.07	8.00	8.36	8.19 - 8.22
8T/S	76	8.21	.07	8.00	8.35	8.19 - 8.22
9T/S	75	8.23	.06	8.10	8.37	8.22 - 8.25
10T/S	74	8.21	.07	8.00	8.36	8.19 - 8.23

Table A6. Total Kjeldahl nitrogen of water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE MINIMUM	RANGE MAXIMUM	95% CONFIDENCE INTERVAL
1TOP	8	.21	.29	.01	.88	.00 - .46
2TOP	6	.32	.37	.01	.96	.00 - .71
3TOP	6	.14	.09	.01	.30	.04 - .24
4TOP	7	.21	.12	.01	.37	.10 - .32
5TOP	7	.15	.08	.01	.27	.07 - .23
6TOP	31	.18	.19	.01	2.0*	.11 - .24
7TOP	9	.19	.13	.01	.35	.08 - .28
8TOP	9	.17	.13	.01	.34	.07 - .28
9TOP	31	.15	.12	.01	.42	.10 - .19
10TOP	10	.13	.13	.01	.39	.04 - .23
1SUB	32	.14	.11	.01	.35	.10 - .18
2SUB	31	.12	.11	.01	.43	.08 - .16
3SUB	32	.18	.25	.01	1.8*	.09 - .27
4SUB	33	.11	.08	.01	.29	.08 - .14
5SUB	32	.13	.12	.01	.49	.08 - .17
6SUB	39	.11	.10	.01	.39	.08 - .14
7SUB	31	.17	.23	.01	.59*	.09 - .25
8SUB	32	.16	.18	.01	1.0*	.09 - .22
9SUB	37	.13	.16	.01	.76	.08 - .18
10SUB	32	.13	.18	.01	1.0*	.06 - .19
1T/S	40	.15	.16	.01	.88	.10 - .21
2T/S	37	.15	.18	.01	.96	.09 - .21
3T/S	38	.18	.23	.01	1.8	.10 - .25
4T/S	40	.13	.10	.01	.37	.09 - .16
5T/S	39	.13	.11	.01	.49	.09 - .17
6T/S	70	.14	.15	.01	2.0	.10 - .17
7T/S	40	.17	.21	.01	.59*	.11 - .24
8T/S	41	.16	.17	.01	1.0*	.11 - .21
9T/S	68	.14	.14	.01	.76	.10 - .17
10T/S	42	.13	.17	.01	1.0*	.08 - .18

*contained values recorded in monthly summaries of >1mg/ℓ which were typographical errors.

Table A7. Total Phosphorus at water quality monitoring stations from September 1978 to December 1981.

STATION	No. of SAMPLES	MEAN	STANDARD DEVIATION	RANGE MINIMUM	RANGE MAXIMUM	95% CONFIDENCE INTERVAL
1TOP	7	.013	.009	.004	.032	.004 - .021
2TOP	7	.059	.123	.004	.339	.000 - .174
3TOP	7	.017	.018	.005	.056	.001 - .034
4TOP	7	.014	.011	.005	.039	.003 - .024
5TOP	9	.010	.004	.004	.016	.007 - .014
6TOP	33	.012	.019	.003	.113	.005 - .019
7TOP	9	.009	.004	.004	.017	.006 - .013
8TOP	11	.041	.069	.005	.205	.000 - .088
9TOP	31	.009	.016	.002	.093	.004 - .015
10TOP	10	.007	.005	.002	.016	.004 - .012
1SUB	33	.011	.016	.001	.093	.005 - .016
2SUB	33	.012	.020	.003	.113	.005 - .019
3SUB	33	.010	.017	.001	.104	.004 - .017
4SUB	33	.012	.019	.001	.104	.006 - .019
5SUB	32	.010	.014	.002	.083	.006 - .016
6SUB	39	.013	.021	.001	.134	.006 - .020
7SUB.	31	.017	.036	.001	.196	.004 - .030
8SUB	31	.008	.005	.001	.024	.006 - .010
9SUB	39	.012	.017	.001	.093	.007 - .018
10SUB	34	.014	.019	.002	.093	.007 - .020
1T/S	40	.011	.015	.001	.093	.007 - .016
2T/S	40	.020	.055	.003	.339	.003 - .038
3T/S	40	.012	.017	.001	.104	.006 - .017
4T/S	40	.013	.018	.001	.104	.007 - .018
5T/S	41	.011	.012	.002	.083	.007 - .014
6T/S	72	.013	.020	.001	.134	.008 - .018
7T/S	40	.015	.032	.001	.196	.005 - .025
8T/S	42	.017	.038	.001	.205	.005 - .029
9T/S	70	.011	.017	.001	.093	.007 - .015
10T/S	44	.012	.017	.002	.093	.007 - .018

Table A8. Comparison of surface and subsurface water quality at monitoring stations. The following abbreviations were used to denote pairs of groups significantly different at P≤.05: 1, turbidity; 2, pH; 3, salinity; 4, total phosphorus; 5, total kjeldahl nitrogen. The analyses were generated by SPSS software with a range T-test comparison. Surface samples (TOP) were taken at -.5m and the subsurface samples (SUB) at ca.1m from the lagoon floor.

		STA 1		STA 2		STA 3		STA 4		STA 5		STA 6		STA 7		STA 8		STA 9		STA 10	
		TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB	TOP	SUB
STA 1	TOP																				
	SUB																				
STA 2	TOP	4	4,5																		
	SUB	2		4,5																	
STA 3	TOP	2		4,5																	
	SUB	2		4																	
STA 4	TOP	2,4	4		4	4	4														
	SUB	2		4,5				4													
STA 5	TOP	1,2	1	1,4	1	1	1	1,4	1												
	SUB	2		4,5				4													
STA 6	TOP	1,2	1	1,4,5	1			1,4	1												
	SUB	1,2	1	1,4,5	1	1	1	1,4	1												
STA 7	TOP	1,2		1,4	1			1,4	1												
	SUB	1,2		1,4,5	1			4													
STA 8	TOP	1,2,4	4	1	1,4		4		4	4	4	4	4	4	4						
	SUB	1,2	1	1,4,5	1	1	1	1,4	1	1	1		1	1	1	1					
STA 9	TOP	2	2	2,4,5	2	2		2,4	2	1	1	1	1	1,2	1	1,2,4	1				
	SUB	2	2	2,4,5	2	2		4		1	1	1	1	1	1	1	1				
STA 10	TOP	2		4,5								1				4	1				
	SUB	1,2	1	1,4	1	1	1	1,4	1							4	1	1	1,3		

APPENDIX B

Statistical Analyses of Meterological and Hydrographic Effects

Meteorological (wind direction and speed, air temperature, precipitation, total sunshine, barometric pressure) and hydrographic (water current direction and velocity, tidal cycle and waves) conditions can greatly influence water quality parameters. For long-term monitoring programs, it is important to understand how existing natural conditions affect those water quality parameters being analyzed. There have been few short-term studies conducted in tropical marine waters which relate weather data, current flow and tidal change to water quality parameters. There appears to be no extensive environmental studies relating to major construction projects involving substantial dredging and filling operations. Monitoring station water quality parameters were analyzed in relation to wind direction [prior day and the day of sampling (Table B1)] wind velocity [prior day and the day of sampling (Table B2)] and precipitation [prior day and the day of sampling (Table B3)]. The hydrographic conditions analyzed in relation to water quality parameters were current flow direction at the time of sampling (Table B4) and tidal change [rising and falling tide (Table B4)].

Sunshine

DO for surface and subsurface waters at all the monitoring stations was analyzed in relation to total percentage of sunshine for the prior day and day of sampling. There was no correlation between DO concentration and the prior day total sunshine. The percentage of sunshine on the sampling day significantly ($F=0.018$) affected DO concentrations. Since sampling was usually done in the mid-morning to early afternoon time period, the percentage of early morning sunshine had the greatest affect on DO. Sunshine was tabulated for the full day at the Weather Service with no shorter counts taken.

Wind

Wind direction 24 hour prior to sampling affected turbidity, temperature, DO and, to a lesser extent, salinity and TP (Table B1). There was no correlation with pH and TKN. Temperature at all monitoring stations was significantly influenced by prior day wind directions with maximum temperature values with and ENE wind. Turbidity was not affected by prior day wind at stations 3, 7, 8 and 10 (Fig. B1). At the remaining stations, maximum turbidities occurred with either a NNW or ESE wind (Fig. B1). DO was not affected by prior day wind at stations 6, 7 and 8. At the remaining stations maximum DO levels generally occurred with a NNW wind while minimum DO occurred with a SSE wind.

Wind direction at the time of sampling affected temperature, salinity, turbidity (at 5 stations) and, to a lesser extent, DO and TKN (Table B1). There was no correlation with pH or TP. Temperatures at all the monitoring stations were influenced by wind directions at the time of sampling. Although the wind directions were generally similar for the prior 24 hour period and the

Table B1. Effect of wind direction 24 hour prior to and at the time of sampling on water quality.

	TURBIDITY		TEMPERATURE		pH		DO		SALINITY		TP		TKN	
	PRIOR DAY ANOVA	SAMPLE DAY ANOVA	PRIOR DAY ANOVA	SAMPLE DAY ANOVA	PRIOR DAY ANOVA	SAMPLE DAY ANOVA	PRIOR DAY ANOVA	SAMPLE DAY ANOVA	PRIOR DAY ANOVA	SAMPLE DAY ANOVA	PRIOR DAY ANOVA	SAMPLE DAY ANOVA	PRIOR DAY ANOVA	SAMPLE DAY ANOVA
STA 1	.007	.001	.004	.001	NS	NS	.040	NS	.019	.001	.029	NS	NS	NS
STA 2	.007	.001	.001	.001	NS	NS	.009	NS	NS	.001	NS	NS	NS	.042
STA 3	NS*	.003	.006	.001	NS	NS	.008	NS	NS	.001	NS	NS	NS	NS
STA 4	.041	.001	.002	.001	NS	NS	.008	NS	NS	.001	NS	NS	NS	NS
STA 5	.007	NS	.001	.001	NS	NS	.008	.016	NS	.001	NS	NS	NS	NS
STA 6	.003	NS	.001	.001	NS	NS	NS	NS	NS	.001	.001	NS	NS	NS
STA 7	NS	NS	.002	.001	NS	NS	NS	NS	NS	.002	NS	NS	NS	NS
STA 8	NS	NS	.001	.001	NS	NS	NS	NS	NS	.002	NS	NS	NS	NS
STA 9	.001	.001	.007	.001	NS	NS	.046	NS	NS	.001	.001	NS	NS	NS
STA 10	NS	NS	.002	.032	NS	NS	.001	NS	.042	.001	.047	NS	NS	.025

*NS, not significant at probability ≤0.05.

Table B-2. Effect of wind speed 24-hour prior to sampling and at the time of sampling on water quality.

24-HOURS PRIOR TO SAMPLING

	TURB ANOVA	TEMP ANOVA	pH ANOVA	DO ANOVA	SAL ANOVA	TP ANOVA	TKN ANOVA
STA 1	.001	.021	NS	NS	NS	NS	NS
STA 2	.001	.031	NS	NS	NS	NS	NS
STA 3	.001	.024	NS	NS	NS	NS	NS
STA 4	.001	NS	NS	NS	NS	NS	NS
STA 5	.011	.045	NS	NS	NS	NS	NS
STA 6	NS*	.024	NS	NS	NS	NS	NS
STA 7	NS	NS	NS	NS	NS	NS	NS
STA 8	.045	.013	.041	NS	NS	NS	NS
STA 9	.001	.003	NS	NS	NS	NS	NS
STA 10	NS	NS	NS	NS	NS	NS	NS

AT SAMPLING TIME

	TURB ANOVA	TEMP ANOVA	pH ANOVA	DO ANOVA	SAL ANOVA	TP ANOVA	TKN ANOVA
STA 1	.001	NS	NS	.020	.026	NS	NS
STA 2	.001	NS	NS	NS	NS	NS	NS
STA 3	.004	NS	.013	NS	NS	NS	NS
STA 4	.001	NS	.017	NS	NS	NS	NS
STA 5	NS	NS	NS	NS	.016	NS	NS
STA 6	NS	NS	.001	NS	NS	NS	NS
STA 7	NS	NS	.012	NS	NS	NS	NS
STA 8	.001	NS	.044	NS	NS	NS	NS
STA 9	.019	NS	.015	NS	NS	NS	NS
STA 10	NS	NS	NS	NS	.030	NS	NS

*NS, not significant at probability ≤0.05.

Table B3. Effect of 24 hour rainfall prior to and for the sampling day on water quality.

	TURBIDITY		TEMPERATURE		pH		DISSOLVED OXYGEN		SALINITY		TOTAL PHOSPHORUS		T K N	
	Prior	Day	Prior	Day	Prior	Day	Prior	Day	Prior	Day	Prior	Day	Prior	Day
STA 1	NS*	NS	NS	NS	.043	NS	NS	NS	NS	.036	NS	NS	NS	NS
STA 2	NS	NS	NS	NS	.014	NS	NS	NS	NS	.023	NS	NS	NS	NS
STA 3	NS	NS	NS	NS	NS	NS	NS	NS	NS	.026	NS	NS	NS	.001
STA 4	NS	NS	NS	NS	NS	NS	NS	NS	NS	.001	NS	NS	NS	NS
STA 5	.001	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
STA 6	NS	NS	NS	NS	NS	NS	NS	NS	NS	.033	NS	NS	NS	NS
STA 7	NS	NS	NS	NS	NS	NS	NS	NS	NS	.040	NS	NS	.001	NS
STA 8	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	.008	NS	NS
STA 9	NS	NS	NS	NS	NS	NS	NS	NS	NS	.038	NS	NS	NS	NS
STA 10	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*NS, not significant at probability ≤0.05.

Table B4. Effect of water current flow direction and tidal change on water quality. The current directions are coded the same as the wind directions.

	TURBIDITY		TEMPERATURE		pH		DISSOLVED OXYGEN		SALINITY		TOTAL PHOSPHORUS		T K N	
	Curr. Dir.	Tide	Curr. Dir.	Tide	Curr. Dir.	Tide	Curr. Dir.	Tide	Curr. Dir.	Tide	Curr. Dir.	Tide	Curr. Dir.	Tide
STA 1	.001	NS*	.001	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
STA 2	.002	NS	.002	NS	.001	.020	NS	NS	NS	NS	NS	NS	NS	NS
STA 3	NS	NS	NS	NS	NS	.018	.034	NS	NS	NS	NS	NS	NS	NS
STA 4	NS	NS	.016	NS	NS	.046	NS	NS	NS	NS	NS	NS	NS	NS
STA 5	NS	NS	NS	.039	NS	.019	NS	NS	.014	NS	NS	NS	NS	NS
STA 6	NS	NS	.010	.050	NS	NS	.050	NS	NS	NS	NS	NS	NS	NS
STA 7	NS	NS	.001	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
STA 8	NS	NS	.001	NS	.001	NS	.038	NS	NS	NS	NS	NS	NS	NS
STA 9	NS	NS	.001	NS	.013	NS	NS	NS	NS	NS	NS	NS	NS	NS
STA 10	NS	NS	.003	NS	NS	NS	.001	NS	NS	NS	.025	NS	NS	NS

*NS, not significant at probability ≤ 0.05.

AVERAGE WIND DIRECTION

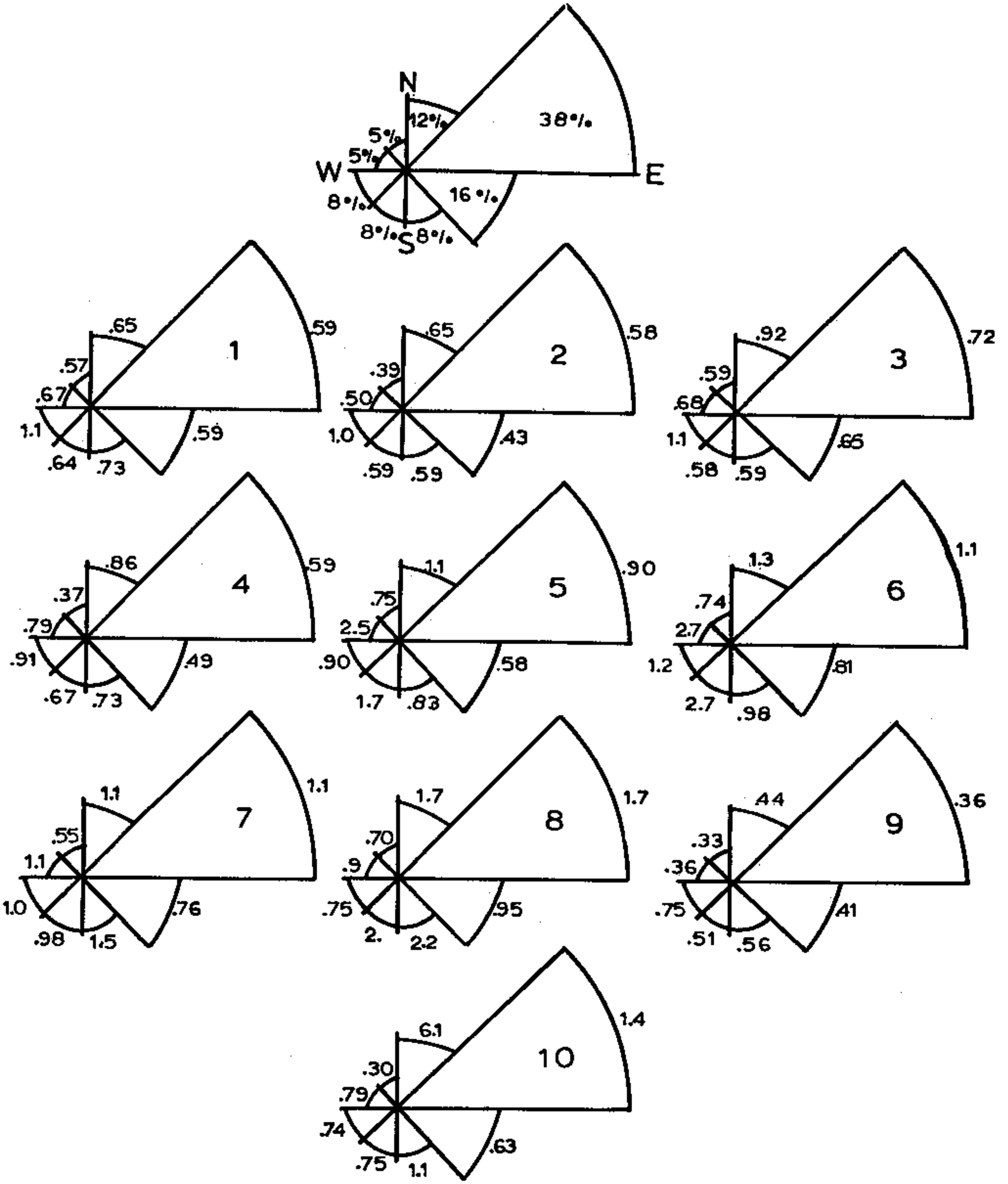

Figure B1. Turbidity levels at monitoring stations compared with wind directions. The wind roses show the direction of wind approach.

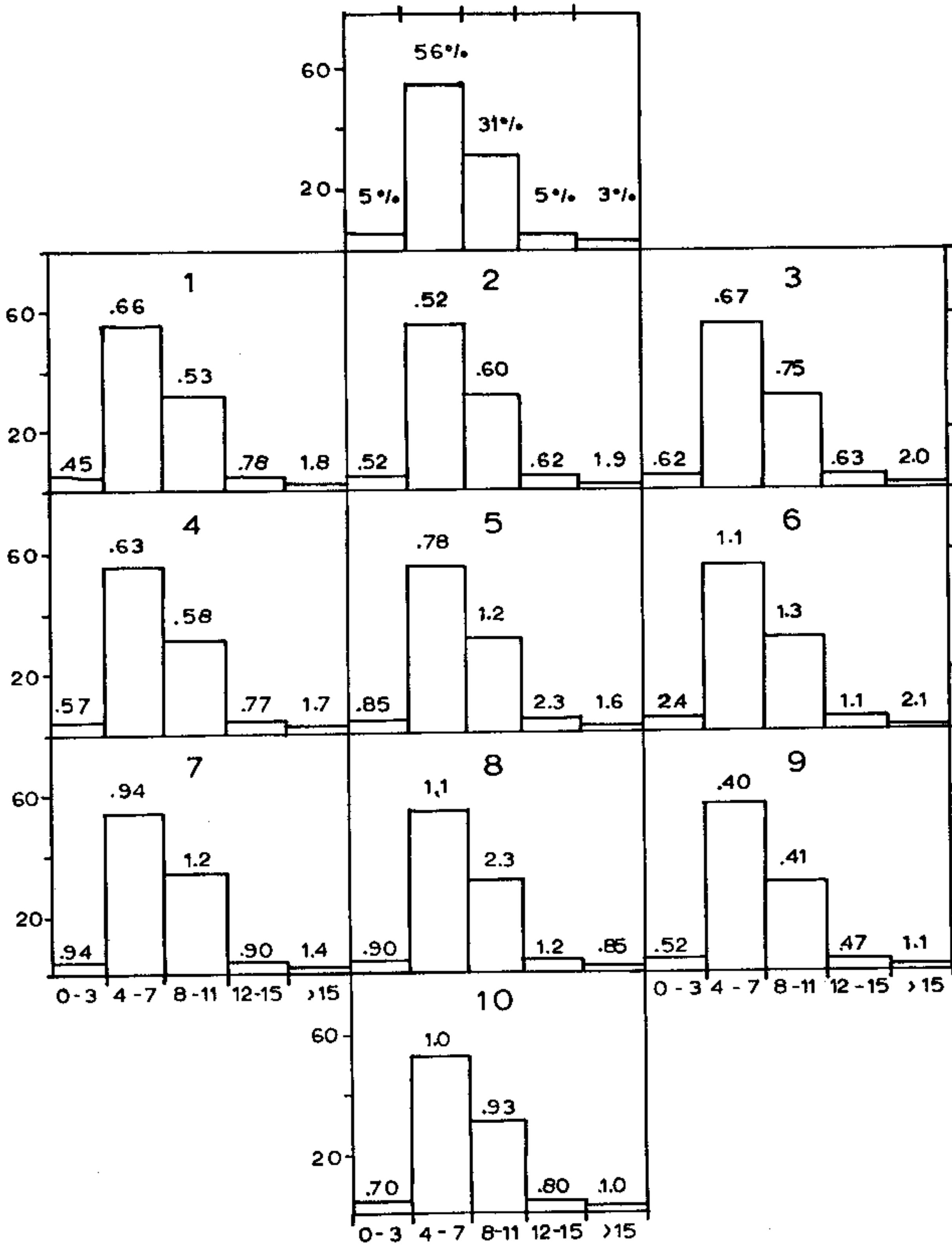

Figure B2. Turbidity levels at monitoring stations compared with wind speeds. The wind speeds are in knots.

day of sampling, there were some distinct wind shifts. Wind from the SSW produced minimum temperature values for the day of sampling and maximum values if it was for the prior day. Turbidities were affected by sampling day wind directions at stations 1, 2, 3, 4 and 9. Maximum turbidities occurred at these stations when the SSW wind blew across the fringing reef.

The wind speed for the prior day affected turbidity (at 7 stations) and temperature (at 7 stations) (Table B2). Maximum turbidities occurred with wind speeds>11 kts (Fig. B2). Wind speeds for the day of sampling affected turbidity (at 6 stations) and pH (at 6 stations) (Table B2). Salinity at stations 1, 5 and 10 was affected by sampling day wind velocities with reduced salinities at the higher wind velocities. Minimum pH values occurred with wind speeds below 3 knots and maximum pH with moderately high speeds between 11 to 20 knots. Sampling was not conducted when wind speeds exceeded 20 knots because of excessive waves in the lagoon. Therefore, the maximum turbidities for the day of sampling occurred with moderately high wind speeds between 11-20 knots. It is probably the wind speeds for the prior day as well as wind direction which maximize turbidity levels.

Rain

Precipitation had limited affect on water quality parameters (Table B3). The prior 24 hour rainfall influenced turbidity at station 5, pH at station 1 and 2, and TKN at station 7. Rainfall for the day of sampling (24 hour period) influenced salinity at stations 1, 2, 3, 4, 6, 7 and 9 and TP at station 8. Analysis of only surface water, showed salinities at all the monitoring stations were reduced by rainfall the day of sampling.

Water Currents and Tide

There was a significant correlation between the wind direction and water current flow. The affect of the water movement on water quality parameters was determined for each monitoring station (Table B4). Tidal change had limited influence on water quality. Turbidity, DO, salinity, TP and TKN were not affected by rising or falling tides (Table B4). Temperature at stations 5 and 6 and pH at stations 2, 3, 4 and 5 were correlated with tidal cycles. Stations 2, 3, 4 and 5 received flushed water from the adjacent reef-flat under falling tide, which could have influenced the pH.

Current flow directions affected turbidity (two stations), temperature (eight stations), pH (three stations) and DO (four stations). TKN was not correlated with current flow. Salinity at station 5 and TP at station 10 were influenced by water flow. Current flow direction influenced turbidity levels (Fig. B3) with water movement away from the fringing reefs and construction area having higher levels, while flow toward the land resulted in minimum turbidities.

AVERAGE WATER MOVEMENT

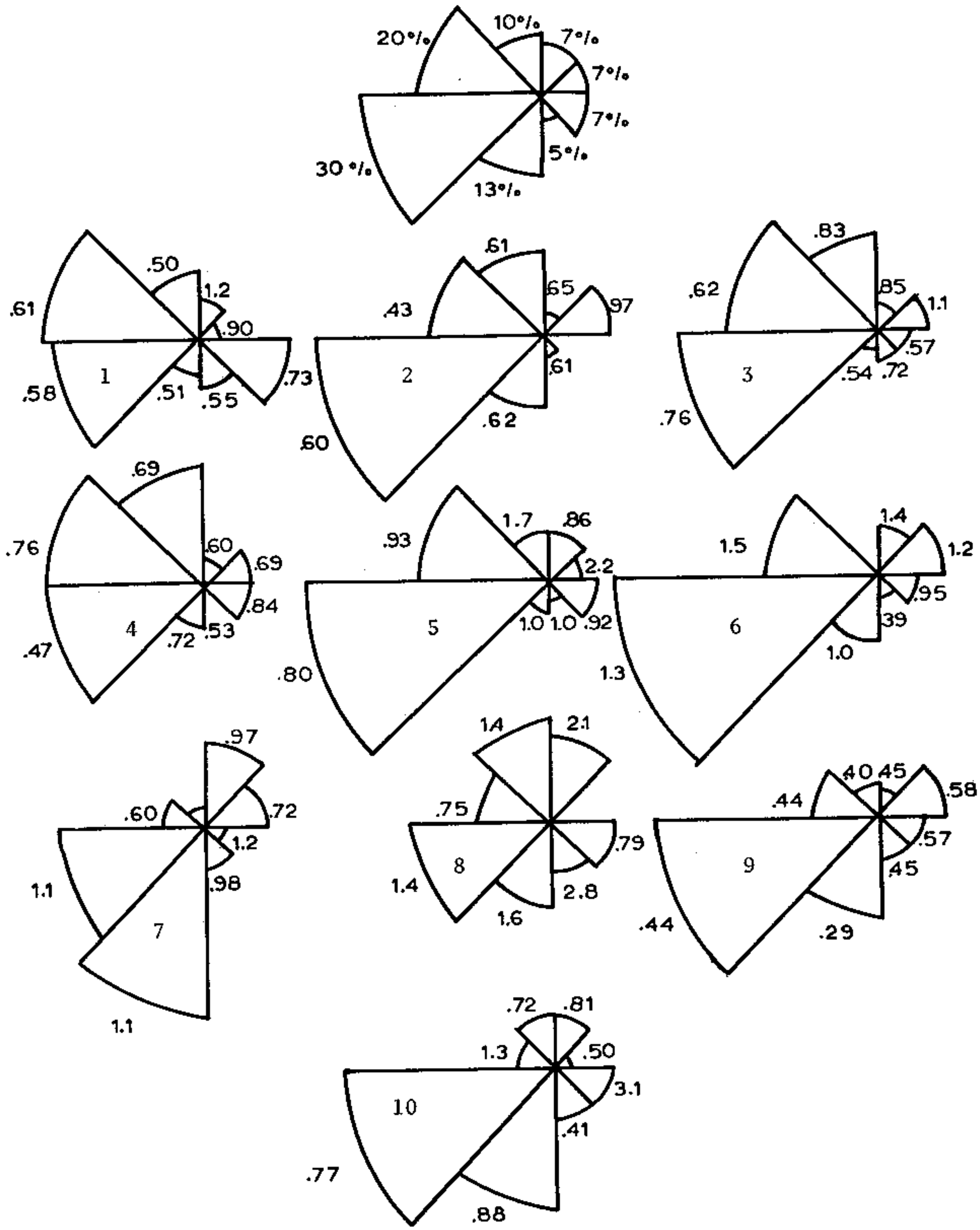

Figure B3. Turbidity levels at monitoring stations compared with water current directions. Current roses show direction of flow.

APPENDIX C

Long-Term Water Quality Trends

In order to access construction-related time dependent trends in the water quality parameters, the combined water masses were analyzed by water quality parameter for six-month and one-year intervals (Table C1). Salinity, pH, TP and TKN did not vary between stations for these analyses intervals. Temperature was significantly different between two station groupings for the September to December 1981 period. Since this was a four-month analysis set, it was possible to have no significant difference between station temperatures for a six-month period. DO was significantly different between three station groupings in the first year of monitoring. Stations 7 and 8 had slightly lower DO concentrations in this sampling interval. There were no construction-related operations which affected these stations in this time period. In the sampling interval between September 1979 to February 1980, DO was significantly different between two station groups. Station 5 had a higher DO level. This station had sedimentation plumes at each sampling date from October 1979 to January 1980.

Turbidity was the primary water quality parameter affected by construction operations for specific time intervals (Table C1). There were no differences in turbidity levels between stations for the first six months of monitoring, since there were no major dredge slurry discharges at this time. Stations 5 and 6 had significant increases in turbidity levels beginning in March 1979. By September 1979, stations 5, 6, 7 and 8 had similar increased turbidity levels with periodic violations of the 2.0 NTU standard. Station 3 began showing increased turbidity by March 1980 which grouped this station, in regard to turbidity with stations 6, 7 and 8. Station 8 had the highest turbidity between March 1981 to August 1981. In this time period, turbidity levels at stations 5, 6 and 7 had slightly decreased which grouped these stations with stations 1, 2, 3, 4 and 10. In the final sampling period between September 1981 to December 1981, there was no significant differences between the monitoring stations. Therefore, at the completion of major dredge slurry discharging and embankment construction turbidity levels began to decrease at those stations impacted by construction operations. However, the turbidity levels in the last sampling period (December, 1981) at these stations were higher compared with the part A monitoring program.

The water quality parameters were analyzed for the entire 3.25 year monitoring program to access long-term trends (Table C2). Temperature, DO, TP and TKN showed no significant difference between stations. Turbidity, pH and salinity showed trends. pH levels were different between 4 station groupings. Station 10 had a lower mean salinity compared with the other 9 stations. Turbidity levels were different between 5 station groupings: control (9); stations 1, 2, and 4; station 3; stations 5, 7 and 10; stations 6 and 8. The control station provides an assessment of turbidity fluctuations in lagoon waters which are removed from inhabited islands. Stations 1, 2 and 4 were not affected by construction operations and represent areas subject to normal fringing reef (station 4) and channel (stations 1 and 2) flushing. Station 3 received minor impacts from construction operations in 1979 and 1980. Stations 5, 7 and 10 were impacted by construction operations and represent areas with occasional sedimentation plumes and coral-filling operations. Station 6 and 8 were located near dredge slurry discharge points and received extensive impacts from construction operations.

Table CI. Analysis of variance of combined water quality monitoring stations for 6-mo and 1-yr sampling intervals. The ANOVA were generated by SPSS software with $P \leq .05$. Station groups are shown by water quality parameter for sampling intervals with significant ($P \leq .05$) difference between stations. Salinity, total phosphorus, pH and total kjeldahl nitrogen did not vary between stations for the analyses intervals.

Time Period	TURBIDITY		TEMPERATURE		DISSOLVED OXYGEN	
	ANOVA	Station Groups	ANOVA	Station Groups	ANOVA	Station Groups
YEAR 1	.001	a. 9 b. 2,4,1,10,8,3 c. 7 d. 5,6	NS		.035	a. 8 b. 7 c. 6,1,4,2,5,10,9,3
Sept 78-Feb 79	NS		NS		NS	
Mar 79-Aug 79	.001	a. 9 b. 2,4,1,10,8,3 c. 7 d. 5,6	NS		NS	
YEAR 2	.001	a. 9 b. 2,1,10,4,3 c. 5 d. 8,7,6	NS		NS	
Sept 79-Feb 80	.023	a. 9,2,1,4,10,3 b. 5,8,7,6	NS		.024	a. 8,4,10,1,2,7,3,6,9 b. 5
Mar 80-Aug 80	.002	a. 9 b. 2 c. 10,1,5,4 d. 3,6,8,7	NS		NS	
YEAR 3	.001	a. 9 b. 3,2,4 c. 1 d. 10,7,5,6 e. 8	NS		NS	
Sept 80-Feb 81	.003	a. 9,3,2,4,1,7,10 b. 6,5,8	NS		NS	
Mar 81-Aug 81	.001	a. 9 b. 4,1,3,2,10,5,7,6 c. 8	NS		NS	
YEAR 4 Sept 81-Dec 81	NS		.019	a. 8,7,2,1,6,4 b. 9,3,10,5	NS	

Table C2. Monitoring stations grouped by water quality parameters. The analyses were generated by SPSS software with a range T-test comparison. Temperature, dissolved oxygen, total phosphorus, and total kjeldahl nitrogen have no two groups which are significantly different at the 0.050 level.

TURBIDITY			pH			SALINITY		
Range Group	Station	Mean ± sd	Range Group	Station	Mean ± sd	Range Group	Station	Mean ± sd
1	9 T/S	.43 ± .22	1	1 T/S	8.17 ± .08	1	10 T/S	33.5 ± .7
2	2 T/S	.58 ± .31	2	2 T/S	8.19 ± .08	2	2 T/S	33.6 ± .7
	1 T/S	.64 ± .28		3 T/S	8.20 ± .07		8 T/S	33.6 ± .7
	4 T/S	.64 ± .35		4 T/S	8.20 ± .07		6 T/S	33.7 ± .7
				7 T/S	8.21 ± .07		1 T/S	33.7 ± .7
3	3 T/S	.73 ± .43		8 T/S	8.21 ± .07		3 T/S	33.7 ± .7
				10 T/S	8.21 ± .07		5 T/S	33.7 ± .7
4	10 T/S	.97 ±1.7					7 T/S	33.7 ± .7
	5 T/S	1.0 ± .9	3	5 T/S	8.21 ± .07		4 T/S	33.7 ± .8
	7 T/S	1.0 ± .6		6 T/S	8.21 ± .08		9 T/S	33.8 ± .7
5	6 T/S	1.2 ±1.1	4	9 T/S	8.23 ± .06			
	8 T/S	1.5 ±1.5						