Marine Water Quality in Okat, Kosrae for Airport and Dock Facility Construction Project Part C Post-Construction

Russell N. Clayshulte

University of Guam
Water and Energy Research Institute
of the
Western Pacific

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INTRODUCTION

Construction of an airport runway and docking facility was begun in early 1981 for Kosrae State (FSM). The construction project was located in a previously pristine marine environment near the natural deep-water harbor at Okat on the northeast end of Kosrae Island (Figure 1). The runway and docking facility were constructed entirely on the wide fringing reef-flat complex north of Okat Harbor (Figure 2). The Kosrae airport and docking facility Part C Post-Construction marine water quality (WQ) monitoring program was conducted in May 1985. In this program, the marine WQ stations used in the Part B program (Clayshulte, 1986) were monitored over a 6-day period. Water quality analyses were used to assess post-construction WQ in relation to: 1) the Part A Pre-Construction turbidity standard (Chun et. al, 1979); 2) the TTPI WQ standards; and 3) Part B Construction WQ data and observations.

The Part B construction monitoring program was conducted on a quarterly basis over a 30-month period (Clayshulte, 1986). Marine water quality (WQ) was monitored at 6 primary and up to 6 secondary WQ stations on a quarterly basis from 05-17-82 to 07-17-84. Primary and secondary WQ station locations are shown in Figure 2. WQ stations were monitored a minimum of 3 days for each quarterly sampling set. There were 11 quarterly sampling sets. The primary objective of the Part B monitoring program was to analyze selected WQ parameters in marine waters outside the WQ boundary adjacent to Okat Harbor and provide for comprehensive and timely reporting of quarterly results to the TTEPB.

The completion of the Part B monitoring program occurred in July 1984. At this time, most of the major construction was completed at the runway and docking facilities. There were still some minor construction activities in progress at the conclusion of the monitoring program. These activities included clean-up, restoration and minor finalizing construction operations which were being conducted by the initial contractor. At the completion of the primary construction of the airport and docking facilities, a second construction company was awarded a new contract to conduct additional construction activities at the dock and airport runway sites. These activities included partial runway pavement, installation of power lines and placement of sewage pipe. These new construction activities were in progress for the Part C Post-Construction WQ analyses program. It was probable that some of these activities affected marine WQ in the vicinity of Okat Harbor during the Part C monitoring period.

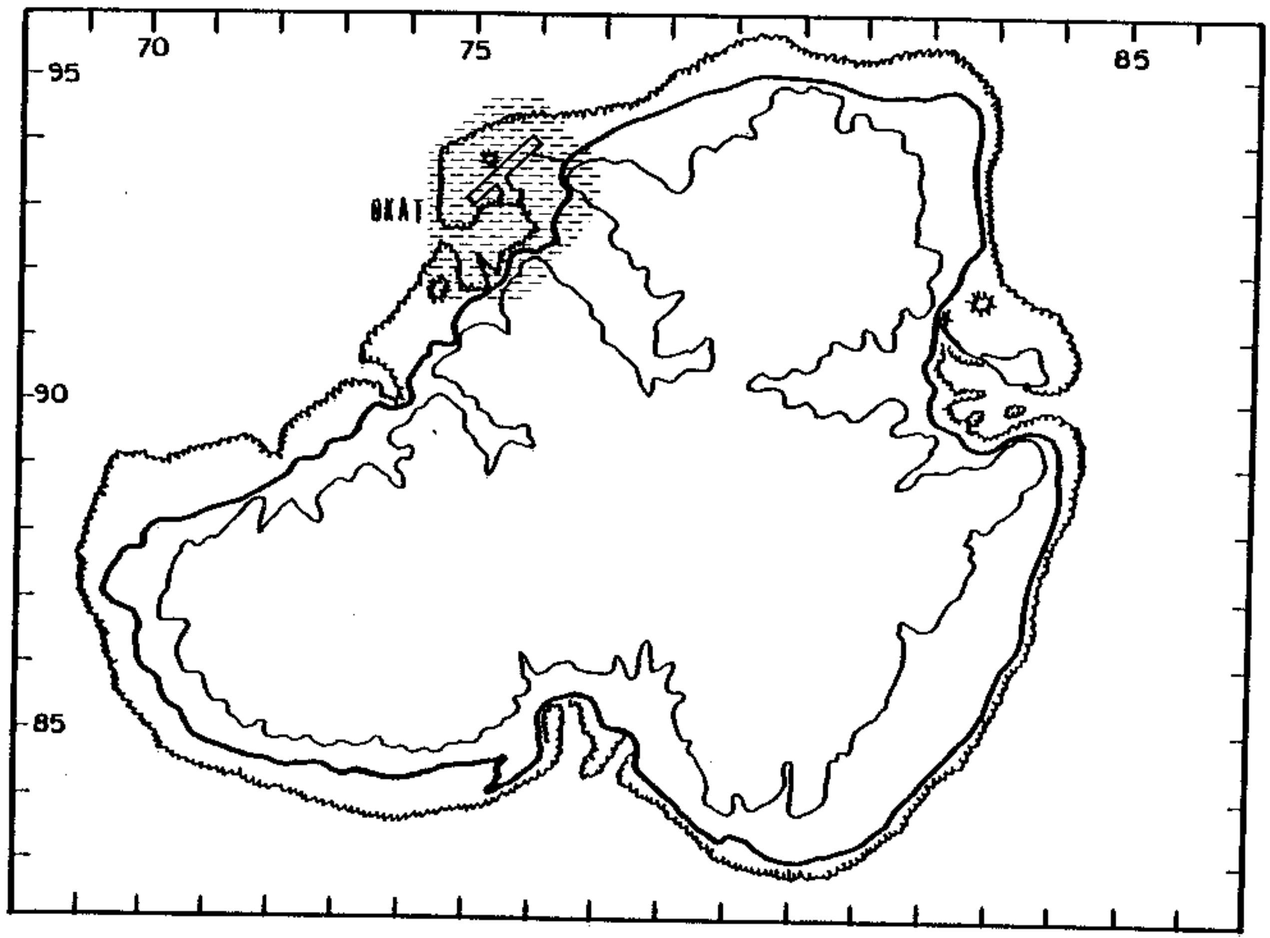

Figure 1. Kosrae Island and location of Okat harbor.

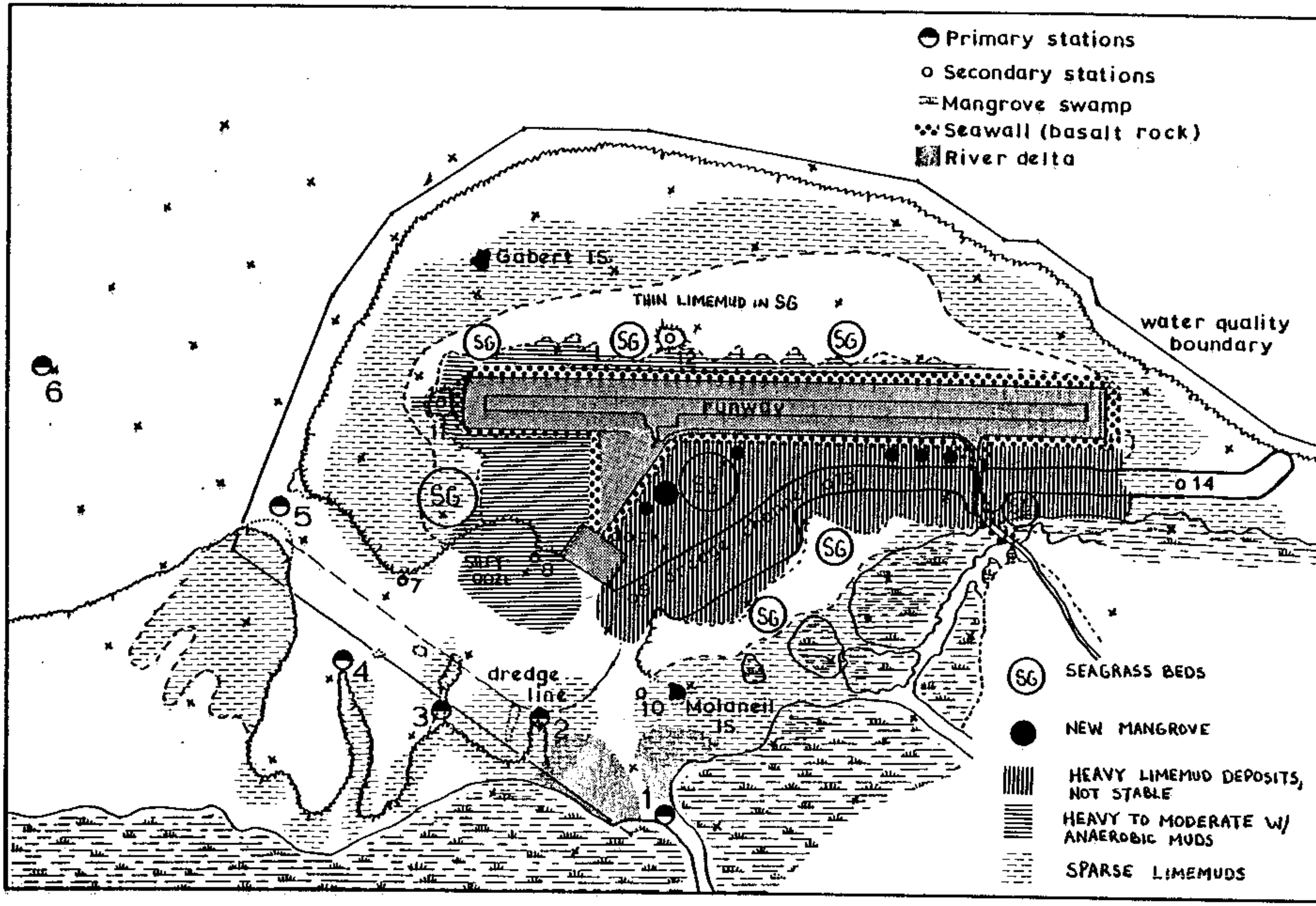

Figure 2. Physiographic changes, location of seagrass beds and lime-mud deposits at Okat harbor and surrounding reef.

OBJECTIVES

The objectives of the Part C Post-Construction WQ monitoring program were to:

1. Determine the Post-Construction marine WQ at stations established in the Part B monitoring program.

2. Compare the data and observations obtained for the Part C monitoring with Part B.

3. Identify any changes in marine WQ at Okat Harbor.

METHODS

Primary and secondary WQ stations established in the Part B monitoring program were sampled over a 4-day period from May 1 to 6, 1985. There were 6 sampling sets taken during this time period. Sampling sets were collected both in the morning and afternoons of May 2 and 3. Sampling times were designated to allow WQ samples to be taken for 2 rising tides, 2 falling tides and at 2 neap tide periods.

The water quality parameters and analytical techniques used in the Part C monitoring were similar to those used in the Part B monitoring program. The water quality parameters routinely measured were pH, temperature, salinity, turbidity, total non-filtrable residue (TNFR), volatile total non-filtrable residue (VTFR), dissolved oxygen (DO), total phosphorus (TP), ortho-phosphate (OP), total Kjeldahl nitrogen (TKN), total nitrogen (TN), nitrite + nitrate-nitrogen (NO) and ammonia-nitrogen (NH). Water quality parameters were analyzed in accordance to Standard Methods (APHA, 1980).

The water column at each station was sampled near the surface at a depth of -1 m. Samples were taken with a PVC Van Dorn sampler. Temperature was measured in the field. Turbidity, pH, TNFR, VTFR and DO were analyzed at the Kosrae Environmental Health Laboratory. The nutrient samples were frozen, transported in ice and analyzed at the WERI Laboratory in Guam. Field salinity measurements were taken with a hand-held refractometer. However, the refractometer was inadvertantly destroyed during initial sampling and salinity measurements were not taken for this monitoring program. The initial salinity measurements taken at stations 1 to 4 showed normal salinities for these stations under the prevalent meteorological conditions. Temperatures were taken with hand-held mercury thermometers for surface and -1 m water samples. Turbidity was nephelometrically measured with a model 2100A Hach

Turbidimeter. TNFR was measured by filtering a 1 liter (1) water sample through a glass fiber filter and drying at 105 degrees C for 24 hours. VTFR was measured by ashing the glass fiber filter at 550 degrees C for 1 hour. VTFR is a measure of the amount of organic matter contained in the suspended residue load of the water column. Subtracting VTFR from TNFR provides an estimate of the silt/clay and very fine sand component of the suspended residue. Table 1 presents the water quality parameters with methods and type and analysis. Abbreviations of water quality parameters found in the text and tables are shown in Table 1.

Heavy metal samples were collected from near surface (-1m) waters at primary and secondary water quality stations. All WQ stations were sampled for set 1 on May 1, 1985. Secondary stations 7 and 9 were also sampled for sampling sets 2 to 5. Stations 5 and 14 were sampled for set 6 on May 6, 1985. The samples were preserved with nitric acid and transported to the WERI Laboratory in Guam for analyses. The water sample for each station was analyzed for zinc (Zn), copper (Cu), lead (Pb), mercury (Hg), arsenic (As), Cadmium (Cd), Chromium (Cr) and Nickel (Ni). Total heavy metal concentrations were determined by atomic absorption with a Perkin Elmer 560 Atomic Absorption Spectrophotometer. Arsenic and Selenium were determined by cold vapor. All other metals were determined by electrothermal graphite furnace. Metals were analyzed according to United States Environmental Protection Agency (USEPA) methods of analyses (USEPA, 1979) and Standard Methods (APHA, 1980).

Wind direction and relative speed were measured at the beginning of each sampling set for all stations. Surface water current flow directions and estimated speeds were obtained at each sampling station by measuring the movement of fluorescein dye tracks. Water flow speeds were classified as slow or diffuse intermediate and fast. Slow flow speeds were recorded for dye tracks which moved a less than 5m per minute, while fast flow movements exceeded 10m per minute. Tidal cycle changes were noted with sampling sets taken for rising, falling and neap tides. The sampling schedule and tidal phase were as follows:

May 1 - morning between 0845 to 1105; low tide rising, 1m rise in about 5 hours.

May 2 - morning between 0805 to 0940; rising toward neap, less than .25m rise in 2 hours.

May 2 - afternoon between 1520 to 1750; strong falling, high tide was at 1430 with a 1.5m drop between 1500-1800.

May 3 - morning between 0845 to 0925; rising near neap, low at 0730 with .20m tidal change in 2 hours.

May 3 - afternoon between 1515 to 1600; falling at neap, high was at 1530.

May 6 - morning between 0815 to 0920; falling toward low, reef-flats exposed at 0900.

Table 1. Water quality parameters and methods of analyses. Abbreviations of parameters used in the text and tables are shown for each parameter.

Water Quality Parameter	Units	Parameter Abbreviation	Method	Type of Analysis
Turbidity	NTU	Turb	Turbidimeter	direct measurement with nephlometer
Total Non-filtrable Residue	mg/ℓ	TNFR	Standard Methods*	membrane dried at 105°C for 24 hr.
Temperature (surface) (at depth)	°C	Sur. Temp -1m Temp	Thermometer	mercury thermometer, 20-50°C
Salinity (surface) (at depth)	ppt	Sur. Sal -1m Sal	Refractive Index	hand-held refractometer, refractive index conversion to salinity (graphic)
pH	pH	pH	pH probe	Specific ion meter and combination probe
Dissolved Oxygen	mg/ℓ	DO/Dis. Oxygen	Standard Methods	Winkler titration
Total Nitrogen	mg/ℓ	TN	Standard Methods	calculation from other nitrogen data
Total Kjeldahl Nitrogen	mg/ℓ	TKN	Standard Methods	macro-Kjeldahl, digestion and distillation
Nitrate + Nitrite-Nitrogen	mg/ℓ	Nitrate/NO	Standard Methods	cadmium-reduction, nitrite determination
Ammonia-Nitrogen	mg/ℓ	Ammonia/NH	Solorzano, 1969	Indophenol technique
Ortho-Phoshorus	mg/ℓ	Ortho Phos/OP	Standard Methods	Ascorbic acid technique
Total Phosphorus	mg/ℓ	Total Phos/TP	Standard Methods	Ammonium persulfate and acid digestion, ascorbic acid

* Standard Methods - Standard methods for the examination of water and wastewater, 15th edition, 1980.

RESULTS AND DISCUSSION

General Physiographic Changes

New construction activities were underway during the Part C Post-Construction program. These activities included partial paving of the runway with asphalt, installation of power lines along runway and at the docking facility and placement of sewage pipe from docking facility back toward the island of Kosrae. There was a large stockpile of sand/fine gravel at the dock site. There had been some restoration work conducted along the runway adjacent to the channel which included primarily the transplating of the seagrass Enhalus (Figure 2). New mangrove shoots had established along he runway and adjacent to the dredge channel (Figure 2). The initial serial reconnaissance of the Okat area showed a generally poor WQ in relation to turbid water. The harbor had extensive turbidity plumes with high organic content (seagrass, mangrove and algal debris drift lines). The dredge channel was very murky with an observable heavy suspended sediment load. There had been heavy rainfall periods in the week prior to the Part C WQ monitoring period. These heavy rains probably contributed to the generally poor WQ within the Okat area. However, there was a distinctly more turbid water mass in Okat harbor and in the surrounding vicinity compared with other coastal regions around Kosrae.

A ground and boat reconnaissance was made of the Okat area prior to the Part C WQ monitoring. This survey was conducted to assess the extent of lime-mud deposition within Okat harbor, on the surrounding reef-flat complexes and in the adjacent mangrove fringe (Figure 2). These lime-mud deposits were a result of the construction project and were indicative of the extent of environmental degradation to the Okat area. Water masses moving off of the reef-flats adjacent to the dredge channel and on both sides of the docking facility were observed to contain considerable quantities of suspended lime-mud (silts/clays and organic detritus). These suspended loads were maximized during strong dropping tidal events. Additionally, in periods of strong tidal rise turbid waters penetrated the adjacent mangrove fringe. Lime-mud deposits, on the western reef-flat, particularly in pockets within the reef framework, were generally beginning to stabilize. Lime-mud deposits surrounding the runway were generally not stabilized. Although large areas of reef-flat were colonized by the blue-green alga Schizothrix which caused some substrata stabilization. A wedge of highly turbid water moved into and partly out-flowed from the dredge channel during tidal changes. This turbid water mass was essentially trapped within the confines of the dredge channel. Near station 14 within the dredge channel, there was abundant growth of the alga Halimeda. This algae is a major sediment producer. These Halimeda sediments were helping to stabilize the lime-mud deposits in the outer portions of the dredge channel. The seaward reef-flat northeast of the runway had zones of ticker lime-mud deposition near the runway. These deposits thinned toward the reef margin with occasional pockets (to .25m depth) of lime-mud along the outer reef-flat. Some of this lime-mud had been trapped within interstices of the reef-flat framework, while most had been flushed from the area. A high percentage of the small Porities coral heads adjacent the runway were dead. The outer reef-flat was primarily rubble deposits with few living corals.

Dredge samples were obtained from the harbor floor between secondary stations 7, 8 and 9 (Figure 2). These sediment samples were composed primarily of soft lime-muds and silty-ooze. In the Part B monitoring program sediment samples taken from these areas were composed of Halimeda plates and very fine sand-to gravel-sized reef derived debris and talus. Lime-mud deposits adjacent to the reef-flat edge near station 8 were measured at over 1m deep. These deposits were not stabilized and posed a long-term WQ degradation problem. Periodic resuspension of these lime-mud deposits along the upper harbor slopes will potentially affect WQ throughout the Okat area, causing stress to the marine biota (flora and fauna). At deeper depths, fish habitates can be altered or destroyed by these lime-mud deposits. This could reduce fish recruitment into the harbor. The continuously turbid water in the harbor causes reduced light penetration which decreases the depth of coral and algal growth.

WQ parameters were monitored at 6 primary and 4 secondary WQ stations. Six sampling sets were taken on 4 different days. Surface flow patterns and turbidity plumes for each sampling day are shown in Figures 3 (1 May 1985; set 1), 4 (2 May 1985; sets 2 and 3), 5 (3 May 1985; sets 4 and 6), and 6 (6 May 1985; set 6). Differences in surface flow patterns between rising and falling tides are shown in Figures 4 and 5. Sampling sets were taken during rising, falling and neap tidal events. Sampling sets coincided with periods of clear weather, light rains in mountains and heavy rainfall at Okat. Surf and wave conditions were moderate, mostly less than 1m. Therefore, the general hydrological and meteorological conditions encountered in the Part C monitoring period typified those conditions in the Part B sampling periods.

WQ Comparisons with Part B

Physical and chemical water quality (WQ) parameters at the monitoring stations were evaluated and regulated by the Part A Pre-construction turbidity standard (1.5 NTU) and the TTPI Marine Water Quality Standards (TTPI, 1978). See Appendix A 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) and heavy metals. The limits for temperature and salinity are "natural conditions" ±10 percent.

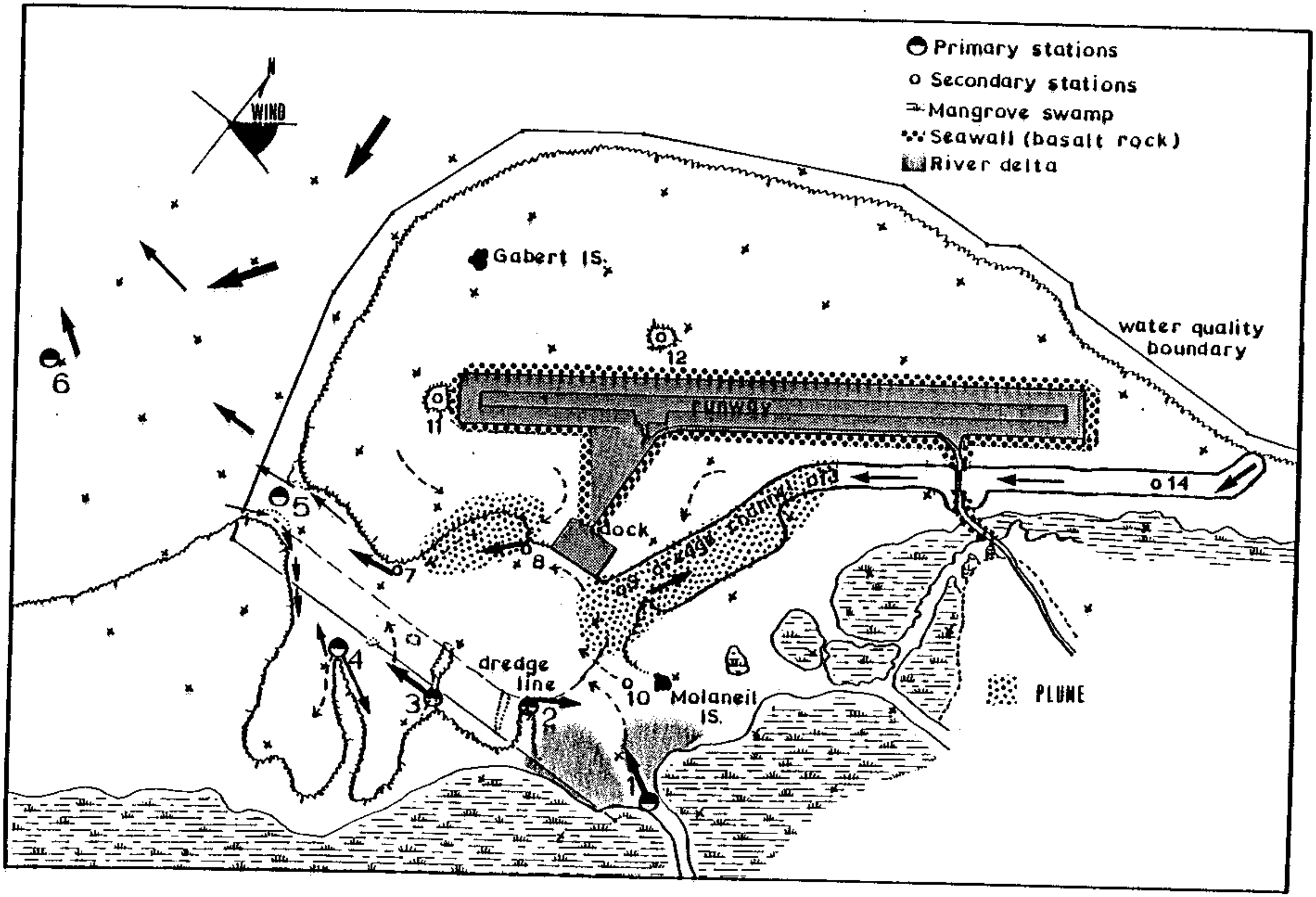

Figure 3. Extent of completed construction of airport and docking facility, general flow patterns, turbidity plumes and physiographic features on May 1, 1985.

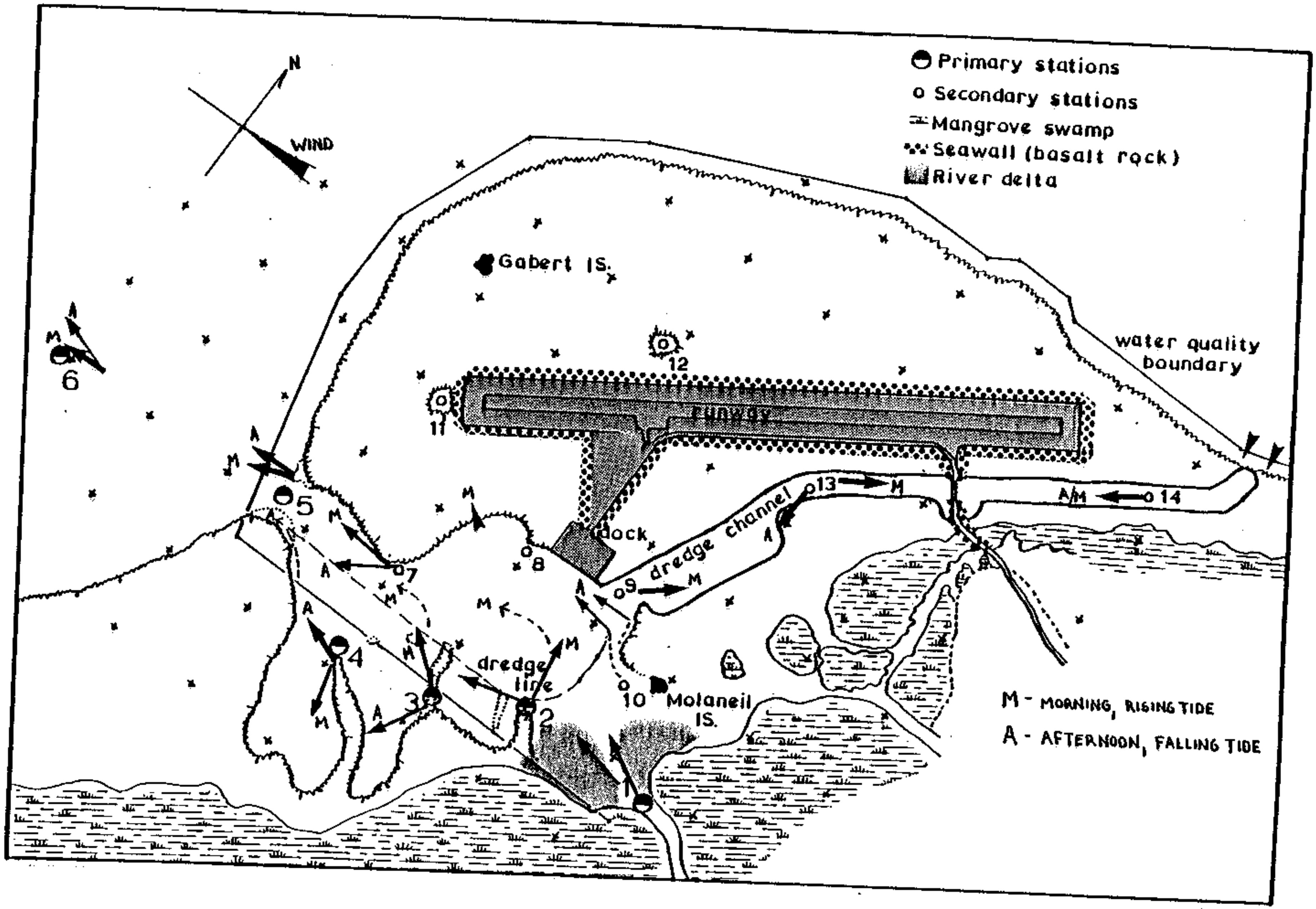

Figure 4. General flow patterns for sampling sets on May 2, 1985.

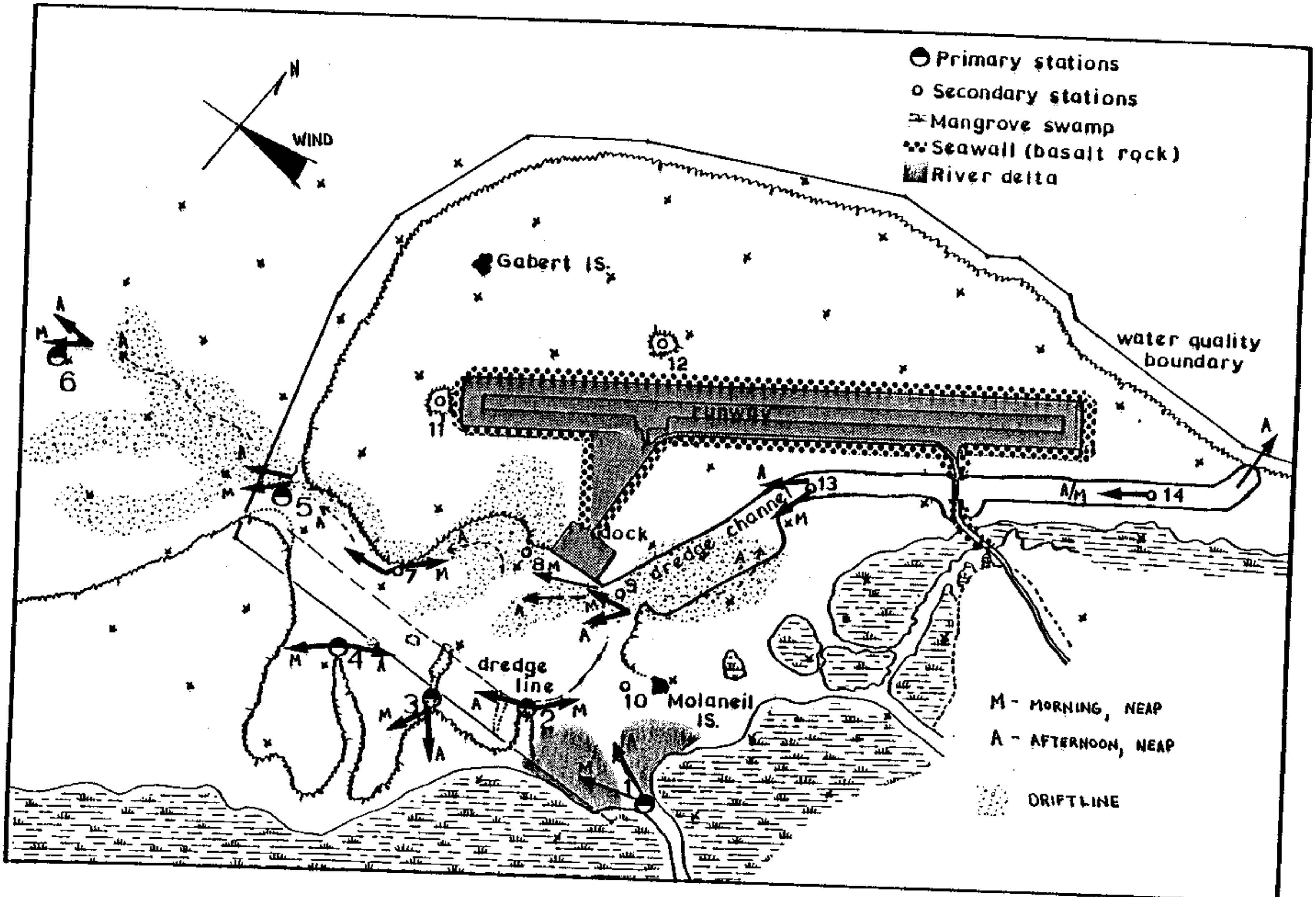

Figure 5. General flow patterns for sampling sets on May 3, 1985.

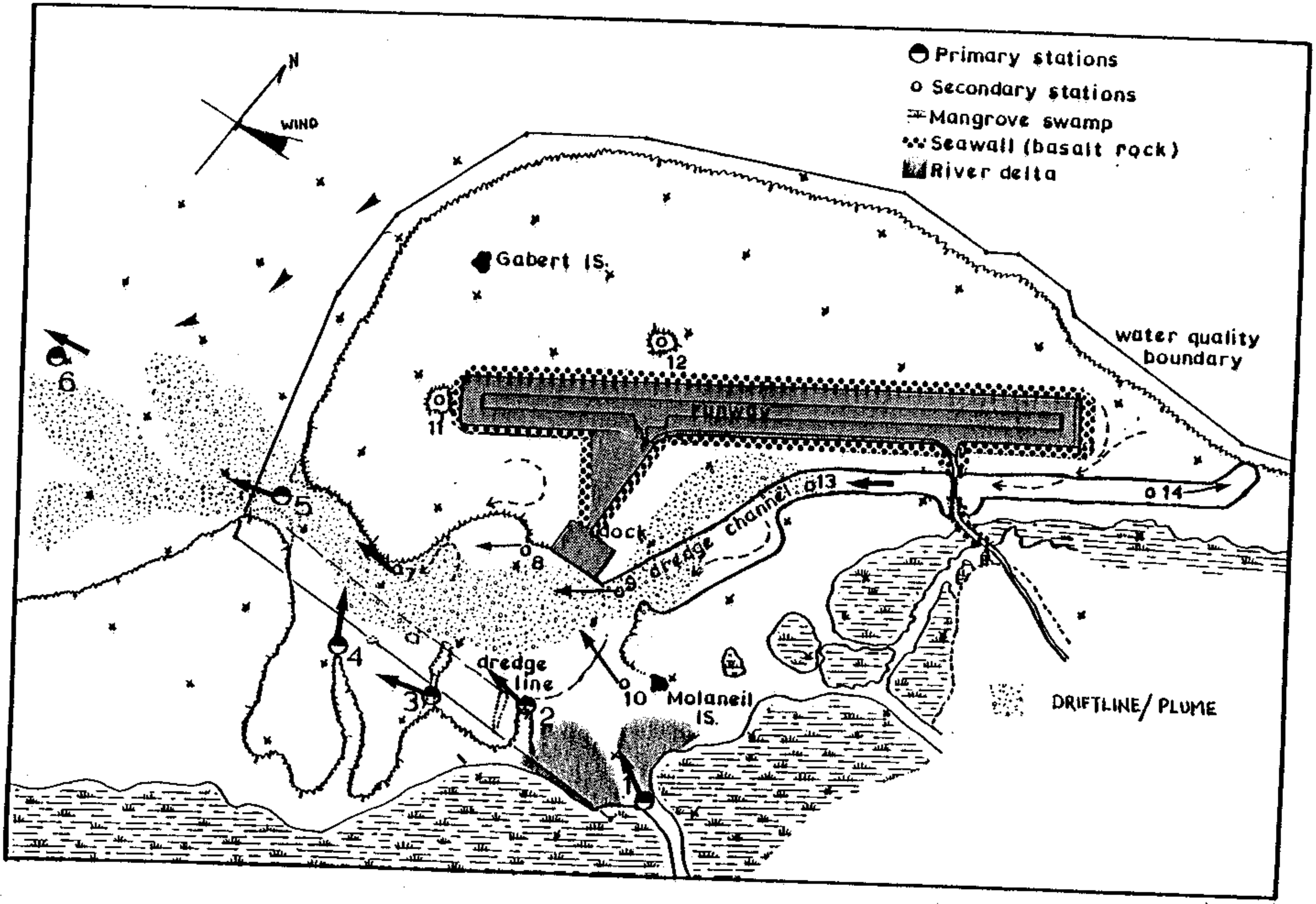

Figure 6. General flow patterns for sampling sets on May 6, 1985.

There were other water quality parameters analyzed which were not included in the TTPI water quality standards. These parameters were total Kjeldahl nitrogen, nitrate-nitrite-nitrogen, ammonia-nitrogen, ortho-phosphorus and total non-filtrable residue. Analyses of these parameters were made in order to provide a more comprehensive evaluation of nutrient and residue cycles in Okat harbor.

Results of the physical and chemical WQ parameter analyses for the WQ stations are shown in Tables 2 to 11. The wind direction and speed, as well as water flow direction and relative speed were measured at each station for all sampling sets (Tables 2 to 11). The water flow movement was classed as slow to diffuse, medium or fast. Water flow direction showed similar patterns to those recorded in the Part B monitoring periods. The wind was generally from the N to NE at speeds of 1 to 5 knots with occasional gusts to 10 knots. Mean values for WQ parameters were calculated in order to compare results of the Parts B and C monitoring programs (Table 12). Mean values of WQ parameters were used in the Part B program for WQ compliance assessments. Since the mean describes the central tendency of data, an average of WQ data for 6 sampling periods would provide a more realistic assessment of general WQ at a specific WQ station.

Turbidity means at primary stations 1, 2 and 3 exceeded the turbidity standard of 1.5 NTU. The mean at station 1 was 4.2 NTU with a range of 1.6 to 11 NTU. Since station 1 was located in the marine delta flood-plain of a major river discharge into Okat harbor, this high mean turbidity reflected natural changes and was not attributable to either past or present construction related perturbations. Throughout the Part B monitoring, mean turbidities at this station always exceeded the turbidity standard (Table 13). The previous lowest turbidity value measured at this station was 2.3 NTU, which occurred during a drought period. Station 2, which was located along the edge of a fringing reef adjacent to the marine delta flood-plain, and a mean turbidity of 2.0 NTU with a range of 1.5 to 2.7 NTU. This station did received periodic impacts from river discharges in periods of heavy runoff. It was also periodically inundated by turbidity plumes originating from the construction area. There were measurable deposits of lime-mud at this station which could be attributed to prior construction related activities. The higher turbidities at this station were caused in part, by resuspension of these lime-mud deposits. Station 3, which was located along the southeast edge of a patch reef, had a mean turbidity of 1.6 NTU with a range of 0.98 to 2.3 NTU. The northern edge of this patch reef was dredged during the construction phase. This dredge operation produced a substantial amount of sedimentation on the patch reef and the upper talus slopes. This station was frequently inundated by sedimentation plumes throughout the Part B construction period. The high mean turbidity at this station was related to resuspension of construction related sediments, including lime-muds and fine sands. Mean turbidities at stations 4, 5 and 6 were below the standard. Station 4 had a mean turbidity of 1.3 NTU with a range of 0.83

Table 2. Marine water quality at station 1.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0845	0805	1520	0845	1515	0815
Turb	11	2.4	2.3	5.3	1.6	2.4
TNFR	154	52	46	81	24	35
VTFR	48	30	18	38	0	5
S.Temp	26.5	27.5	29.5	28.0	29.5	28.4
-1mTemp	--	28.0	29.5	27.9	29.6	28.5
pH	7.50	7.60	7.92	7.55	8.00	7.65
DO	2.4	3.2	4.5	3.1	4.9	3.2
TN	.11	.09	.04	.09	.05	.10
TKN	.099	.076	.029	.076	.046	.076
NO	.016	.009	.009	.010	.006	.035
NH	.026	.011	.020	.023	.023	.007
TP	.042	.026	.055	.034	.025	.031
OP	.014	.014	.032	.018	.015	.022
Wind,Dr	90	360	90	360	90	80
Wind,Sp	3	0	1	0	1	1
Current*	300F	300F	290M	200S	290M	290F

* F - fast water movement
M - medium water movement
S - slow to diffuse water movement

Table 3. Marine water quality at station 2.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0905	0820	1530	0820	1520	0820
Turb	2.4	1.8	1.6	2.7	1.5	1.8
TNFR	27	33	16	40	11	18
VTFR	5	25	14	24	5	3
S.Temp	29.3	29.1	30.1	28.9	29.7	28.8
-1mTemp	--	29.3	30.0	29.0	29.5	29.3
pH	8.12	8.10	8.18	8.00	8.08	8.00
DO	5.0	5.2	4.7	4.9	5.7	4.0
TN	.07	.08	.07	.13	.07	.07
TKN	.058	.070	.064	.110	.058	.058
NO	.009	.011	.009	.016	.007	.010
NH	.017	.020	.011	.020	.020	.005
TP	.013	.020	.015	.024	.014	.018
OP	.009	.012	.011	.014	.009	.014
Wind,Dr	85	360	90	360	90	85
Wind,Sp*	4	0	1	0	1	2
Current	010S	345S	250M	040S	340S	275M

* M - medium water movement
S - slow to diffuse water movement

Table 4. Marine water quality at station 3.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0910	0830	1535	0830	1500	0830
Turb	1.7	2.0	1.4	2.3	0.98	1.5
TNFR	21	29	22	17	16	10
VTFR	6	19	9	6	2	0
S.Temp	29.6	29.3	30.1	29.0	29.6	29.3
-1mTemp	--	29.3	29.8	29.1	29.6	29.3
pH	8.12	8.18	8.22	8.10	8.18	8.10
DO	4.4	5.5	4.8	5.3	6.2	4.9
TN	.09	.06	.04	.06	.04	.08
TKN	.081	.052	.023	.052	.035	.064
NO	.011	.010	.013	.012	.008	.011
NH	.005	.013	.020	.030	.009	.011
TP	.011	.014	.010	.018	.013	.018
OP	.009	.009	.007	.011	.009	.011
Wind,Dr	83	90	90	90	90	85
Wind,Sp*	3	1	1	1	1	3
Current	245S	210M	210M	220S	140S	260M

* M - medium water movement
  S - slow to diffuse water movement

Table 5. Marine water quality at station 4.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0920	0835	1550	0835	1525	0835
Turb	1.2	1.6	1.3	1.8	0.90	0.83
TNFR	13	14	22	15	5	7
VTFR	1	7	12	9	2	2
S.Temp	29.6	29.0	29.6	28.6	29.5	29.3
-1mTemp	--	29.0	29.6	28.8	29.5	29.2
pH	8.18	8.15	8.30	8.12	8.20	8.16
DO	6.8	5.3	6.1	4.7	5.8	4.7
TN	.03	.09	.09	.05	.09	.01
TKN	.023	.076	.081	.035	.081	.006
NO	.011	.009	.008	.010	.011	.008
NH	.012	.015	.011	.009	.002	.006
TP	.011	.018	.009	.013	.008	.010
OP	.008	.014	.006	.012	.006	.006
Wind,Dr	70	80	90	90	90	75
Wind,Sp*	5	1	1	1	1	3
Current	130M	170S	280S	245M	070S	340M

* M - medium water movement
S - slow to diffuse water movement

Table 6. Marine water quality at station 5.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0930	0845	1615	0845	1530	0840
Turb	0.96	1.4	1.3	1.2	0.82	1.2
TNFR	18	20	9	15	9	8
VTFR	8	17	9	1	2	0
S.Temp	29.7	29.0	29.7	28.8	29.4	29.3
-1mTemp	--	29.5	29.2	29.1	29.3	29.4
pH	8.23	8.22	8.30	8.22	8.30	8.25
DO	5.2	5.7	6.3	5.8	6.8	5.5
TN	.09	.15	.02	.09	.02	.05
TKN	.076	.145	.017	.081	.012	.035
NO	.009	.009	.006	.010	.009	.010
NH	.004	.009	.025	.005	.005	.011
TP	.008	.011	.009	.013	.005	.012
OP	.006	.006	.005	.010	.006	.007
Wind,Dr	90	90	110	85	90	90
Wind,Sp	5	1	5	2	1	3
Current*	260F	270F	280F	250S	290S	255M

* F - fast water movement
M - medium water movement
S - slow to diffuse water movement

Table 7. Marine water quality at station 6.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0935	0850	1700	0850	1540	0850
Turb	0.72	0.84	0.86	0.93	0.68	0.83
TNFR	8	11	5	3	5	6
VTFR	0	9	3	0	0	0
S.Temp	29.3	29.5	29.3	29.0	29.3	29.4
-1mTemp	--	29.3	29.4	29.2	29.3	29.2
pH	8.30	8.32	8.32	8.32	8.36	8.30
DO	5.0	6.0	5.8	5.2	6.3	5.7
TN	.14	.04	.03	.14	.06	.14
TKN	.128	.035	.029	.134	.052	.128
NO	.010	.008	.003	.008	.009	.007
NH	.011	.004	.023	.004	.013	.018
TP	.009	.006	.013	.006	.008	.008
OP	.005	.005	.006	.007	.004	.005
Wind,Dr	90	90	90	90	90	85
Wind,Sp*	6	1	3	1	1	3
Current	220M	270S	280M	250S	300S	260S

* M - medium water movement
S - slow to diffuse water movement

Table 8. Marine water quality at station 7.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	0945	0905	1705	0855	1545	0855
Turb	1.4	1.5	1.6	1.3	1.3	1.6
TNFR	21	24	13	23	14	20
VTFR	5	9	12	3	4	5
S.Temp	29.8	28.5	29.4	28.8	30.3	29.2
-1mTemp	--	29.5	29.8	29.2	29.4	29.5
pH	8.12	8.28	8.30	8.25	8.22	8.25
DO	4.8	5.0	7.8	5.0	8.4	4.9
TN	.62	.08	.03	.09	.09	.08
TKN	.616	.029	.017	.076	.081	.041
NO	.008	.055	.013	.012	.010	.034
NH	.062	.005	.005	.031	.004	.024
TP	.013	.008	.009	.013	.009	.014
OP	.008	.007	.006	.010	.007	.011
Wind,Dr	93	100	90	90	90	85
Wind,Sp*	3	2	3	1	1	2
Current	260M	240S	240M	050S	300S	265M

* M - medium water movement
S - slow to diffuse water movement

Table 9. Marine water quality at station 9.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	1010	0920	1720	0910	1550	0905
Turb	1.2	1.2	2.2	1.8	2.3	1.7
TNFR	21	23	31	19	19	10
VTFR	10	20	30	11	9	3
S.Temp	29.4	29.4	28.8	29.3	29.8	29.5
-1mTemp	--	29.6	29.3	29.5	29.5	30.0
pH	8.28	8.22	8.38	8.28	8.25	8.22
DO	5.7	5.7	4.5	5.2	6.3	5.0
TN	.08	.08	.12	.08	.09	.07
TKN	.070	.064	.099	.076	.076	.064
NO	.011	.016	.016	.008	.009	.008
NH	.007	.026	.026	.009	.033	.026
TP	.006	.013	.024	.009	.013	.017
OP	.005	.006	.008	.007	.009	.007
Wind,Dr	85	80	90	90	90	90
Wind,Sp*	8	3	2	1	1	3
Current	090S	360S	280M	360S	295S	285S

* M - medium water movement
S - slow to diffuse water movement

Table 10. Marine water quality at station 13.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	1100	0925	1740	0920	1555	0910
Turb	0.82	1.5	2.3	1.3	1.7	2.6
TNFR	14	26	23	9	8	25
VTFR	2	22	1	0	0	11
S.Temp	29.7	29.7	29.3	29.4	29.5	29.7
-1mTemp	29.7	29.2	29.1	29.1	29.3	29.8
pH	8.34	8.30	8.39	8.22	8.32	8.30
DO	5.8	6.3	5.5	5.3	5.7	4.9
TN	.09	.16	.06	.09	.06	.10
TKN	.076	.151	.046	.076	.052	.064
NO	.010	.010	.009	.011	.007	.037
NH	.006	.011	.006	.071	.015	.009
TP	.005	.013	.007	.010	.010	.011
OP	.005	.008	.006	.008	.006	.008
Wind,Dr	90	90	95	90	90	70
Wind,Sp*	4	3	2	1	1	5
Current	190F	008S	185M	190S	190M	190S

* F - fast water movement
M - medium water movement
S - slow to diffuse water movement

Table 11. Marine water quality at station 14.

WQ PARAMETER	SAMPLING SETS 1	2	3	4	5	6
Time	1105	0940	1750	0925	1600	0920
Turb	0.65	1.2	1.2	0.95	1.0	0.88
TNFR	17	17	7	2	17	8
VTFR	7	12	5	0	7	3
S.Temp	29.6	29.5	29.3	29.1	29.3	29.8
-1mTemp	29.6	29.3	28.8	29.0	29.2	29.8
pH	8.38	8.42	8.32	8.32	8.42	8.35
DO	6.5	7.3	6.3	6.8	6.5	6.6
TN	.15	.05	.26	.27	.34	.35
TKN	.140	.041	.256	.256	.331	.343
NO	.008	.009	.008	.015	.008	.012
NH	.028	.011	.011	.038	.022	.088
TP	.006	.016	.009	.008	.008	.014
OP	.007	.006	.007	.012	.006	.018
Wind,Dr	90	90	105	85	90	80
Wind,Sp*	3	1	6	3	1	4
Current	190F	190S	225M	190S	190M	030S

* F - fast water movement
M - medium water movement
S - slow to diffuse water movement

Table 12. WQ parameter means for WQ stations.

WQ PARAMETER	WQ STATIONS 1	2	3	4	5	6	7	9	13	14
Turb	4.28*	2.0*	1.6*	1.3	1.1	0.81	1.5*	1.6*	1.7*	0.98
TNFR	65	24	19	13	13	6	19	21	18	11
VTFR	15	13	7	6	6	2	6	14	6	6
S.Temp	28.2	29.3	29.5	29.3	29.3	29.3	29.3	29.4	29.6	29.4
-1mTemp	28.7	29.4	29.4	29.2	29.3	29.2	29.5	29.6	29.4	29.3
pH	7.70	8.08	8.13	8.19	8.25	8.32	8.24	8.27	8.27	8.37
DO	3.2	4.9	5.2	5.6	5.9	5.7	6.0	5.4	5.6	6.7
TN	.08	.08	.06	.06	.07	.09	.17	.09	.09	.24
TKN	.067	.070	.051	.034	.061	.084	.143	.075	.077	.228
NO	.016	.010	.011	.009	.009	.007	.021	.011	.014	.010
NH	.018	.016	.015	.009	.010	.012	.022	.021	.020	.033
TP	.036	.017	.013	.012	.010	.009	.011	.014	.009	.010
OP	.019	.013	.009	.009	.007	.005	.008	.007	.007	.009

* exceeds the turbidity standard of 1.5 NTU.

Table 13. Comparison of mean WQ data for selected parameters between Parts B and C at primary and secondary WQ stations.

WQ PARAMETER	Station 1 B	Station 1 C	Station 2 B	Station 2 C	Station 3 B	Station 3 C	Station 4 B	Station 4 C	Station 5 B	Station 5 C
Turb	8.4	4.2	2.4	2.0	1.7	1.6	1.1	1.3	1.1	1.1
TNFR	179	65	45	24	32	19	33	13	29	13
S.Temp	28.4	29.2	28.8	29.3	28.9	29.5	29.0	29.3	29.0	29.3
-1mTemp	28.8	28.7	28.9	29.4	28.9	29.4	29.0	29.2	29.0	29.3
pH	7.75	7.70	8.08	8.08	8.13	8.13	8.14	8.19	8.15	8.25
DO	4.0	3.2	5.1	4.9	5.3	5.2	5.2	5.6	5.6	5.9
TN	.32	.08	.31	.08	.39	.06	.38	.06	.30	.07
TKN	.292	.067	.293	.070	.304	.051	.362	.034	.289	.061
NO	.023	.016	.016	.010	.016	.011	.012	.009	.007	.009
NH	.035	.018	.028	.016	.025	.015	.032	.009	.029	.010
TP	.149	.036	.121	.017	.071	.013	.069	.012	.086	.010
OP	.066	.019	.053	.013	.030	.009	.033	.009	.033	.007

WQ PARAMETER	Station 6 B	Station 6 C	Station 7 B	Station 7 C	Station 9 B	Station 9 C	Station 13 B	Station 13 C	Station 14 B	Station 14 C
Turb	0.54	0.81	1.6	1.5	2.3	1.6	3.8	1.7	1.1	0.98
TNFR	20	6	70	19	50	21	68	18	29	11
S.Temp	29.0	29.3	28.9	29.3	28.8	29.4	29.0	29.6	29.5	29.4
-1mTemp	29.1	29.2	29.0	29.5	28.9	29.6	29.0	29.4	29.3	29.3
pH	8.21	8.32	8.12	8.24	8.09	8.27	8.07	8.27	8.22	8.37
DO	5.7	5.7	5.4	6.0	5.5	5.4	5.5	5.6	5.3	6.7
TN	.28	.09	.40	1.7	.31	.09	.35	.09	.15	.24
TKN	.277	.084	.390	.143	.304	.075	.339	.077	.143	.228
NO	.003	.007	.012	.021	.009	.011	.011	.014	.011	.010
NH	.025	.012	.035	.022	.034	.021	.044	.020	.029	.033
TP	.104	.009	.125	.011	.138	.014	.140	.009	.196	.010
OP	.023	.005	.060	.008	.057	.007	.052	.007	.050	.009

to 1.8 NTU. The high turbidity value was caused by a turbidity plume which moved across the harbor and originated between stations 7 and 8. This turbidity plume was composed of resuspended silts/clay and organic detritus. Visual scans of the patch reef southeast of station 4 showed common pockets of lime-mud. These lime-mud deposits were generally trapped within the larger interstices of the reef framework. Station 5 had a mean turbidity of 1.1 NTU with a range of 0.82 to 1.4 NTU. There were very large turbidity plumes at this station during outflowing tides. These plumes contained extensive quantities of organic matter, particularly the seagrass Enhalus and the blue-green alga Schizothrix. Station 6 had a mean turbidity of 0.82 NTU with a range of 0.68 to 0.93 NTU. Secondary stations 7, 9 and 13 had mean turbidities in excess of 1.5 NTU. Higher mean turbidities were expected at these stations during the construction period. However, turbidities at these stations should have decreased to levels below 1.5 NTU at the completion of major construction. These higher turbidities indicate that these areas were still undergoing environmental degradation and being stressed a year after construction was completed. Resuspension of construction derived lime-muds was occurring throughout the northern edge of Okat harbor. Station 14 had a mean turbidity of 0.98 NTU with a range of 0.65 to 1.2 NTU. The lower turbidities at this secondary station were caused by the inflowing of cleaner oceanic waters coming across the reef margin near the seaward end of the dredge channel (Figures 3 and 4).

The physical WQ parameters (TNFR, VTFR, water temperature, pH and dissolved oxygen) showed no abnormal trends for coastal marine waters and were consistent with results obtained during Part B monitoring (Table 13). The highest mean TNFR was at station 1 with most (average 77%) of the residue as inorganic matter (silts/clay and fine sands). The lowest mean TNFR measurements were taken at station 6, which was the ocean control station (Table 7). The residue at station 6 had a low average organic content. The residue concentrations were similar at WQ stations 3, 4, 5 and 14 with mean TNFR values of 19, 13, 13 and 10, respectively. Residue at these stations was generally 50 percent organic. There were higher residue concentrations at secondary stations 7, 9 and 13 (Tables 8, 9 and 10). This residue contained white lime-muds and 30 to 60 percent organic detritus. Water temperatures were slightly lower at station 1 as a result of fresh water input from the river discharge. Surface temperatures at the remaining stations were similar and averaged from 29.2 to 29.6 degrees C. These temperatures were slightly higher when compared to Part B measurements taken under similar meteorological conditions. There was no significant changes in mean pH values at any of the stations. Dissolved oxygen concentrations were generally low at station 1 with a mean of 3.2 mg/l (Table 2). This DO was lower than generally associated with station 1. DO concentrations at the remaining stations averaged from 4.9 to 6.7 mg/l. There were high (supersaturated) DO concentrations in water samples taken near reef-flats and in the dredge channel for afternoon sampling sets, particularly at station 14 (Table 11).

Nutrient WQ parameters (TN, TKN, NO, NH, OP and TP) showed similar trends to thoses recorded for the Part B monitoring program (Table 13). Total nitrogen is composed of several nitrogen species which include organic and ammonia-nitrogen (=total Kjeldahl nitrogen) and nitrite-nitrate nitrogen. Nitrite-nitrogen is a readily convertible nitrogen species (to nitrate-nitrogen) and is generally measured at low levels in marine waters. The nitrate + nitrite-nitrogen levels at Okat were generally low (Table 12). The lowest mean values were in the open marine waters at station 6, while river water discharges produced higher mean levels at station 1. Ammonia- and organic-nitrogen concentrations were variable between different types of marine environmental systems. Mean ammonia-nitrogen concentrations were highest at secondary stations 7, 9, 13 and 14. TKN concentrations were generally high at all the WQ stations (Table 12). Ammonia-nitrogen concentrations were consistently much lower than the TKN values (Table 12). This means that most of the nitrogen in the marine water at Okat was in the form of organic-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 assessment of the nitrogen cycle influence at WQ stations.

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 species is used by marine biota in metabolic processes. Ortho-phosphorus was the primary component of the total phosphorus at most of the WQ stations (Table 12). Phosphorus, like nitrogen, is an essential nutrient for plant growth. As a result, ortho-phosphorus 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 caused by man-induced or natural perturbations can stress marine ecosystems. Stress in the ecosystem can be assessed by the ratio of nitrogen to phosphorus.

Nitrogen and phosphorus algae growth rate limitation can be evaluated by the ratio of total soluble inorganic nitrogen (TSIN=nitrate+nitrite- and ammonia-nitrogen to ortho-phosphate phosphorus. The maximum TSIN/ORTHO-PO mass ratio where nitrogen is still the limiting nutrient is 15/1 (Specht, 1975). The TSIN/ORTHO-PO mass ratios were calculated for each WQ stations. The maximum mass ration occurred at station 14 with an average of 6/1. These mass ratios were consistent with baseline values obtained in previous studies prior to construction perturbations (Cowan and Clayshulte, 1980).

Comparisons were made of mean WQ data for selected WQ parameters between Parts B and C monitoring programs (Table 13). These comparisons were made to assess general changes in marine WQ one year after the completion of the construction project. There were no significant differences in mean turbidities between Parts B and C at WQ stations 2, 3, 4, 5, 6, 7, and 14. There were decreases in mean turbidities for Part C at stations 1, 9 and 13. However, these apparent decreases in turbidity at these stations may not characterize the longer-term turbidity trends. These stations had very skewed data recorded for the Part B monitoring program which tended to raise their mean values (Clayshulte, 1986). In general, turbidity levels at WQ stations had not significantly decreased in the post-construction monitoring period. This indicated that construction perturbations had a long-term impact on marine WQ within Okat harbor and on the surrounding reef-flat complexes. The physical WQ parameters of temperature, pH and dissolved oxygen showed few significant changes. DO concentrations were higher at stations 9 and 14. Slight increases in mean pH were recorded at stations 7 and 9. Mean residue concentrations as measured by TNFR were lower at all WQ stations. These mean TNFR levels measured for Part C were consistent with mode levels measured for Part B. In general, the physical WQ parameters measured in the Part C monitoring were consistent with Part B WQ data. Nitrogen and phosphorus concentrations were generally lower when compared with Part B mean data. However, comparisons made with Part B modes show consistent results. The highest nitrogen concentrations occurred at station 14 (Table 13). Total phosphorus concentrations are significantly lower during Part C monitoring. The Part B TP data was very skewed and mean values were much higher than mode values.

<u>Heavy Metals</u>

Concentrations of heavy metals in marine waters at Okat harbor were determined in May, 1985 (Table 14). The heavy metals analyzed were arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn).

Mercury exceeded the TTPI marine WQ standard at WQ stations 2, 5, 6, 7, 9, 13, and 14. Mercury concentrations were below the standard at WQ stations 1, 3 and 4. Nickel exceeded the standard at station 2. This higher nickel concentration was probably related to river discharge. The remaining heavy metals were below the marine WQ standards. Station 1 near the river discharge generally had higher concentrations of heavy metals, particularly Ni and Zn, compared with other WQ stations (Table 14). Heavy metal enrichment was recorded for station 1 throughout the Part B monitoring (Clayshulte, 1986).

Five consecutive heavy metal samples were taken at stations 7 and 9 (Table 14). These samples were collected to assess the fluctuation of metals in marine water near previous construction areas. Excessive Hg occurred at station 7 only once with the remaining samples having Hg concentrations below detection limits. Station 9 had excessive Hg for 3 samples. These higher Hg levels were associated with more moderate tidal

TABLE 14. Concentration of heavy metals in marine water at Okat harbor, May 1985.

WQ SITE	DATE	TIDE CHANGE	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
			HEAVY METAL (ug/l)							
1	1May	Rise	0.3	0.20	0.3	2.0	<0.1	1.5	0.56	17
2	1May	Rise	2.3	0.12	0.6	1.4	14	11*	0.22	3.3
3	1May	Rise	0.8	0.09	0.3	1.2	<0.1	0.8	0.26	4.0
4	1May	Rise	2.0	0.13	0.3	1.3	<0.1	0.9	0.38	12
5	1May	Rise	1.0	0.13	0.3	3.3	12*	0.8	0.52	14
5	6May	Fall	1.9	0.11	0.9	1.1	<0.1	0.7	0.30	4.0
6	1May	Rise	1.2	0.05	0.2	1.1	2.0*	0.6	0.90	7.6
7	1May	Rise	2.0	0.06	0.4	1.8	<0.1	0.8	0.26	4.3
7	2May	Rise	1.6	0.10	0.2	1.0	<0.1	0.9	0.90	6.6
7	2May	Fall	3.4	0.13	1.1	1.3	<0.1	0.9	0.38	9.4
7	3May	Neap	3.8	0.06	0.3	0.6	<0.1	0.6	1.4	3.0
7	3May	Neap	1.5	0.07	0.1	1.2	1.3*	0.7	0.30	8.2
9	1May	Rise	1.8	0.21	1.0	1.4	1.1*	0.7	0.30	14
9	2May	Rise	2.2	0.13	0.8	1.4	<0.1	0.9	0.34	10
9	2May	Fall	6.8	0.07	0.3	1.2	<0.1	0.9	0.30	10
9	3May	Neap	2.0	0.10	0.7	2.0	8.7*	1.2	0.38	9.7
9	3May	Neap	3.4	0.08	0.3	1.2	0.2*	1.3	1.0	4.3
13	1May	Rise	1.8	0.08	1.9	1.3	0.8*	0.6	0.30	6.0
14	1May	Rise	1.7	0.05	0.2	1.8	<0.1	0.9	0.22	6.6
14	6May	Fall	4.6	0.05	0.2	1.0	0.2*	0.6	0.30	2.4
TTPI Marine WQ Standard			10.0	5.00	50.0	10.0	0.10	2.0	10.0	20.0

*exceeds TTPI Standard

changes where currents in the dredge channel were reduced. An excessive Hg concentration occurred at station 5 on a rising tide. This sample was taken when there was an extensive sedimentation plume in the harbor mouth which extended outward to station 6. Station 6 also had a high Hg concentration at this time. This plume contained resuspended lime-muds which had originated from the construction area. There still appears to be a Hg contamination problem occurring at Okat.

Previous water analyses showed that the Okat area had total mercury concentrations in excess of the TTPI standard throughout the construction project (Clayshulte and Zolan, 1985; Clayshulte, 1986). There was no obvious low level chronic mercury source located at the construction site in Part B monitoring. Clayshulte and Zolan (1985) anticipated that most excess mercury in Okat marine waters would become bound within marine sediments. There would be only small amounts of Hg released into the water column by micro-organism methylation. However, there was periodic release of excessive Hg into marine waters above expected levels. This Hg contamination appears to be associated with the lime-mud deposits, particularly the area between the dredge channel and the airport runway. Assuming that there is no longer a chronic mercury source associated with the airport and dock construction project, mercury levels in Okat marine waters should return to normal background levels.

SUMMARY

The Part B Construction monitoring program at Okat harbor showed a degradation of marine water quality (WQ) around the airport runway, docking facility, harbor system and surrounding reef-flat complexes. The major impact was caused by increased turbidity levels attributed to dredge and fill construction operations (Clayshulte, 1986). The Part C Post-construction monitoring program showed few significant decreases in physical, chemical or heavy metal WQ parameters compared to Part B. Turbidity levels were generally unchanged at the WQ stations. This indicates that previous construction perturbations had a long-term impact on marine WQ within Okat harbor and on the surrounding reef-flat complexes. The heavy metal Hg was still a WQ problem with excessive levels occurring throughout the Okat area.

The overall WQ within Okat harbor was poor during the Part C Post-construction monitoring. This was due primarily to the turbid water mass in the area. Although part of this higher turbidity could be attributed to natural conditions, it was evident that resuspension of construction derived lime-muds had increased turbidity levels. The restricted water circulation within Okat harbor and in the dredge channel has hindered

the removal of the silty-ooze and lime-mud deposits to deeper off-shore waters. Accumulations of lime-muds deposited in the shallow waters adjacent to the runway and docking facility and in the dredge channel were easily resuspended into the water column by normal tidal changes and hydrographic conditions, which occurred in Part C monitoring. These resuspended turbidity plumes impacted large areas of the harbor complex and mangrove system, including periodic influence on the off-shore control site. It is anticipated that these lime-mud deposits will eventually become stabilized, which will minimize resuspension. However, there may be a long-term period required for this stabilization. Therefore, the marine ecosystem in Okat harbor will undergo some modification as a result of this long-term stress.

CONCLUSIONS

1. Turbidity was the analyzed parameter most affected by the construction activities. Turbidity is also easy to do and in expensive.

2. Turbidity is a measure of suspended material, principally lime mud, which was derived from construction activities.

3. This suspended material presents both a short term and a long term potential for environmental degradation. Suspension of the material during construction provides stress on the environment. Further, resuspension of settled material provides for more long term environmental stress. Part B monitoring demonstrated numerous violations of the Water Quality Standard for turbidity. Part C monitoring also demonstrated violations of the Water Quality Standard for turbidity. This is caused by resuspension of non stabilized sediments in response to water currents and turbulence. It is expected that eventually the construction derived sediments will consolidate and stabilize. This will take considerable time, however.

4. The creation of sediments is an undesirable, but unavoidable consequence of dredge and fill activity. It is probably preferable that these materials rapidly make their way to deep water. Transport to deep water will minimize resuspension problems and impact in the lagoon and coastal areas.

5. Measures need to be provided early in a project, perhaps before the initiation of construction to ensure good water circulation at the work site and, optimally, good exchange with deep water.

6. It was noted that turbidity elevations, apparently related to turbidity plumes produced at the work site, occurred at the offshore control site. It may be that at these times good transport was occurring to deep water and that these times represented a desirable condition.

7. Mercury (Hg) levels were elevated at several stations during the Part B and Part C phases. It is unclear whether these elevations represented increases due to construction activities. Mercury levels were also elevated at the control station. The control station may have been located at a site which was influenced by construction activities.

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APPENDIX A

Table A1. 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 (ratio)	--	----------[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, TU	Normal ±5%	Normal ±10%	Normal ±20%
Heavy Metals:				
Arsenic	µg/l	10.0	All marine water classess have the same standards	
Copper		10.0		
Lead		10.0		
Mercury		0.10		
Zinc		20.0		
Nickel		2.0		
Chromium		50.0		
Cadmium		5.0		