

**WATER QUALITY MONITORING PROGRAM  
PALAU AIRPORT PROJECT  
NGURUSAR BAY  
BABELTHUAP ISLAND  
PALAU DISTRICT  
TRUST TERRITORY OF THE PACIFIC ISLANDS  
PART A  
PRE-CONSTRUCTION**

Charles J. Romeo  
William J. Zolan  
Stephen J. Winter

*Water Resources  
Research Center*

**UNIVERSITY OF GUAM**

Technical Report NO. 12

January, 1981



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for

CONTRACT NO. N62742-80-0002, PART A

Department of the Navy  
Pacific Division  
Naval Facilities Engineering Command



Aerial photpgraph of the dredge site in Ngurusar Bay (Refer to Figures 2 and 3 in text).

## EXECUTIVE SUMMARY

The Palau Airport located at Babelthuap Island, Palau District, Trust Territory of the Pacific Islands (TTPI), is being improved and developed. The project will require the dredging of coral fill material from a 30-acre site located at Ngurusar Bay, Airai Village, on Babelthuap Island. Approximately 300,000 cubic yards of coral fill will be dredged using dragline methods.

It is required that the dredging activity be controlled and that protection be provided so that waters outside of the Water Quality Boundary, defined as 200 feet outside of the dragline limits, are not degraded below the water quality standards of the TTPI.

To satisfy this requirement (in accordance with U.S. Navy Contract No. N62742-80-C-0002) eight water quality monitoring stations were established along the outside perimeter of the Water Quality Boundary. A sampling program was set up to determine baseline water quality prior to the start of dredging operations. For this objective, water samples were collected daily from December 20, 1979 - January 11, 1980 (December 24 and 25 excepted) and analyzed for turbidity (NTU), suspended solids, dissolved oxygen, temperature, salinity, and pH. One time measurements were made for total nitrogen, total phosphorus and the following metals: arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

During the sampling period turbidity ranged from 1.1 to 3.9 (NTU) at the water quality monitoring stations. Statistical analyses of the data showed that turbidity levels at stations 1 through 7 were essentially the same. Station 8 had higher turbidities, most likely due to its shallow location on the reef flat. Based on the turbidity data collected, a turbidity standard of 5 NTU is recommended for the waters outside the Water Quality Boundary.

Water temperatures at the stations ranged from 26.6 to 31.9°C. pH values ranged from 7.45 to 8.01 with a study area mean of 7.85. Salinity ranged from 28.8 to 35.5 parts per thousand ( $^0/_{00}$ ) with a mean of 31.4  $^0/_{00}$ .

Total phosphorus ranged from 0.003 to 0.011 mg/l. Total nitrogen ranged from 0.011 to 0.257 mg/l. Both total phosphorus and total nitrogen concentrations fall within the TTPI Water Quality Standards for these waters.

Dissolved oxygen concentrations ranged from 3.82 to 10.73 mg/l with a mean of 5.91 mg/l.

Suspended solids ranged from below 0.1 mg/l to 12.6 mg/l with an overall mean of 2.4 mg/l. The ratio of turbidity (NTU) to suspended solids was from .41 to .62.

Concentrations of arsenic, cadmium, copper, and zinc were either below detectable limits and/or below the TTPI Water Quality Standards. Nickel concentrations ranged from 0.2 to 5.8  $\mu\text{g}/\text{l}$ . Mercury concentrations ranged from below 0.1  $\mu\text{g}/\text{l}$  to 1.7  $\mu\text{g}/\text{l}$ . A few of the higher mercury and nickel concentrations measured were in excess the TTPI Water Quality Standards for these metals. Chromium concentrations ranged from 46 to 67  $\mu\text{g}/\text{l}$  with an average (56  $\mu\text{g}/\text{l}$ ) above the 50  $\mu\text{g}/\text{l}$  water quality standard for chromium. Lead concentrations ranged from 160 to 375  $\mu\text{g}/\text{l}$  well exceeding the 10  $\mu\text{g}/\text{l}$  water quality standard for lead. An earlier sampling and analysis (by a different laboratory) for these metals also reported lead concentrations in excess of 200  $\mu\text{g}/\text{l}$ .

## TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES. . . . .	vi
LIST OF TABLES . . . . .	vii
INTRODUCTION . . . . .	1
OBJECTIVES . . . . .	1
SCOPE. . . . .	1
METHODS. . . . .	2
Sampling Station Descriptions . . . . .	2
Chemical and Physical Analyses. . . . .	3
Meteorological Data . . . . .	6
RESULTS AND DISCUSSION . . . . .	6
Turbidity . . . . .	6
Suspended Solids. . . . .	8
Dissolved Oxygen. . . . .	8
Salinity. . . . .	9
Temperature . . . . .	9
pH. . . . .	9
Total Phosphorus. . . . .	9
Total Nitrogen. . . . .	10
Heavy Metals. . . . .	10
Comparison of Water Quality with the TTPI Water Quality Standards for Class AA Waters . . . . .	11
Previous Studies. . . . .	12
RECOMMENDED TURBIDITY STANDARD . . . . .	12
SUMMARY. . . . .	13
ACKNOWLEDGEMENTS . . . . .	14
LITERATURE CITED . . . . .	15
FIGURES. . . . .	16
TABLES . . . . .	22

## LIST OF FIGURES

	<u>Page</u>
1. Location of dredge site [adapted from Environmental Consultants, Inc. (1978)]. . . . .	16
2. Location of Water Quality Boundary [adapted from Environmental Consultants, Inc. (1978)]. . . . .	17
3. Location of the eight water quality stations in vicinity of dredge site [adapted from Environmental Consultants, Inc. (1978)]. . . . .	18
4. Location of the control water sampling station (No. 9) in outer Ngurusar Bay [adapted from Environmental Consultants, Inc. (1978)]. . . . .	19
5. Probability distribution of turbidity measurements at the eight water quality stations. . . . .	20
6. Bar graph of turbidity measurements at the eight water quality stations . . . . .	21

## LIST OF TABLES

	<u>Page</u>
1. Meteorological data from December 19, 1979 to January 11, 1980. . . . .	22
2. Turbidity measurements at the Water Quality Monitoring stations. . . . .	23
3. Turbidity measurements at station 1 according to tidal state . . . . .	25
4. Suspended solids measurements at the water quality monitoring stations . . . . .	26
5. Ratio of mean turbidity to mean suspended solids at the water quality monitoring stations . . . . .	28
6. Dissolved oxygen measurements at the water quality monitoring stations . . . . .	29
7. Salinity measurements at the water quality monitoring stations. . . . .	31
8. Temperature measurements at the water quality monitoring stations. . . . .	33
9. pH measurements at the water quality monitoring stations. . . . .	35
10. Total phosphorus and total nitrogen measurements at the water quality monitoring stations . . . . .	37
11. Heavy metal concentrations of samples collected April 1, 1980 at the water quality monitoring stations . . . . .	38
12. Comparison of water quality at the water quality monitoring stations with the Trust Territory water quality standards for Class AA waters . . . . .	39
13. Water quality data collected during the Environmental Consultants, Inc. (1978) survey . . . . .	40

## INTRODUCTION

The Palau Airport located at Babelthuap Island, Palau District, Trust Territory of the Pacific Islands (TTPI), will be improved and developed to enhance safety and reduce maintenance costs. The project includes the construction of a 7,200 by 150-foot paved runway with associated taxiway, markings, and lighting.

The project will require the dredging of coral material from a 30-acre site located at Ngurusar Bay near Airai Village on Babelthuap Island (Figure 1). Approximately 300,000 cubic yards of coral fill will be dredged using dragline methods.

It is required that the dredging activity be controlled and that protection be provided so that waters outside of the Water Quality Boundary (Figure 2), defined as 200 feet outside of the dragline limits, are not degraded below the water quality standards of the TTPI.

This study of water quality prior to construction was requested by the U. S. Navy in accordance with Contract No. N62742-80-C-0002, Part A. It is the first part of a two part water quality monitoring program which consists of:

1. Part A. Pre-Construction Monitoring Program
2. Part B. Construction Monitoring Program

## OBJECTIVES

The objectives of this study are to:

1. Obtain, prior to construction, water quality information for the dredge site.
2. Develop a turbidity standard to be used for controlling water quality changes caused by construction activity.

## SCOPE

In order to accomplish the objectives of this study, the Water Resources Research Center was directed to:

1. In coordination with the Trust Territory Environmental Protection Board (TTEPB), establish a minimum of eight water sampling stations at the dredge site. Locate the sampling stations outside the Water Quality Boundary such that they are accessible and usable during the duration of dredging activity.



2. Conduct on-site surveys and adequate field and laboratory studies to establish a water quality baseline for the following parameters at the sampling stations cited in the preceding paragraph: turbidity, suspended solids, dissolved oxygen, temperature, salinity, pH, total nitrogen, total phosphorus, lead, mercury, zinc, copper, arsenic, nickel, cadmium, and chromium.
3. Compile and summarize the water quality data using statistical methods to establish a baseline for each and all stations. Indicate the effect of tidal change, time of day, and water depth on the water quality of the study area. Incorporate the water quality data from previous studies where appropriate.
4. Develop a standard for turbidity that is consistent with the TTEPB Standards of Water Quality for the Waters of the TTPI. Provide the basis and rationale for the standard recommended.

## METHODS

### Sampling Station Descriptions

Eight water sampling stations were established such that monitoring of water quality in predominant currents away from the dredge site would be possible. In addition, a control station was established in an area that is expected to be unaffected by dredging activity. All stations were selected in coordination with the TTEPB.

Environmental Consultants, Inc. (1978) indicate that the predominant current away from the dredge site is through the narrow channel between Garayamu and Garreru Islands (Figure 2). Wind and tides are the two main forces governing this current with a net flow out of Ngurusar Bay driven by the predominantly east and northeast winds. Little flushing occurs in the shallow area over Ngurusar Reef flat (Figure 2) east of the dredge site. Portions of this reef flat become exposed during low tides. Observations during the present study indicate that some flushing may also occur through Garusaru Channel (Figure 2) south of the dredge site.

The eight sampling stations (1-8) in the vicinity of the dredge site were located on an east-west line with station 1, the western-most, being adjacent to the mouth of the channel between Garayamu and Garreru Islands; station 8, the eastern-most, is on Ngurusar Reef flat east of the main channel (Figure 3). These stations were positioned approximately 100 meters south of the southern-most limit of the dredge site. The distance between stations 1 and 7 is approximately 400 meters and station 8 is an additional 400 meters onto the Ngurusar Reef flat east of station 7.

A control station (9) was located approximately 2 kilometers east of the dredge site (Figure 4). This station is in approximately the same location as station 14 used by Environmental Consultants, Inc. (1978).

All stations except 1, 3, and 6 were buoyed to insure relocatability. Stations 1, 3, and 6 were in the middle of existing channels and were located by aligning landmarks with one's position along the east-west station line. Following are the locations of the nine water sampling stations (Figures 3 and 4):

Station 1 - is located in the channel between Garayamu and Garreru Islands.

Station 2 - is off the margin of the fringing reef of Garreru Island at an average depth of 2.9 meters.

Station 3 - is in the middle of Garusaru Channel between the Garreru Reef and the southern end of Middle Reef at an average depth of 6.9 meters.

Station 4 - is off the western margin of Middle Reef at an average depth of 6.9 meters.

Station 5 - is off the eastern margin of Middle Reef at an average depth 3.0 meters.

Station 6 - is in the middle of East Channel between station 5 and station 7 at an average depth of 7.2 meters.

Station 7 - is off the western margin of the Ngurusar Reef flat at an average depth of 3.2 meters.

Station 8 - is approximately 400 meters east of station 7 on the Ngurusar Reef flat in an eel grass bed at an average of 0.9 meters.

Station 9 - is approximately 2 kilometers east of the dredge site in an area of deeper water beyond the Ngurusar Reef flat at an average depth of 6.4 meters.

#### Chemical and Physical Analyses

Water quality parameters were measured daily from December 20, 1979 to January 11, 1980, except December 24 and 25, for the following: turbidity, suspended solids, dissolved oxygen, temperature, salinity, and pH. This was a total of twenty-one days. One time measurements

were made for total nitrogen, total phosphorus, and the following heavy metals: lead, mercury, zinc, copper, arsenic, nickel, cadmium, and chromium.

Water samples were collected by Van Dorn water sampler (3.2 liter capacity) and taken to the Environmental Health Laboratory in Koror for analysis that same day. All surface samples were taken at a depth of 1 meter except at station 8 where the average depth was 0.9 m, in which case one-half the depth was used. At stations 3, 6, and 9, where the depth was greater than 4 meters, a bottom sample was also taken at one meter above the bottom. Samples for turbidity, suspended solids, and pH were stored in an insulated container until returned to the lab. The nutrient samples, total nitrogen and total phosphorus, were collected and frozen for shipment to the Water Resources Research Center Laboratory on Guam. The heavy metal samples were collected in specially cleaned 1 liter plastic bottles and fixed with 5 ml of nitric acid for shipment to the Water Resources Research Center Laboratory on Guam.

At each station, depth was measured with a lead-line marked in 0.05 meter increments and the time of day recorded. The first sample removed was always for dissolved oxygen followed by 500 mls for suspended solids and 250 mls for pH and turbidity measurements. The dissolved oxygen sample was fixed immediately while temperature and salinity were measured directly in the Van Dorn sampler with the remaining water. Temperature was measured by mercury thermometer and salinity was measured by a YSI model 33 S-C-T meter and probe.

Nephelometry was used to obtain turbidity data at the eight water quality stations and control station. A Hach Chemical Company model 16800 turbidimeter was used for the analysis and results were expressed in nephelometric turbidity units (NTU).

The following modified technique for suspended solids determination of seawater samples was used in order to eliminate interference from dissolved salts. A previously washed, dried, and weighed 5.5 cm Reeve Angel 934 AH glass fiber filter was pre-wet with distilled water and then a 500 ml seawater sample was filtered. The filter was then washed with 2 x 50 ml of distilled water. At this point a significant amount of salt was still remaining in the edges of the filter covered by the Millipore filtering apparatus. To remove this salt the top of the filtering apparatus was removed and the edges of the filter rinsed under vacuum with about 10 mls of distilled water applied with a squeeze bottle. Under vacuum, only the edge of the filter was washed and none of the material on the filter disturbed. The filters were dried at 105°C overnight, desiccated, and weighed on an analytical balance accurate to tenths of milligrams. This provided satisfactory results. Initially, erroneously high suspended solids concentrations were obtained due to salt retention on the filters. These initial four days of data for suspended solids are not included in this report.

Dissolved oxygen was measured by the azide modification of the Winkler titration as outlined in Standard Methods (1975). An Orion Research Ionalyzer Model 407A with a combination electrode was used to measure pH.

Total kjeldahl nitrogen (TKN) was determined by macrodigestion-distillation and nesslerization. The nitrite plus nitrate-nitrogen ( $\text{NO}_2 + \text{NO}_3\text{-N}$ ) concentration was determined by cadmium reduction. The values for TKN and  $\text{NO}_2 + \text{NO}_3\text{-N}$  were added to obtain total nitrogen (TN). Total phosphorus (TP) was determined by persulfate digestion and ascorbic acid reduction. These procedures were performed as outlined in Standard Methods (1975).

Samples for heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) were collected from 1 meter below the surface with the Van Dorn water sampler. One liter samples were passed into 1 liter linear polyethylene bottles which had been precleaned by soaking them in "Nochromix" acid overnight then rinsed with distilled-deionized water. Five milliliters of "ultrex" grade nitric acid were added to each sample as a preservative. The samples were stored at 4°C until the analyses could be completed at the Water Resources Research Center. The initial set of metal samples collected December 21, 1979 were disregarded due to suspected errors in sampling or analyses and a second set was collected April 1, 1980.

The metal samples were analyzed on a recently installed and calibrated Perkin-Elmer model 560 atomic absorption spectrophotometer equipped with a Perkin-Elmer HGA2200 graphite furnace and a Perkin-Elmer MHS-10 mercury/hydride generation system. Methods of analyses were selected from Methods for Chemical Analysis of Water and Wastes (EPA, 1979). These methods were modified if necessary by procedures outlined in the Perkin-Elmer analytical technique manuals that accompany the instruments. The method of standard additions was routinely employed in those analyses where seawater samples were injected directly into the furnace without matrix modification. Also, for direct injection analyses, background correction was utilized throughout.

Arsenic analysis was performed on predigested sample aliquots (200 mL each) digested according to EPA method 206.5 (EPA, 1979). The digested samples were then analyzed using the hydride generation system (Sodium Borohydride method) as presented in the Perkin-Elmer analytical manual for the MHS-10 system (Perkin-Elmer, 1978).

Mercury analysis was by the cold vapor technique as presented in the Perkin-Elmer analytical manual (Perkin-Elmer, 1978). Aliquots of sample (100 mL each) were first predigested according to EPA method 245.2 using additional amounts of potassium permanganate and hydroxylamine hydrochloride solutions (25 mL each).

Copper and zinc were analyzed directly in the HGA2200 graphite furnace without prior sample pretreatment. Chromium was also analyzed by injection into the graphite furnace after the addition of calcium nitrate and hydrogen peroxide according to EPA method 218.2 (EPA, 1979). Sample spurring (during the drying state) was initially a problem. This was alleviated by reducing the drying temperature from 125°C to as low as necessary (110-90°C) and increasing the drying time to 60 seconds.

Lead, cadmium, and nickel were analyzed with the use of the graphite furnace after sample-metal extraction techniques. Aliquots (200 ml) of samples for lead and cadmium analyses were extracted using ammonium 1-pyrrolidinedithioate (APDC) chelate and a double extraction into chloroform. This was followed by a back extraction into 6 normal ultrex nitric acid. This system is similar to the APDC-DDDC system described by Linrade and Van Loon (1974) except the back extraction into 6N HNO<sub>3</sub> which was added here to increase the stability of the extracted metals since diethylammonium diethyldithiocarbamate (DDDC) was unavailable for the analyses. The back extraction step and the use of chloroform for the extraction solvent is described by Bruland et al. (1978). Another 200 ml volume of sample was extracted using a APDC-MIBK (methyl iso-butyl ketone) system (APHA, 1975). The organic extracts were then directly injected into the graphite furnace for determination of nickel concentrations. Detection limits in all cases were adequate to detect metals in excess of TTPI water quality standards.

#### Meteorological Data

Weather data including air temperature, wind speed and direction, precipitation, and total sunshine were obtained from the U. S. Department of Commerce, National Weather Station, Koror, Palau (Table 1).

### RESULTS AND DISCUSSION

#### Turbidity

Turbidity values (Table 2) ranged from 0.49 to 3.9 NTU with a grand mean of 1.3 NTU and standard deviation of 0.54 for the eight water quality stations. The control (station 9) values ranged from 0.30 to 1.0 NTU with a mean value for surface and bottom samples of 0.55 NTU and standard deviation of 0.18. When the turbidity data for the eight water quality stations are plotted on probability paper (Figure 5) or illustrated as a bar graph (Figure 6), there appears a cluster of values in the higher range of turbidity. The higher values are primarily from station 8. A priori, one might expect station 8 to

be different because of its location on the shallow reef flat in an eel grass bed. For statistical purposes station 8 as well as the control (station 9) can be regarded as separate cases for water quality monitoring. Excluding these two stations, the data illustrated appear to be normally distributed. The medium turbidity from the probability distribution is 1.1 NTU for the eight stations.

One-way and two-way analyses of variance (anova) (Sokal and Rohlf, 1969) were employed to statistically analyze differences between stations and between surface and bottom samples. One-way anova allows multiple comparisons of mean value between stations; however, day to day variation in turbidity was often great enough to obscure differences between means. Therefore, two-way anova was employed to separate variation between days from variation among stations.

There was no significant difference between stations 1 through 7, including surface and bottom samples, by one-way anova. However, station 8 was found to be significantly different from stations 1 through 7. To test for significant differences between surface and bottom samples, a two-way anova (paired comparison test) was used. A significant difference was found between surface and bottom turbidity at station 3, but not at stations 6 and 9. Station 3 was in the main channel and may be influenced by current or terrestrial inputs from the river at the mouth of the bay. The effect, though, is slight.

In order to test the influence of tide on turbidity at station 1, which is located in the Garayamu-Garreru Channel, turbidity values were separated into samples taken during current flow into and out of Ngurusar Bay (Table 3). Turbidity values for water flowing out of Ngurusar Bay are significantly higher than for water flowing into the bay. Therefore, turbidity is usually higher on falling tides than rising tides. However, some outflow of water occurs during flood tides as well, whereas inflow appears to be restricted to flood tides and slack tide around high tide. Seasonal changes in wind direction may alter this pattern. These data imply that waters and reef areas on the east side of the Toagel Channel may be adversely affected by turbidity if the recommended turbidity standard is not adhered to.

When other stations were tested for a pattern similar to station 1 on corresponding days, no significant differences in turbidity were observed. This implies little effect from water flowing into Ngurusar Bay from Toagel Channel on water quality at the other stations.

### Suspended Solids

Suspended solids values ranged from no detectable difference to 12.6 mg/ℓ with a grand mean of 2.4 mg/ℓ and standard deviation of 1.8 at the eight water quality stations (Table 4). No significant differences were observed between the eight water quality stations. The results were highly variable as indicated by a relatively high standard deviation as a per cent of the mean. This is in part inherent in the technique when working with samples that are relatively low in suspended solids. An increase in sample size to at least one liter is recommended and will be used in future sampling.

Using mean values at each station for suspended solids and turbidity, the ratio of turbidity to suspended solids was calculated (Table 5). The control (station 9) has the lowest ratio and station 8 has the highest ratio with all other stations having intermediate values. This tends to indicate the influence of a relatively smaller sized particle (clay and silt) in the study area as compared to the control area. This result, based on more extensive sampling, tends to reinforce that obtained by Environmental Consultants, Inc. (1978).

Suspended solids and turbidity give independent measures of particulate matter in water, which should correlate well in the water quality area given the similar influences. Therefore, changes in water quality would not only be indicated by changes in the absolute measure of turbidity and suspended solids, but also by their ratio. An increase in the ratio of turbidity to suspended solids would imply an increase in smaller size particles and a decrease in the ratio would imply an increase in large size particles.

Suspended solids values should be expected to remain under 20 mg/ℓ with a turbidity to suspended solids ratio of about 0.50.

### Dissolved Oxygen

Dissolved oxygen values ranged from 3.52 to 10.73 mg/ℓ with a grand mean of 5.91 mg/ℓ and a standard deviation of 0.72 for the eight water quality stations (Table 6). The extreme values were from station 8 which showed undersaturation in the early morning and supersaturation in the middle of the day. The effect of time of day was reflected in the dissolved oxygen concentration in the surface samples of all other stations as well. The high variability at station 8 was accentuated by the presence of a shallow eel grass bed.

Using two-way anova a significant difference was found between surface and bottom samples at station 6 but not at station 3 or the control (station 9).

### Salinity

Salinity values ranged from 28.8 to 35.5 parts per thousand (ppt) with a grand mean of 31.4 ppt and standard deviation of 2.1 for the eight water quality stations (Table 7). An obvious trend of decreasing salinity over the sampling period is evident from the data in Table 7 for all the stations, including the control. This probably represents a technical problem with the instrument calibration or probe and salinity values may be underestimated.

A statistically significant difference was found between surface and bottom samples at stations 3 and 6 by two-way anova. No significant difference was found at station 9. However, the difference was slight and the effect, if a result of terrestrial run-off, was very small during the sampling period. During heavy rains and tropical storms, when peak flow rates in the nearby river occur, a more prominent effect may be observed.

### Temperature

Temperature ranged from 26.6 to 31.9°C with a grand mean of 28.8°C and a standard deviation of 0.8 for the eight water quality stations (Table 8). Station 8 was the most variable with lower temperatures in the early morning and higher temperatures at midday from solar insolation. While bottom temperatures were often lower than surface temperatures, no significant differences were detected.

### pH

Values for pH ranged from 7.45 to 8.01 with a grand mean of 7.85 and standard deviation of 0.10 for the eight water quality stations (Table 9). There were no significant differences among the eight water quality stations by one-way anova; however, the value of pH at station 9 was significantly higher than all other stations.

### Total Phosphorus

Total phosphorus concentrations ranged from 0.003 to 0.187 mg/l for all the water quality stations (Table 10). The value of 0.187 mg/l for a bottom sample at station 3 was high and may be contaminated



by sediments. Excluding sample 3b (bottom), the range is 0.003 to 0.011 mg/ℓ for total phosphorus. These values are well within the limits designated for class AA waters in the TTPI (1978). Mean values of 0.006 to 0.008 mg/ℓ total phosphorus (0.21 to 0.26 µg-at PO<sub>4</sub>-P/ℓ) were reported by Environmental Consultants, Inc. (1978) for areas similar to the water quality monitoring area.

If water quality for phosphorus is expected to remain in the class AA designation in the water quality monitoring area, values for total phosphorus should not exceed 0.025 mg/ℓ.

#### Total Nitrogen

Total nitrogen values ranged from less than 0.011 mg/ℓ to 0.257 mg/ℓ (Table 10). The limit of detection for total kjeldahl nitrogen is 0.01 mg/ℓ. Several samples were below the limits of detection. In all cases, water quality was within the limits designated for class AA waters in the TTPI (1978). Mean values of 0.127 to 0.160 mg/ℓ nitrogen (9.1 to 11.4 µg-at N/ℓ) were reported by Environmental Consultants Inc. (1978) for areas similar to the water quality monitoring area.

If water quality for nitrogen is expected to remain in the class AA designation in the water quality monitoring area, values for total nitrogen should not exceed 0.400 mg/ℓ.

#### Heavy Metals

Concentrations of heavy metals at the water quality monitoring stations and the control station are presented in Table 11 along with the marine water quality standards for the metals tested. Concentrations of arsenic were below the detectable limit of 2 µg/ℓ. Cadmium concentrations ranged from 0.6 to 1.2 µg/ℓ, well below the water quality standard of 5 µg/ℓ. Chromium levels were high at all stations with seven of the nine stations having values up to 34% in excess of the water quality standard (50 µg/ℓ). Initial metal analyses of Ngurusar Bay waters carried out a few months earlier also reported high chromium concentrations (100 to 130% in excess of the water quality standard). Copper concentrations ranged from below 0.7 µg/ℓ to 3.1 µg/ℓ, well below the 10 µg/ℓ marine water quality standard. Lead concentrations were extremely high ranging from 160 to 375 µg/ℓ, well exceeding the marine water quality standard of 10 µg/ℓ. The initial water sampling in December 1979 also reported high lead concentrations (240 to 250 µg/ℓ). The Ngurusar Bay study site is partially enclosed by land (Fig. 1) and receives runoff from the land thru mangrove swamps and the

Gihmel River. Concentrations of metals in excess of concentrations normally observed in open ocean seawater would be expected. However, the magnitude of the lead excess suggests that lead leaching or contamination of the samples while in the sample bottle may have occurred. The sample containers are now being tested to see if they can contribute lead to stored water samples. Mercury concentrations ranged from below the detectable limit (0.1  $\mu\text{g}/\ell$ ) to 1.7  $\mu\text{g}/\ell$ . The marine water quality standard for mercury is 0.1  $\mu\text{g}/\ell$ . The one sample (station 1) which had 1.7  $\mu\text{g}/\ell$  was an exception. Five of the remaining stations had values below 0.1  $\mu\text{g}/\ell$  and the other four stations had concentrations ranging from 0.4 to 0.8  $\mu\text{g}/\ell$ . Nickel concentrations ranged from 0.2 to 5.8  $\mu\text{g}/\ell$ . Two stations had values in excess of the 2  $\mu\text{g}/\ell$  standard. Zinc concentrations ranged from less than 10  $\mu\text{g}/\ell$  to 16  $\mu\text{g}/\ell$  and were all below the marine water quality standard of 20  $\mu\text{g}/\ell$ .

A set of water samples from Truk Lagoon were analyzed along with the Palau samples. Those Truk metal concentrations which were above the detectable limits were below those reported from Palau (one sample excepted). The Truk samples were from waters outside the reef margin of Moen Island where effects from land runoff would be expected to be less than in the Palau site. Future metal testing in both sites will test this observation.

It appears that concentrations of lead and chromium in waters of northwest Ngurusar Bay usually exceed the water quality standards for these metals. Levels of mercury and nickel may approach or exceed the standards. Further metal analyses will determine if these results are unusual or typical of conditions to be expected.

#### Comparison of Water Quality with the TTPI Water Quality Standards for Class AA Waters

Table 12 compares the water quality data obtained at the water quality monitoring stations with the TTPI water quality standards (TTEPB, 1978) for class AA waters. All waters outside the immediate vicinity of docks and landings on Babelthuap Island are classified A A (TTEPB, 1979). Since only one set of samples were analyzed for nutrients and metals (the initial metal set being disregarded) the representativeness of the observed concentrations to the ambient range of concentrations cannot be determined.

### Previous Studies

In January 1978, Environmental Consultants, Inc. (1978) conducted an environmental survey for the proposed Palau Airport Project. During their field studies, water quality data were collected in the Ngurusar Bay-Airai Bay area. A summary table of their results is reproduced herein (Table 13). For most stations in the areas described, one-time-only measurements (with replication) were taken.

In general, turbidity, suspended solids, and their ratio (turbidity/suspended solids) decrease with distance from the point source influents. This is consistent with the data of the present study with station 9 (the control) corresponding to area 2 (outer Ngurusar Bay) and the water quality monitoring stations occupying an intermediate position between area 1 and area 2.

The Environmental Consultants, Inc. (1978) report concludes that the water quality in the Ngurusar Bay-Airai Bay area is presently a function of terrestrially derived sediment inputs and the poor water circulation characteristics of the bay.

### RECOMMENDED TURBIDITY STANDARD

The following methods were used to arrive at a recommended turbidity standard. The subsequent monthly monitoring at stations 1-8 during the construction phase (part B) will generate a total of 300 samples for a thirty month duration. Therefore, for a significance level greater than once in every 300 samples,  $P < .001$  was chosen to calculate a critical value for turbidity using either the t-distribution or normal distribution.

Using the data from Table 3 for outflow at station 1 with a sample size of  $N = 12$ , a significance level of  $P < .001$  (two tailed test) is obtained for values greater than 4.3 standard deviation units from the mean. This gives a critical value of 4.1 NTU ( $1.5 \text{ NTU} + 4.3 \times 0.6 \text{ NTU} = 4.08 \text{ NTU}$ ). If station 8 is taken as the worst case, then, for a sample size of  $N = 21$ , a significance level of  $P < .001$  (two-tailed test) is obtained for values greater than 3.8 standard deviations from the mean. This gives a critical value of 5.0 NTU ( $2.1 \text{ NTU} + 3.8 \times 0.75 \text{ NTU} = 4.95 \text{ NTU}$ ). Finally, using all the data from stations 1-8 and assuming a normal distribution, a critical value is obtained 3.3 standard deviations from the mean at a significance level of  $P < .001$  (two-tailed test). This gives a critical value of 3.1 NTU ( $1.3 \text{ NTU} + 3.3 \times 0.54 = 3.08 \text{ NTU}$ ). However, the data was not normally distributed, because of station 8, and turbidity values greater than 3.0 NTU were obtained.

Based on the above calculations, a turbidity standard of 5 NTU is justified and recommended if waters beyond the water quality boundary are to be kept free of substantial dredge-produced turbidity. A turbidity standard of 5 NTU also will be close to the turbidity standard for the TTPI (1978). The turbidity standard requires that natural turbidities are not affected by more than 5% in class AA waters (protected for oceanographic research, propagation of marine life, and compatible recreation), not more than 10% in class A waters (recreational, aesthetic enjoyment, support, and propagation of marine life), and no more than 20% in class B waters (areas immediately adjacent to boat docking facilities). If natural turbidity reaches 3.9 NTU (the highest turbidity measured in the study) 20% or 10% of this value added to 3.9 NTU will give a figure close to but below 5 NTU.

Furthermore, it is recommended that sampling be conducted during falling tides or current outflow from Ngurusar Bay through the Garayamu-Garreru Channel. Significantly different turbidities as a function of current flow at station 1 (Table 3) warrant this sampling procedure.

If a turbidity reading in excess of 5 NTU is found, subsequent (hourly, or more frequent) readings are recommended for two additional hours to insure that the excess reading is a result of construction operations and not sampling error or unnatural events. Additional turbidity readings should be undertaken in areas outside the monitoring area that are likely to be affected by excess turbidity so that the extent of the effect can be determined.

#### SUMMARY

Eight water quality monitoring stations and one control station were selected for twenty-one days of sampling from December 20, 1979 to January 11, 1980 for the purposes of (1) obtaining, prior to construction, water quality information for the Palau Airport Project dredge site and (2) developing a turbidity standard to be used during construction activity at the dredge site.

Daily measurements were made for the following parameters: turbidity, suspended solids, dissolved oxygen, temperature, salinity, and pH. One time measurements were made for total nitrogen, total phosphorus, and the following heavy metals: lead, mercury, zinc, copper, arsenic, nickel, cadmium, and chromium.

A turbidity standard of 5 NTU is recommended in order to maintain water quality beyond the Water Quality Boundary during construction activity at the dredge site.

## ACKNOWLEDGEMENTS

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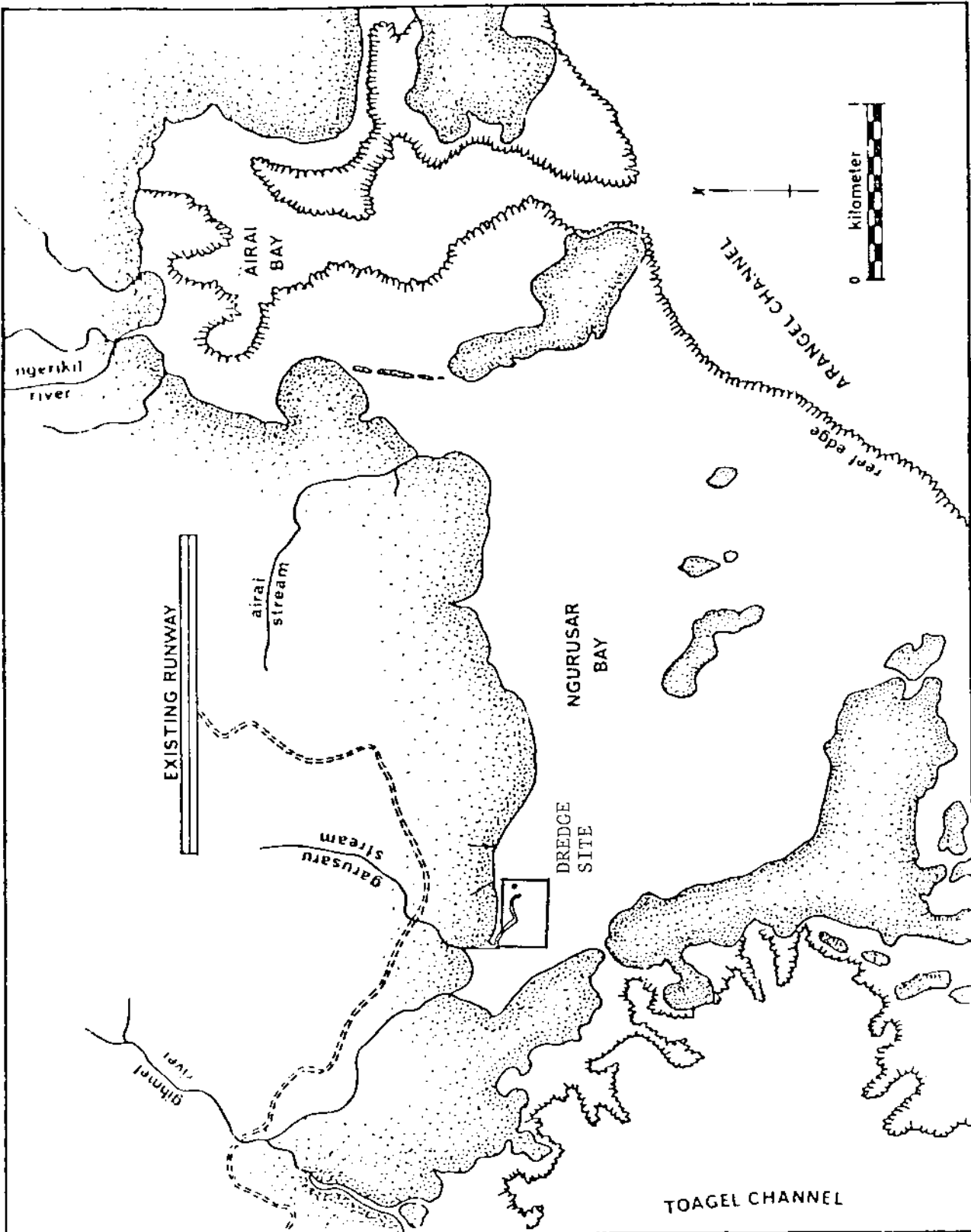


Figure 1. Location of dredge site [adapted from Environmental Consultants, Inc. (1978)].

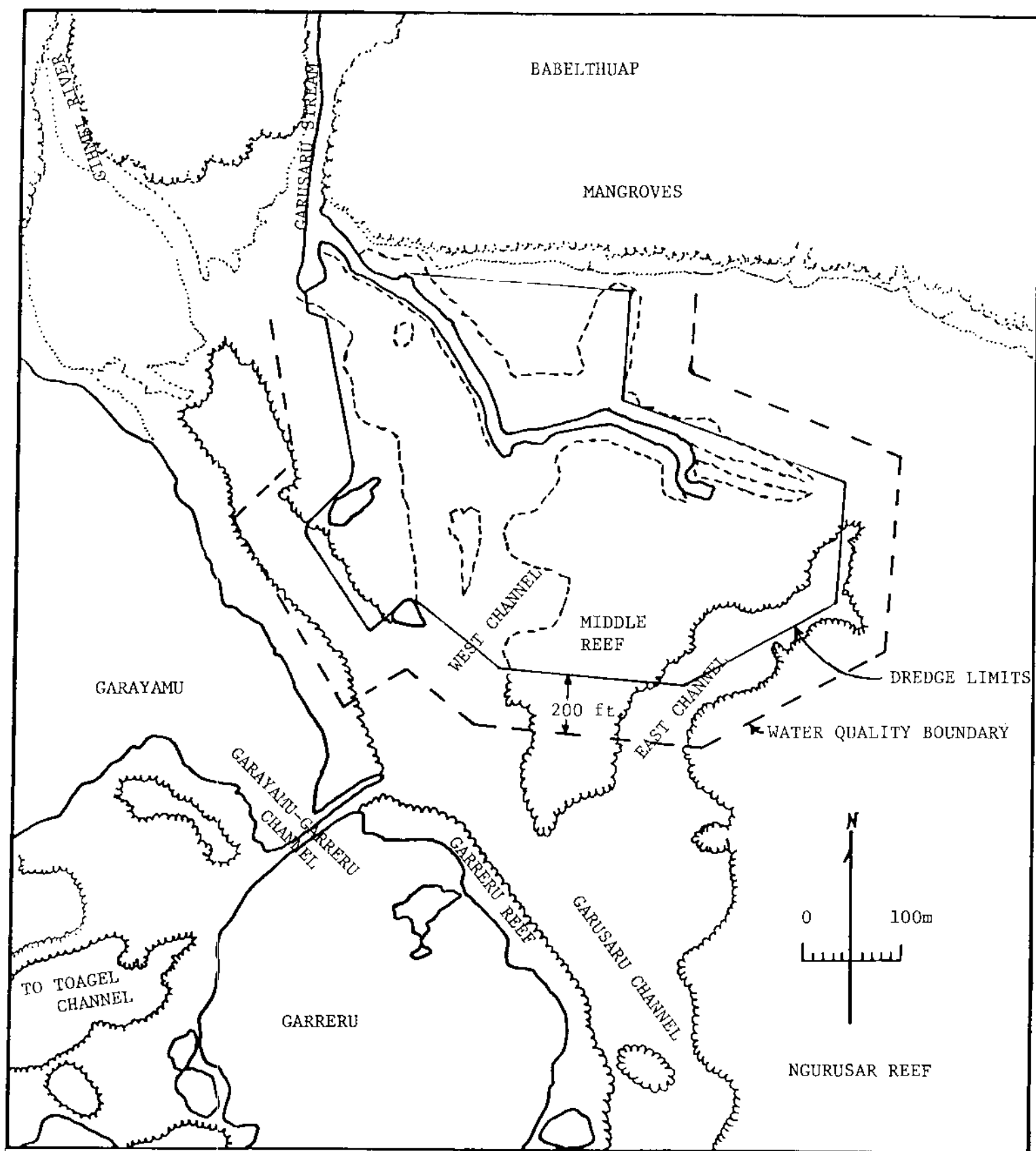


Figure 2. Location of the Water Quality Boundary [adapted from Environmental Consultants, Inc. (1978)].



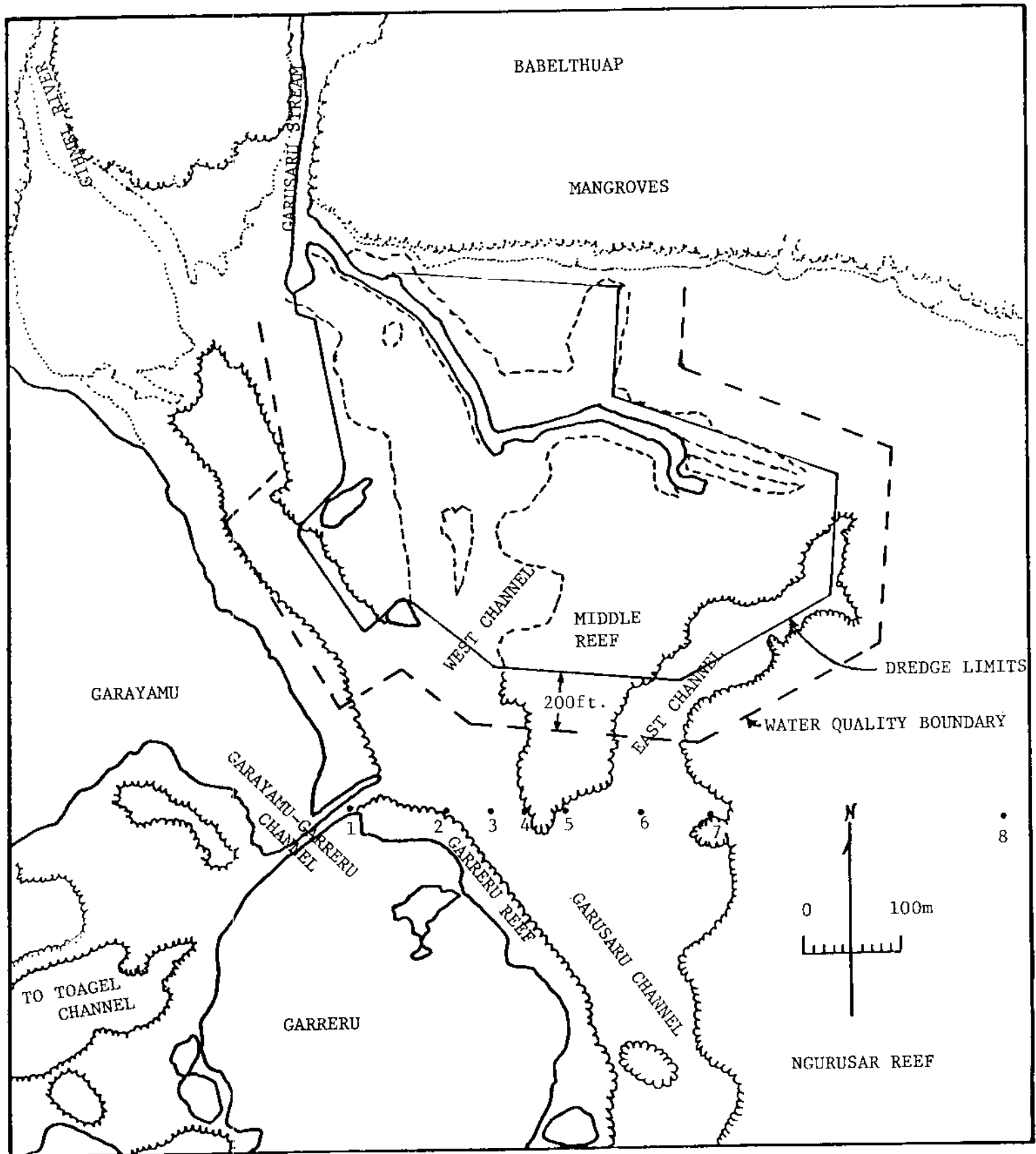


Figure 3. Location of the eight water quality stations in vicinity of dredge site [adapted from Environmental Consultants, Inc. (1978)].

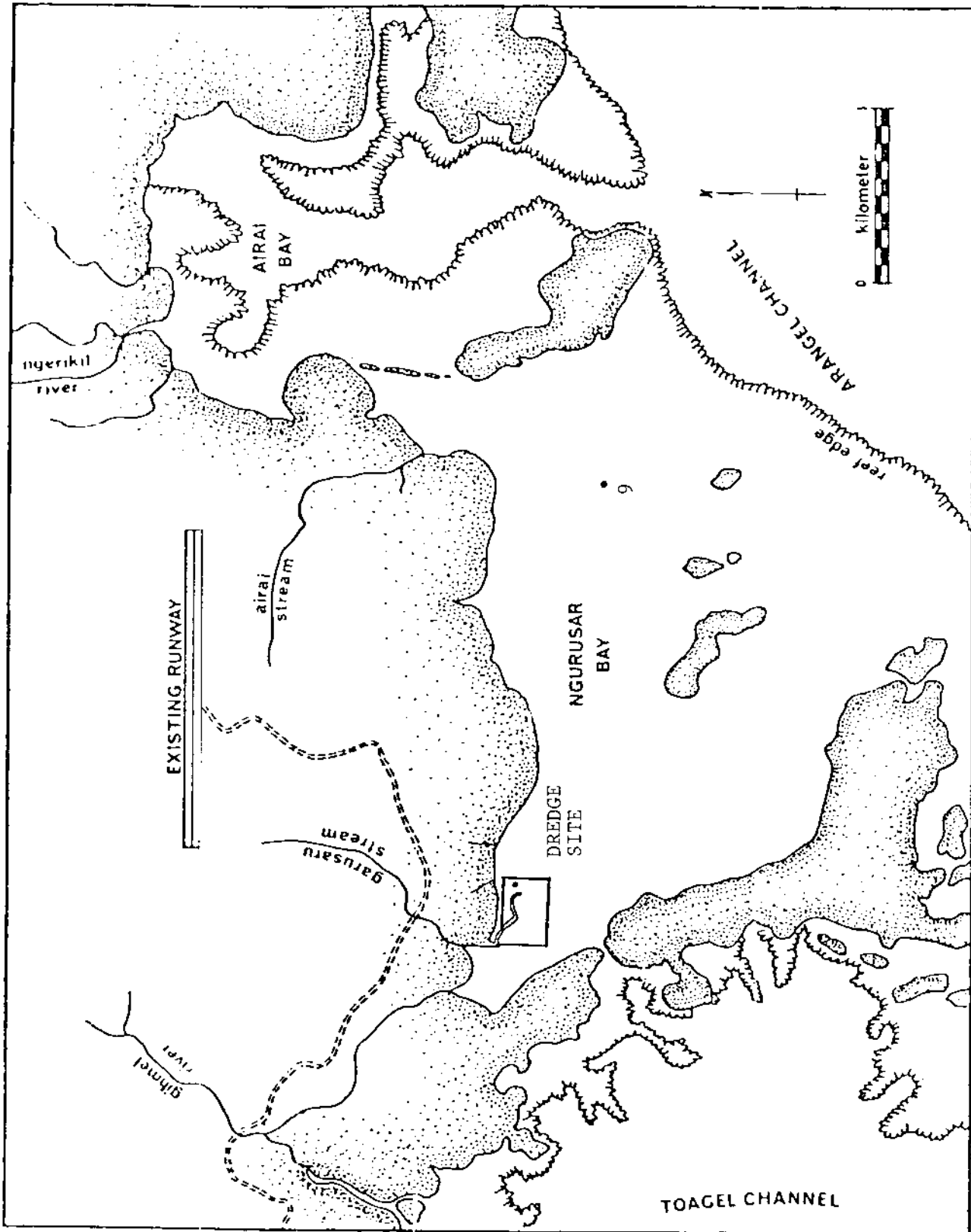


Figure 4. Location of the control water sampling station (No. 9) in outer Ngurusar Bay [adapted from Environmental Consultants, Inc. (1978)J.

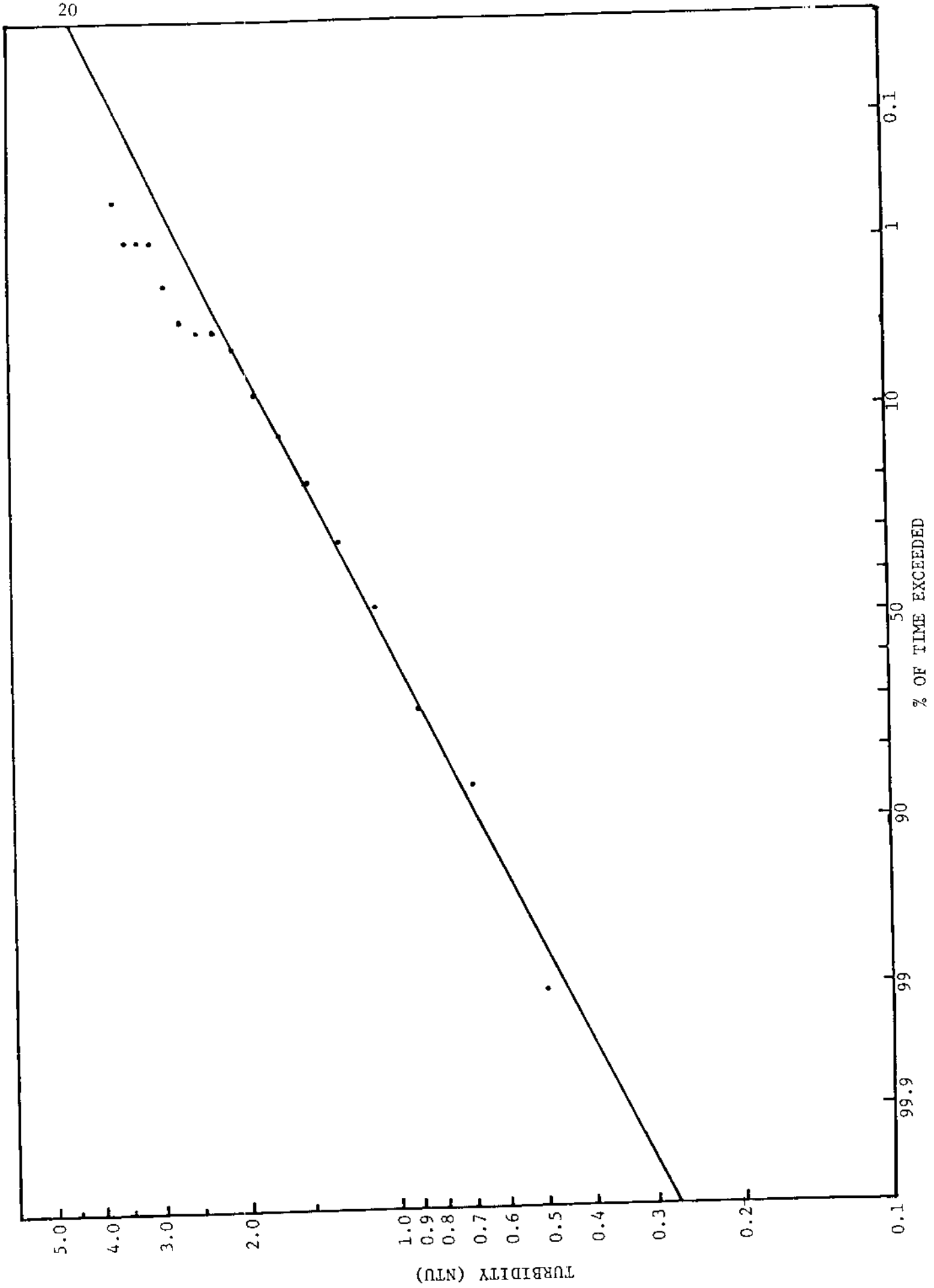


Figure 5. Probability distribution of turbidity measurements at the eight water quality stations.

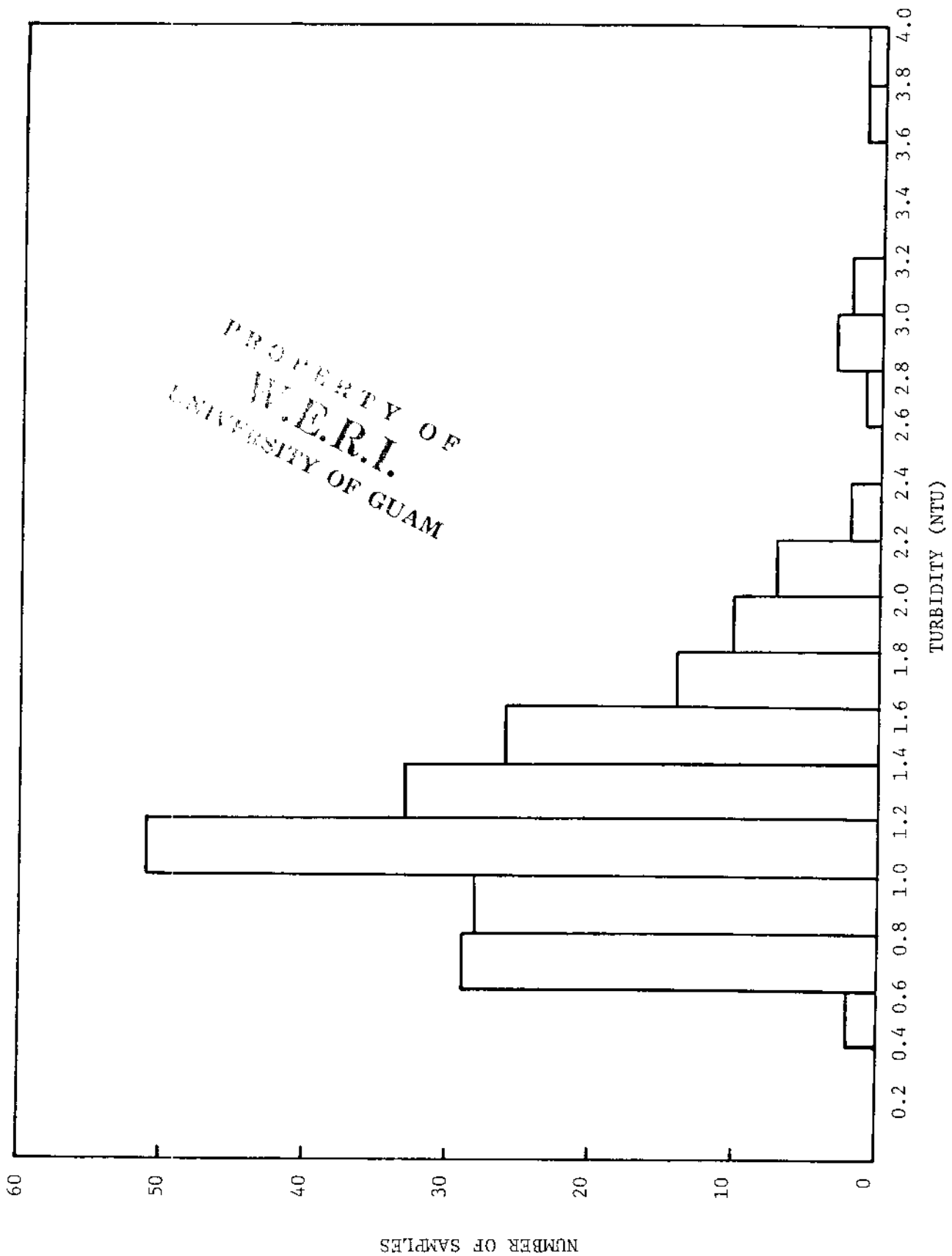


Figure 6. Bar graph of turbidity measurements at the eight water quality stations.

Table 1. Temperature, rain, wind speed and direction, and sunshine measurements from the Koror, Palau Weather Station for the period December 19, 1979 - January 11, 1980.

DATE	T E M P E R A T U R E (°C)		R A I N (in.)		AV. SPEED (mph)	HIGHEST SPEED	D I R E C T I O N	S U N S H I N E (min.)
	MAX	MIN	AVERAGE	TOTAL 24 HR.				
12/19/79	30.6	23.3	27.2	0.15	3.3	14	NE	44
12/20/79	31.1	23.9	27.8	0.04	2.6	6	E	265
12/21/79	31.7	24.4	28.3	0.01	3.7	9	S	590
12/22/79	28.9	23.9	26.7	0.10	4.2	11	NE	33
12/23/79	28.9	22.2	25.6	3.54	4.8	13	NE	166
12/24/79	29.4	22.2	26.1	1.94	6.3	14	SW	39
12/25/79	31.1	23.3	27.2	0.01	5.5	13	NE	623
12/26/79	31.1	23.9	27.8	0.00	7.4	14	NE	498
12/27/79	31.1	23.3	27.2	0.00	6.2	11	NE	572
12/28/79	31.1	23.3	27.2	0.03	6.0	11	SE	603
12/29/79	31.7	23.3	27.8	0.14	7.2	14	NE	315
12/30/79	31.1	25.0	28.3	0.46	7.8	17	SE	131
12/31/79	29.4	23.3	26.7	1.37	6.8	14	SE	16
1/1/80	29.4	24.4	27.2	0.61	6.6	14	SE	268
1/2/80	31.1	23.9	27.8	0.12	6.9	14	SE	333
1/3/80	31.1	23.9	27.8	0.58	8.8	17	NE	425
1/4/80	29.4	25.0	27.2	0.58	8.0	18	NE	21
1/5/80	31.7	23.9	27.8	0.09	9.1	18	NE	292
1/6/80	30.6	23.9	27.2	0.13	9.1	16	NE	398
1/7/80	30.6	24.4	27.8	0.04	12.4	22	NE	431
1/8/80	30.6	23.3	27.2	0.01	9.3	20	NE	320
1/9/80	30.0	23.3	26.7	0.07	6.9	17	NE	277
1/10/80	31.7	23.9	27.8	0.35	5.4	15	SE	386
1/11/80	30.7	23.9	27.2	0.02	7.0	13	NE	227

Table 2. Turbidity measurements (NTU) and mean values ( $\bar{Y}$ ), standard deviation (s), and sample size (N) at the water quality monitoring stations. Sampling period and time of the nearest high tide are included at the bottom.

STATION	AV. DEPTH	J A N U A R Y															
		20	21	22	D	E	C	E	M	B	E	R	29	30	31	1	2
1	1.9m	1.1	0.70	0.80	0.77	1.0	1.2	0.84	1.1	2.3	2.8	1.7	1.5				
2	2.9m	1.8	1.5	1.5	1.9	1.6	0.72	0.76	1.3	2.0	2.2	1.3	1.8				
3s*	6.9m	1.7	1.3	1.2	1.25	1.1	0.77	0.61	0.73	1.6	2.2	1.5	1.4				
3b*	6.9m	1.3	1.4	2.0	1.2	1.6	1.8	1.2	1.4	1.8	1.5	1.7	1.6				
4	3.0m	1.1	2.0	1.2	0.9	1.1	0.71	0.72	0.81	1.5	2.1	1.4	1.2				
5	3.0m	1.5	1.4	1.0	0.75	1.0	0.75	0.81	0.77	0.93	2.4	0.96	1.4				
6s*	7.2m	2.1	1.7	1.2	0.7	1.0	0.86	1.3	0.81	0.74	1.6	1.2	1.4				
6b*	7.2m	1.3	1.4	2.1	1.1	3.7	0.79	0.78	1.9	1.5	1.3	1.3	1.5				
7	3.2m	1.8	1.4	1.5	1.6	0.8	1.1	0.78	1.3	1.3	1.5	1.2	1.7				
8	0.9m	2.8	2.2	2.0	1.7	3.0	1.8	1.9	3.9	2.9	3.2	1.9	1.6				
9s*	6.4m	0.8	1.0	0.5	0.35	0.42	0.36	0.52	0.36	0.63	0.33	0.42	0.71				
9b*	6.4m	0.5	0.65	0.45	0.3	0.4	0.32	0.35	0.35	0.37	0.33	0.42	0.71				
SAMPLING PERIOD		0900	0830	0829	0852	0937	1221	1259	1205	0810	0823	0816	0820				
		1110	1035	1002	1017	1115	1340	1430	1315	0927	0920	0913	0925				
HIGH TIDE		0812	0852	0932	1015	1248	1347	1451	1555	0517	0618	0709	0749				

\*s = surface sample  
b = bottom sample

Table 2 . Cont.

STATION	3	4	J	A	N	U	A	R	Y	8	9	10	11	$\bar{Y}$	S	N
1	1.2	1.6	1.9	1.5	0.78	1.5	0.75	0.79	0.83	0.58	1.2	0.58	21	1.2	0.58	21
2	1.1	1.3	1.7	1.1	0.85	1.1	1.3	0.97	1.6	1.1	1.4	0.41	21	1.4	0.41	21
3s*	1.3	1.0	1.6	0.85	1.1	0.85	1.1	1.0	1.3	1.1	1.2	0.37	21	1.2	0.37	21
3b*	1.2	1.2	1.4	1.0	1.1	1.0	1.4	1.3	1.7	0.88	1.4	0.29	21	1.4	0.29	21
4	0.78	1.1	1.3	1.3	0.75	1.3	1.2	1.1	1.2	1.1	1.2	0.37	21	1.2	0.37	21
5	0.76	1.1	1.3	0.89	0.95	0.89	1.2	0.83	0.85	0.68	1.1	0.39	21	1.1	0.39	21
6s*	1.0	1.3	1.4	0.95	1.1	0.95	1.1	0.95	0.75	0.49	1.1	0.38	21	1.1	0.38	21
6b*	1.1	1.5	1.2	1.1	1.1	1.1	1.1	1.1	1.2	0.62	1.4	0.63	21	1.4	0.63	21
7	1.2	1.4	1.4	1.1	1.2	1.1	1.2	1.1	0.77	0.68	1.2	0.31	21	1.2	0.31	21
8	1.1	1.5	1.6	1.3	1.3	1.3	1.5	2.2	3.1	1.9	2.1	0.75	21	2.1	0.75	21
9s*	0.68	0.58	0.67	0.65	0.65	0.65	0.63	0.63	0.35	0.42	0.56	0.17	21	0.56	0.17	21
9b*	0.79	0.66	0.83	0.75	0.75	0.75	0.71	0.58	0.65	0.37	0.54	0.18	21	0.54	0.18	21
SAMPLING PERIOD	0803	0813	0855	0847	0824	0847	0856	0922	0935	1024	1024	0935	1024	AV. TIDE HEIGHT		
	0907	0913	0949	0957	0919	0957	1029	1035	1048	1129	1129	1048	1129	LOW	0.6m	
HIGH TIDE	0824	0859	0931	1036	1001	1036	1111	1151	1235	1321	1321	1235	1321	HIGH	1.7m	

\*s = surface sample

b = bottom sample

TABLE 3. Turbidity measurements (NTU) at Station 1 comparing values for inflow (into Ngurusar Bay) and out flow (out of Ngurusar Bay) through the channel (see Fig. 3).

DATE	SAMPLE TIME		DATE	SAMPLE TIME	
	RELATIVE TO HIGH TIDE	TURBIDITY (NTU)		RELATIVE TO HIGH TIDE	TURBIDITY (NTU)
12/20/79	+ 48 min.	1.1	12/26/79	-191 min.	1.0
12/21/79	- 22 min.	0.7	12/27/79	- 86 min.	1.2
12/22/79	- 63 min.	0.8	12/28/79	- 91 min.	0.84
12/23/79	- 83 min.	0.77	12/30/79	+250 min.	2.3
12/29/80	-230 min.	1.1	12/31/79	+182 min.	2.8
1/8/80	-135 min.	0.75	1/1/80	+124 min.	1.7
1/9/80	-149 min.	0.79	1/2/80	+ 96 min.	1.5
1/10/80	-180 min.	0.83	1/3/80	+ 43 min.	1.2
1/11/80	-177 min.	0.58	1/4/80	+ 14 min.	1.6
			1/5/80	+ 18 min.	1.9
			1/6/80	- 96 min.	0.78
			1/7/80	-109 min.	1.5
$\bar{Y}$		0.82	$\bar{Y}$		1.5
S		0.17	S		0.6
N		9	N		12

One-way Anova

$F_s = 11.60^{**}$   $p < .005$

$F .005 [1, 19] = 10.1$



Table 4. Suspended solids measurements (mg/l) and mean values ( $\bar{Y}$ ); standard deviation (s), and sample size (N) at the water quality monitoring stations.

STATION	D E C E M B E R				J A N U A R Y					
	26	27	28	29	30	31	1	2	3	4
1	3.2	3.8	3.6	1.6	4.4	1.8	4.4	3.8	2.2	3.0
2	5.0	2.0	2.2	1.6	2.6	1.0	5.6	3.0	1.8	3.0
3s*	2.2	0.8	2.0	1.6	2.4	0.8	5.8	2.4	2.6	1.8
3b*	3.4	3.0	2.0	1.6	2.6	1.2	5.8	2.4	2.6	2.2
4	4.0	n.d.	5.4	n.d.	1.0	0.8	6.0	2.0	2.0	2.2
5	n.d.	n.d.	5.4	0.4	1.4	1.0	4.8	2.4	3.4	2.4
6s*	4.2	2.4	3.2	1.6	1.6	1.4	4.6	2.4	2.2	2.6
6b*	4.2	2.6	3.4	2.4	1.6	1.6	5.4	2.4	3.6	3.4
7	4.2	4.4	3.6	2.2	0.8	0.6	4.6	2.4	3.0	2.2
8	2.6	2.8	3.4	4.4	3.6	2.8	8.0	2.2	2.4	1.6
9s*	0.6	2.8	2.6	0.6	n.d.	n.d.	n.d.	0.8	3.0	1.8
9b*	2.6	2.4	3.6	1.0	2.0	0.2	4.6	1.2	2.0	0.6

\*s = surface sample  
 b = bottom sample  
 n.d. = not detectable

Table 4. Cont.

STATION	5	J A 6	N 7	U 8	A 8	R 9	Y 9	10	11	$\bar{Y}$	S	N
1	3.0	1.2	1.4	1.2	1.2	n.d.	3.8	3.8	4.6	2.9	1.21	16
2	3.0	0.8	0.8	2.2	2.2	3.8	12.6	12.6	6.4	3.4	2.87	17
3s*	1.8	1.0	0.6	0.8	0.8	3.2	7.2	7.2	3.6	2.4	1.79	17
3b*	2.4	0.6	0.8	2.0	2.0	4.4	4.8	4.8	n.d.	2.6	1.42	16
4	2.4	1.4	0.8	0.8	0.8	5.0	4.6	4.6	5.6	2.9	1.95	15
5	1.6	1.8	1.2	2.4	2.4	n.d.	6.2	6.2	n.d.	2.6	1.80	13
6s*	0.8	2.8	1.0	2.0	2.0	4.0	n.d.	n.d.	4.4	2.6	1.21	16
6b*	1.8	2.0	0.8	1.8	1.8	2.6	3.6	3.6	3.4	2.7	1.14	17
7	0.8	3.2	1.2	2.8	2.8	6.6	2.8	2.8	4.0	2.9	1.59	17
8	0.4	3.4	1.6	2.4	2.4	6.8	5.4	5.4	3.6	3.4	1.91	17
9s*	0.8	2.2	0.8	0.6	0.6	n.d.	n.d.	n.d.	4.6	1.8	1.3	12
9b*	0.4	1.8	1.0	1.4	1.4	0.6	n.d.	n.d.	3.2	1.8	1.2	16

\*s = surface sample  
 b = bottom sample  
 n.d. = not detectable

Table 5. Ratio of mean turbidity (NTU) to mean suspended solids (mg/l) values at the water quality monitoring stations.

STATION	MEAN TURBIDITY (NTU)	MEAN SUSPENDED SOLIDS (mg/l )	MEAN TURBIDITY/MEAN SUSPENDED SOLIDS (NTU/mg/l)
1	1.2	2.9	0.41
2	1.4	3.4	0.41
3s*	1.2	2.4	0.50
3b*	1.4	2.9	0.41
4	1.2	2.9	0.41
5	1.1	2.6	0.42
6s*	1.1	2.6	0.42
6b*	1.4	2.7	0.52
7	1.2	2.9	0.41
8	2.1	3.4	0.62
9s*	0.56	1.8	0.31
9b*	0.54	1.8	0.30

\*s = surface sample  
b = bottom sample

Table 6. Dissolved oxygen measurements (mg/l) and mean values ( $\bar{Y}$ ), standard deviation (s), and sample size (N) at the water quality monitoring stations. The sampling period is included at the bottom.

STATION	J A N U A R Y													
	20	21	22	23	24	25	26	27	28	29	30	31	1	2
1	5.04	5.49	5.58	5.15	6.35	6.18	6.27	6.52	5.49	5.24	5.32	5.49	5.24	5.32
2	5.20	5.32	5.41	5.15	6.01	6.09	6.01	5.67	5.49	5.32	5.49	5.49	5.32	5.49
3s*	4.99	5.32	5.32	5.24	5.67	6.18	6.18	6.44	5.41	5.49	5.84	5.41	5.49	5.84
3b*	5.15	5.49	5.49	5.32	6.09	5.84	6.18	6.09	5.32	6.09	5.58	6.09	5.58	5.58
4	5.11	5.84	5.49	5.41	5.58	6.44	6.52	6.78	6.18	6.78	5.84	5.24	5.75	5.84
5	5.75	6.44	5.58	5.49	5.84	6.52	6.78	6.27	6.01	4.64	5.75	4.64	5.75	6.35
6s*	5.84	6.18	5.67	5.32	5.67	6.70	7.81	6.18	6.01	5.92	5.84	5.92	5.84	5.84
6b*	5.84	5.58	5.49	5.32	5.75	5.67	5.84	5.49	5.58	6.09	5.84	6.09	5.75	5.84
7	5.97	5.41	5.58	5.32	5.75	6.70	6.70	6.18	5.84	5.67	5.84	5.67	5.67	6.44
8	6.66	5.24	4.64	4.46	8.93	7.73	8.07	10.73	5.49	4.72	3.52	4.72	3.52	4.72
9s*	6.18	6.52	6.27	5.67	6.44	6.87	7.90	6.87	6.27	6.09	5.92	6.09	5.92	5.92
9b*	5.84	6.35	6.18	5.58	6.44	6.70	7.55	6.70	6.35	6.70	5.75	6.70	5.75	5.92
SAMPLING PERIOD	0900	0830	0829	0852	0937	1221	1259	1205	0810	0823	0816	0820	0816	0820
	1110	1035	1002	1017	1115	1340	1430	1315	0927	0920	0913	0925	0913	0925
HIGH TIDE	0812	0852	0932	1015	1248	1347	1451	1555	0517	0618	0709	0749	0709	0749

\*s = surface sample  
b = bottom sample

Table 6. Cont.

STATION	3	4	J	A	N	U	A	R	Y	8	9	10	11	$\bar{Y}$	S	N
1	5.58	5.84	5.92	5.92	5.32	5.75	5.75	6.01	5.92	6.18	6.35	6.18	6.35	5.75	0.446	21
2	5.67	6.01	5.75	5.58	5.84	5.84	5.84	5.84	5.92	5.75	6.52	5.75	6.52	5.69	0.338	21
3s*	5.49	6.18	6.01	5.84	5.84	6.01	6.01	6.01	5.92	6.01	7.04	6.01	7.04	5.81	0.475	21
3b*	6.09	6.01	6.09	5.84	5.84	5.84	5.84	5.58	5.49	5.32	5.49	5.32	5.49	5.71	0.324	21
4	5.67	5.84	6.44	6.44	5.84	6.01	6.01	6.27	6.70	6.52	7.47	6.52	7.47	6.04	0.578	21
5	5.67	6.01	6.35	6.35	5.75	6.01	6.01	5.92	6.27	6.35	6.18	6.35	6.18	6.00	0.460	21
6s*	5.84	5.92	5.92	5.75	5.75	6.01	6.01	6.18	6.18	6.35	6.27	6.35	6.27	6.07	0.493	21
6b*	6.27	6.18	6.01	5.92	5.92	5.92	5.92	6.01	6.09	5.58	5.58	5.58	5.58	5.80	0.254	21
7	5.84	5.84	6.01	5.92	5.92	6.18	6.18	6.18	6.01	6.18	6.01	6.18	6.01	5.97	0.363	21
8	4.46	5.06	4.46	4.46	5.58	6.70	6.70	7.38	7.64	7.55	8.24	7.55	8.24	6.28	1.87	21
9s*	6.09	6.27	6.09	6.18	6.18	6.27	6.27	6.44	6.44	6.70	6.44	6.70	6.44	6.37	0.460	21
9b*	6.18	6.35	6.09	6.09	6.09	6.27	6.27	6.27	6.35	6.52	6.27	6.52	6.27	6.31	0.413	21
SAMPLING PERIOD	0803 0907	0813 0913	0855 0949	0824 0919	0847 0957	0856 1029	0922 1035	0935 1048	1024 1129	AV. TIDE HEIGHT	LOW	0.6m	HIGH	1.7m		
HIGH TIDE	0824	0859	0931	1001	1036	1111	1151	1235	1321							

\*s = surface sample  
b = bottom sample

Table 7. Salinity measurements in parts per thousand (ppt) and mean values ( $\bar{Y}$ ), standard deviation (s), and sample size (N) at the water quality monitoring stations.

STATIONS	20	21	D	E	C	E	M	B	E	R	27	28	29	30	31	J A N U A R Y	
																1	2
1	-	31.5	33.5	33.0	33.0	32.0	33.2	35.0	34.0	32.0	31.9	32.5	30.0				
2	-	31.5	33.5	33.0	33.0	33.8	33.8	33.8	33.8	33.0	32.5	32.5	30.2				
3s*	-	32.0	33.2	33.0	32.2	34.5	34.5	32.5	34.2	33.2	32.5	32.5	30.2				
3b*	-	32.0	33.2	33.5	33.9	34.5	34.5	33.8	34.2	33.5	33.5	32.8	30.5				
4	-	31.5	33.5	33.5	33.1	35.5	35.5	33.8	34.2	33.3	32.6	32.5	30.1				
5	-	31.5	33.5	33.9	33.4	35.5	35.5	34.0	34.3	33.5	32.2	32.5	30.2				
6s*	-	34.5	33.2	33.5	34.0	34.5	34.5	34.2	34.0	33.0	32.5	32.5	30.2				
6b*	-	35.0	33.6	33.5	34.9	35.9	35.9	34.0	34.1	33.0	33.2	33.0	30.5				
7	-	34.5	33.5	33.0	33.7	35.5	35.5	34.2	34.2	33.0	32.3	32.5	30.5				
8	-	34.2	32.5	32.9	32.5	35.5	35.5	34.3	35.5	32.3	30.0	32.0	31.5				
9s*	-	34.9	34.0	35.3	34.6	36.5	36.5	34.8	34.9	32.8	32.0	33.5	31.2				
9b*	-	34.8	34.0	35.3	34.9	36.5	36.5	34.5	35.0	33.0	32.5	33.5	31.0				

\*s = surface sample

b = bottom sample

Table 7. Cont.

STATION	3	4	5	J	A	N	U	A	R	Y	8	9'	10	11	$\bar{Y}$	S	N
1	29.5	29.4	29.2	29.0	28.9	29.3	29.1	29.5	29.0	29.0	29.3	28.7	29.2	28.8	31.1	1.99	20
2	29.9	29.6	29.2	29.0	29.1	29.0	28.7	29.2	28.8	29.0	29.0	28.7	29.2	28.8	31.2	2.03	20
3s*	29.9	29.8	29.3	29.2	29.3	29.1	28.8	29.0	29.0	29.0	29.3	29.1	29.0	29.0	31.2	1.97	20
3b*	30.5	29.8	29.8	29.5	29.2	29.0	29.0	29.3	29.1	29.1	29.0	29.2	29.3	29.1	31.5	2.11	20
4	29.8	29.5	29.3	29.7	29.8	28.9	29.2	29.1	29.1	29.1	28.9	29.2	29.5	29.2	31.4	2.15	20
5	29.8	29.5	29.5	29.8	29.9	29.2	29.3	29.5	29.2	29.2	29.2	29.3	29.5	29.2	31.5	2.13	20
6s*	29.8	29.5	29.0	29.7	29.7	29.3	29.3	29.5	29.2	29.2	29.3	29.3	29.5	29.2	31.6	2.17	20
6b*	30.2	29.5	29.2	29.9	29.8	29.3	29.2	29.5	29.3	29.3	29.3	29.2	29.5	29.3	31.8	2.36	20
7	30.0	29.5	29.2	29.9	29.6	29.4	29.3	29.5	29.2	29.2	29.4	29.3	29.5	29.2	31.6	2.19	20
8	29.5	29.9	28.8	29.5	29.8	29.8	29.6	29.8	29.6	29.8	29.8	29.6	29.8	29.6	31.5	2.15	20
9s*	30.5	31.5	29.5	30.6	30.4	31.1	29.9	30.0	29.9	30.0	31.1	29.9	30.0	29.9	32.4	2.22	20
9b*	30.5	31.8	29.5	30.6	30.5	31.1	30.0	30.2	30.0	30.2	31.1	30.0	30.2	30.0	32.5	2.20	20

\*s = surface sample

b = bottom sample

Table 8. Temperature measurements ( $^{\circ}\text{C}$ ) and mean values ( $\bar{Y}$ ), standard deviation (s), and sample size (N) at the water quality monitoring stations.

STATION	J A N U A R Y													
	20	21	22	23	24	25	26	27	28	29	30	31	1	2
1	29.4	29.4	28.9	29.0	29.2	29.2	30.0	30.2	29.8	28.8	28.9	28.9	28.9	28.3
2	29.4	30.0	29.4	29.3	29.2	29.8	29.9	29.9	29.7	28.9	28.9	28.9	28.9	28.3
3s*	28.9	30.0	28.9	29.3	29.0	29.7	29.7	29.7	30.2	28.9	29.4	29.4	28.9	28.3
3b*	29.4	30.6	29.4	29.4	29.5	29.5	29.6	29.6	29.9	28.9	29.4	29.4	28.9	28.3
4	28.9	30.0	29.4	29.6	28.9	29.8	30.0	30.0	30.2	28.9	28.9	28.9	28.9	28.3
5	30.0	30.0	29.4	29.8	28.9	29.7	30.3	30.3	30.0	29.4	28.9	28.9	28.9	28.3
6s*	29.4	30.0	29.4	29.4	29.0	29.8	30.7	30.7	29.9	29.2	28.9	28.9	28.9	28.3
6b*	28.9	30.6	29.4	29.4	29.5	29.5	29.5	29.5	29.6	28.9	29.4	29.4	28.9	28.9
7	29.4	30.0	29.4	29.4	29.0	29.9	30.0	30.0	29.8	29.4	28.9	28.9	28.9	28.3
8	30.0	30.0	28.9	28.6	29.0	29.8	30.6	30.6	31.9	28.9	28.3	28.3	26.6	27.2
9s*	28.9	30.0	29.4	29.3	28.7	29.4	29.9	29.9	29.6	28.9	28.3	28.3	28.3	28.9
9b*	28.9	29.4	28.9	29.0	29.0	29.3	29.7	29.7	29.4	29.1	28.3	28.3	28.9	28.9

\*s = surface sample

b = bottom sample



Table 8. Cont.

STATION	3	4	J	A	N	U	A	R	Y	8	9	10	11	$\bar{Y}$	S	N
1	28.3	28.3	28.3	28.5	28.3	28.3	28.1	28.1	28.1	28.1	28.1	28.3	28.3	28.8	0.67	21
2	28.3	28.3	28.3	28.3	28.3	28.3	28.1	28.1	21.8	21.8	21.8	27.8	28.6	28.6	0.72	21
3s*	28.3	28.3	28.3	28.3	28.1	28.1	28.1	28.1	27.8	27.8	27.8	27.8	28.9	28.8	0.73	21
3b*	28.3	28.9	28.3	28.6	28.3	28.3	28.1	28.1	27.7	27.7	27.2	27.2	27.8	28.8	0.90	21
4	28.3	28.3	28.3	28.9	28.3	28.3	28.1	28.1	27.8	27.8	27.8	27.8	28.9	28.9	0.75	21
5	28.3	28.3	28.3	28.3	28.3	28.3	28.1	28.1	27.8	27.8	27.8	28.1	28.3	28.9	0.81	21
6s*	28.3	28.3	28.3	28.3	28.3	28.3	28.1	28.1	27.8	27.8	27.8	27.8	28.3	28.9	0.82	21
6b*	28.3	28.6	28.3	28.3	28.9	28.9	28.1	28.1	27.8	27.8	27.8	27.2	27.8	28.8	0.81	21
7	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	27.8	27.8	27.8	27.8	28.3	28.8	0.75	21
8	27.2	27.8	27.8	27.2	27.8	27.8	27.2	27.2	27.2	27.2	26.9	28.3	28.9	28.5	1.39	21
9s*	28.3	28.3	28.3	28.3	28.3	28.3	28.1	28.1	27.8	27.8	27.8	27.8	27.8	28.7	0.71	21
9b*	28.3	28.3	28.3	28.3	28.3	28.3	27.8	27.8	27.8	27.8	27.8	27.8	27.8	28.6	0.61	21

\*s = surface sample

b = bottom sample

Table 9. Measurements of pH and mean values ( $\bar{Y}$ ), standard deviation (s), and sample size (N) at the water quality monitoring stations.

STATION	J A N U A R Y													
	20	21	22	23	24	25	26	27	28	29	30	31	1	2
1	8.00	8.10	7.80	7.90	8.00	8.00	7.90	7.90	7.91	8.00	7.80	7.75	7.80	7.75
2	7.90	8.05	7.70	7.85	7.95	7.95	7.82	7.82	7.85	7.75	7.70	7.75	7.75	7.79
3s*	7.90	8.00	7.69	7.85	7.89	7.89	7.89	7.89	7.79	7.75	7.70	7.75	7.75	7.79
3b*	8.00	8.05	7.70	7.90	7.95	7.95	7.98	7.98	7.85	7.80	7.70	7.82	7.80	7.80
4	7.93	8.00	7.70	7.90	7.80	7.80	7.90	7.90	7.80	7.75	7.75	7.75	7.80	7.79
5	7.97	8.00	7.70	7.90	7.85	7.85	7.90	7.90	7.75	7.75	7.80	7.70	7.80	7.80
6s*	7.95	7.95	7.85	7.89	7.85	7.85	7.90	7.90	7.81	7.80	7.80	7.79	7.80	7.80
6b*	7.95	8.00	7.70	7.90	7.90	7.90	7.90	7.90	7.75	7.72	7.75	7.82	7.80	7.80
7	7.90	7.90	7.80	7.82	7.80	7.80	7.85	7.85	7.75	7.80	7.80	7.75	7.80	7.75
8	8.00	7.90	7.60	7.70	7.89	7.89	8.00	8.00	7.89	8.05	7.70	7.61	7.45	7.61
9s*	8.00	8.05	7.90	7.89	7.89	7.89	8.01	8.01	7.98	7.95	7.90	7.90	7.90	7.98
9b*	8.10	8.10	7.91	7.90	8.00	8.00	8.02	8.02	7.95	7.95	7.95	8.00	7.90	7.98

\*s = surface sample

b = bottom sample

Table 9. Cont.

STATION	3	4	5	J	A	N	U	A	R	Y	8	9	10	11	$\bar{Y}$	S	N
1	7.80	7.65	7.91	7.65	7.80	7.92	8.00	7.95	7.99	7.89	0.098	21					
2	7.79	7.85	7.95	7.81	7.82	7.81	7.90	7.82	7.89	7.83	0.086	21					
3s*	7.75	7.88	7.91	7.83	7.88	7.89	7.83	7.82	7.91	7.83	0.080	21					
3b*	7.80	7.88	8.01	7.88	7.88	7.82	7.81	7.80	7.88	7.86	0.095	21					
4	7.79	7.83	7.99	7.82	7.85	7.88	7.90	7.89	7.97	7.85	0.084	21					
5	7.78	7.85	8.00	7.81	7.87	7.89	7.90	7.89	7.90	7.85	0.087	21					
6s*	7.80	7.85	7.99	7.82	7.89	7.90	7.90	7.90	7.90	7.86	0.059	21					
6b*	7.85	7.89	8.00	7.85	7.89	7.88	7.89	7.85	7.89	7.86	0.082	21					
7	7.80	7.82	7.98	7.82	7.88	7.89	7.88	7.90	7.90	7.84	0.061	21					
8	7.60	7.72	7.70	7.75	7.81	7.95	7.92	7.98	8.01	7.80	0.173	21					
9s*	7.99	8.00	8.10	7.99	7.99	8.01	8.00	8.01	8.01	7.97	0.058	21					
9b*	8.00	8.01	8.10	8.00	8.00	7.99	8.00	8.01	8.01	7.99	0.053	21					

\*s = surface sample

b = bottom sample

Table 10. Total phosphorus, total kjeldahl nitrogen, nitrogen as nitrate-nitrite, and total nitrogen measurements in milligrams per liter (mg/l) at the water quality monitoring stations. All samples were collected on December 19, 1979.

STATION	TOTAL PHOSPHORUS	TOTAL KJELDAHL NITROGEN (TKN)	NITROGEN NITRATE-NITRITE	TKN + NITRATE-NITRITE	TOTAL NITROGEN
1	0.007	0.010	0.011	0.011	0.021
2	0.011	<0.010	0.015	0.015	<0.025
3s*	0.005	0.133	0.010	0.010	0.143
3b*	0.187	<0.010	0.006	0.006	<0.016
4	0.008	<0.010	0.005	0.005	<0.015
5	0.008	<0.010	<0.001	<0.001	<0.011
6s*	0.006	<0.010	0.017	0.017	<0.027
6b*	0.007	0.036	0.010	0.010	0.046
7	0.007	0.085	0.013	0.013	0.098
8	0.005	0.020	0.006	0.006	0.026
9s*	0.003	0.254	0.003	0.003	0.257
9b*	0.005	0.109	0.006	0.006	0.115

\* s = surface sample  
b = bottom sample

TABLE 11. Heavy metal concentrations of samples collected April 1, 1980 at the water quality monitoring stations. All concentrations are in micrograms per liter ( $\mu\text{g}/\ell$ ).

Station.	As	Cd	Cu	Pb	Hg	Ni	Zn	Cr
1	<2.0	0.8	3.1	160	1.7	0.6	12	57
2	<2.0	0.9	<0.7	338	0.8	0.5	13	56
3	<2.0	0.6	<0.7	300	<0.1	5.8	14	46
4	<2.0	0.9	1.0	206	<0.1	2.5	13	62
5	<2.0	1.2	1.5	362	<0.1	1.0	11	55
6	<2.0	0.9	<0.7	369	0.8	0.5	11	63
7	<2.0	0.8	0.8	375	0.4	0.2	16	56
8	<2.0	0.9	<0.7	369	<0.1	0.2	11	67
9	<2.0	0.7	<0.7	250	<0.1	0.2	<10	47
TTPI Standard	10	5	10	10	0.1	2	20	50

TABLE 12. Comparison of water quality at the water quality monitoring stations with the Trust Territory water quality standards for class AA waters.

Parameter	Range of Station Means (Stations 1-8)	Mean - Station 9 (surface, bottom)	Water Quality Standard (class AA Waters)
Temperature °C	28.5 - 28.9	28.6, 28.7	Ambient ± 0.9°C - all waters
Turbidity (NTU)	1.1 - 2.1	0.56, 0.54	Ambient ± 5%, 5 NTU <sup>1</sup>
Salinity 0/00	31.1 - 31.8	32.4, 32.5	Ambient ± 10% <sup>2</sup> - all waters
pH, units	7.80 - 7.89	7.97, 7.99	Ambient ± 0.2 units
Dissolved Oxygen (mg/l)	5.69 - 6.28	6.37, 6.31	Ambient ± 25% - all waters
Total Phosphorus <sup>3</sup> (mg/l)	0.005 - 0.011 <sup>4</sup>	0.003, 0.005	0.025
Total Nitrogen (mg/l)	<0.011 - 0.143	0.257, 0.115	0.400
Nitrogen:Phosphorus ratio <sup>5</sup>			Ambient ± 10%
Arsenic (µg/l)	<2.0 - all stations	<2.0	10
Cadmium (µg/l)	0.6 - 1.2	0.7	5
Chromium (µg/l)	46 - 67	47	50
Copper (µg/l)	<0.7 - 3.1	<0.7	10
Lead (µg/l)	160 - 375	250	10
Mercury (µg/l)	<0.1 - 1.7	<0.1	0.1
Nickel (µg/l)	<0.2 - 5.8	0.2	2
Zinc (µg/l)	11 - 16	<10	20

1 The recommended turbidity standard in this study is 5.0 NTU.

2 Change in salinity concentrations are referred to as "permanent change as a result of alteration of channels, basin geometry or freshwater influx".

3 Phosphorus, nitrogen and metal concentrations are ranges of observed concentrations not means.

4 One phosphorus measurement of 0.187 is not included since its validity is suspect.

5 There is insufficient data to compute a reliable baseline N:P ratio.

Table 13. Inter-area mean-value comparisons for the Babelthuap study area from Environmental Consultants, Inc. (1978).

Location	Turbidity (NTU)	Suspended Solids (mg/l)	T:SS (NTU:mg/l)	Phosphate ( $\mu\text{g-at/l}$ )	Nitrate + Nitrite ( $\mu\text{g-at/l}$ )	Ammonia ( $\mu\text{g-at/l}$ )	Chl. a ( $\text{mg/m}^3$ )	T.P	T.N.
Garusaru Stream	19.2	19.3	0.92	1.51	0.37	1.28	0.62	1.70	17.7
Area 1	3.7	7.6	0.50	0.21	0.33	0.14	0.61	0.35	11.4
Area 2	0.84	2.5	0.42	0.26	0.48	0.15	0.24	0.28	9.1
Area 3	5.3	8.2	0.67	0.36	0.33	0.12	0.53	--	10.7
Airai Bay	1.3	2.5	0.57	0.22	0.11	0.06	0.28	0.25	9.2
Ngerikil River									
Top	5.7	3.6	1.61	3.14	0.27	0.84	0.20	--	8.5
Bottom	3.6	5.9	0.62	0.39	0.31	0.36	0.73	--	13.6

\*Location description:

- Garusaru Stream - near the mouth of the Garusaru Stream.
- Area 1 - immediately adjacent to and surrounding the existing dragline causeway.
- Area 2 - outer Ngurusar Bay.
- Area 3 - near Airai Village.
- Area 4 - Airai Bay proper
- Ngerikil River - near the mouth of the Ngerikil River