A PRELIMINARY STUDY OF NATURAL AQUIFER DISCHARGE ON GUAM

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Water and Energy Research Institute

of the

Western Pacific

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Project Completion Report

for

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ABSTRACT

Water from groundwater seepage and springs along the northwest coast of Guam was collected and analyzed bimonthly over an eight month period to determine water quality characteristics. Additionally, water in three caves and one open sink hole along the coast (though not connected at the surface with the sea) were similarly analyzed for comparative purposes. All samples were collected by grab sampling. The shoreline stations were sampled during lower low spring tides. Marine waters approximately five meters outward from the spring collection site were also analyzed for inorganic nutrients, chlorophylls a, b, and c, and carotenoids.

Water quality tests indicate that shoreline seepage averages six to seven percent seawater as based on chloride and sulfate concentrations. The larger springs have two to three percent seawater. Caves and sink hole waters average three percent seawater. Hence, very little dilution takes place with seawater prior to groundwater discharge at the surface. Nitrate-nitrogen concentrations fall within the same range observed for most well groundwater (i.e., 1 to 2 mg/ℓ NO_3-N). Other inorganic nutrients (NH_3-N, NO_2-N and PO_4-P) are also close to typical groundwater concentrations or only slightly higher. Coliform bacteria were absent or few in number in almost all samples excepting those collected near a sometimes overflowing sewage collection system.

Separate analyses of marine waters adjacent to the groundwater seepage areas found higher chlorophyll and carotenoids concentrations (chlorophyll a averaged 1.0 mg/m^3) than observed in waters in the same area removed from shore. Nutrient concentrations, particularly NO_3-N, were frequently in excess of the established water quality standard (0.20 mg/ℓ) for NO_3-N in these waters.

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INTRODUCTION

Guam can be divided into two distinct hydrogeologic areas, a limestone northern plateau and a volcanic southern upland. The only major exceptions to this scheme are volcanic outcropings at Mt. Santa Rosa and at Mataguac Hill in Yigo and the narrow band (1km wide or less) of limestone substrata that extends along the southeast coast of Guam from Ipan to Inarajan.

The limestone substrata is very porous due to the manner in which it was deposited (a heterogenous mixture of coral growth and detrital deposition) and its inherent physical and chemical nature. Rates of water flow through limestone range anywhere from tens to nearly a hundred meters per day depending upon the purity of the limestone and its structural integrity. Because the northern limestone plateau is very thick (well over 100 meters in areas) a large volume of rainfall becomes percolate in the limestone and percolates to sea level where it forms a lens of freshwater floating on seawater. The water in this lens flows outward toward the edge of the plateau and eventually mixes with seawater at an interface zone that separates seawater from freshwater. Along the shoreline, during tides below the lower low mean level, the elevation of the freshwater lens exceeds that of the seawater. This results in the formation of freshwater springs or seeps at the surface. This flow is observed at all the major beaches in Northern Guam (Figure 1 and 2).

Large and small fissures and faults extend throughout the limestone substrata. These fissures arise from discontinuities in the deposition of the limestone parent material combined with natural faulting and dissolution by carbolic acid and other organic acids picked up by percolating rainfall in the surface soil layer. These fissures often lead to shoreline areas where extensive outflows of freshwater occur from countless tiny seeps or from a few large springs with discharges of hundreds to hundreds of liters per minute.

The groundwater of Northern Guam is very hard because it percolates through thick limestone deposits. Mink (1978) describes the aquifer water quality with respect to the influence of limestone. The groundwater also contains relatively large concentrations of nitrate-nitrogen, typically averaging 1-2 mg/ℓ NO_3-N but with some wells averaging from 4 to 5 mg/ℓ NO_3-N. The nitrate is derived from biological sources in the soil layer overlying the limestone (Mink, 1976). Adsorption and percolation studies using limestone have shown that phosphorus is readily adsorbed while nitrate is unadsorbed when the percolate NO_3-N and PO_4-P concentrations were those characteristic of surface runoff from residential and commercial development areas (Zolan et al., 1978). In a later study using sewage effluent where the concentrations of nitrate-nitrogen and phosphate-phosphorus were two orders of magnitude higher (i.e. 3-4 mg/ℓ phosphate-phosphorus) the adsorption capacity of limestone for phosphate was reached and the limestone eventually released phosphorus to the percolate (Cowan and Clayshulte, 1980).

The levels of nutrients in the groundwater are particularly important because they encourage algal and plant growth. Marine tropical waters characteristic of open reef flats that are not directly influenced by river runoff have very low nutrient levels (Marsh, 1977). The increased concentration of nutrients along shoreline areas where groundwater seepage and

Figure 1. Groundwater seep flow characteristic of the Ypao Beach, Gongna Beach and Hilaan Point sampling stations. (This photo was taken at the Ypao Beach sampling area near the Pacific Island Hotel.)

Figure 2. Spring discharge north of the pillbox at Ypao Beach. Springs issue from several vents where observer is standing.

springs are located commonly results in blooms of phytoplankton and aggregation of macroalgae. The growth and abundance of the predominant algae in these areas, Enteromorpha clathrata, has been directly related to the presence of groundwater flows and to higher levels of nutrients in water (Fitzgerald, 1976). Water quality standards (GEPA, 1981) for nearshore waters in the areas under investigation allow 0.20 mg/ℓ NO_3-N. Under the general criteria of the regulations, discharges which result in the propagation of undesireable aquatic life are prohibited. Nutrient enrichment from seeps and springs would lead to violations of this water quality standard if the enrichment was the result of man-made discharge instead of natural phenomena.

OBJECTIVE

The primary objective of this study is to investigate the quality of groundwater seeps along the northern coast of Guam to determine if major regional differences in quality exist. Samples are collected over an eight month period to evaluate the consistency of seepage water quality. A further objective of the study is to determine the effects of groundwater discharge on the immediate marine receiving waters through the measurement of inorganic nutrients, chlorophyll and carotenoid pigments.

METHODS AND MATERIALS

Sampling Site Selection and Description

Sampling sites were selected to cover most of those shoreline areas where spring discharges are commonly observed (Figure 3). Sites were restricted to those with relatively easy access during low spring tides and with a minimum of surface marine water influence. Areas along Uruno Beach and beaches north to Tarague were not sampled due to strict military security regulations, and their comparative inaccessibility. No large spring sources such as those occurring on the reef flats of Tumon and East Agana Bay are known for the Uruno area. One large spring exists at the southern end of Haputo Beach. The landowners (the Artero family) of the Uruno area report that no cenote or water filled caves exist in the Uruno area.

The spring discharging into the storm drain at Trinchera Beach in East Agana Bay (commonly referred to as NAS storm drain) was selected because it is one of the largest near-shore springs. Samples were collected at the mouth of the storm drain pipe. The samples at this site that were affected by surface runoff are noted in the data tables. A smaller storm drain 20m north of the large pipe was sampled once after a heavy rain to obtain surface runoff water for comparative purposes. The storm water drainage system and some groundwater springs were included in an urban runoff study conducted in 1975-1977 (Zolan et al., 1978). These analyses can be compared with the 1981 results to see if water quality has changed during the intervening five-year period.

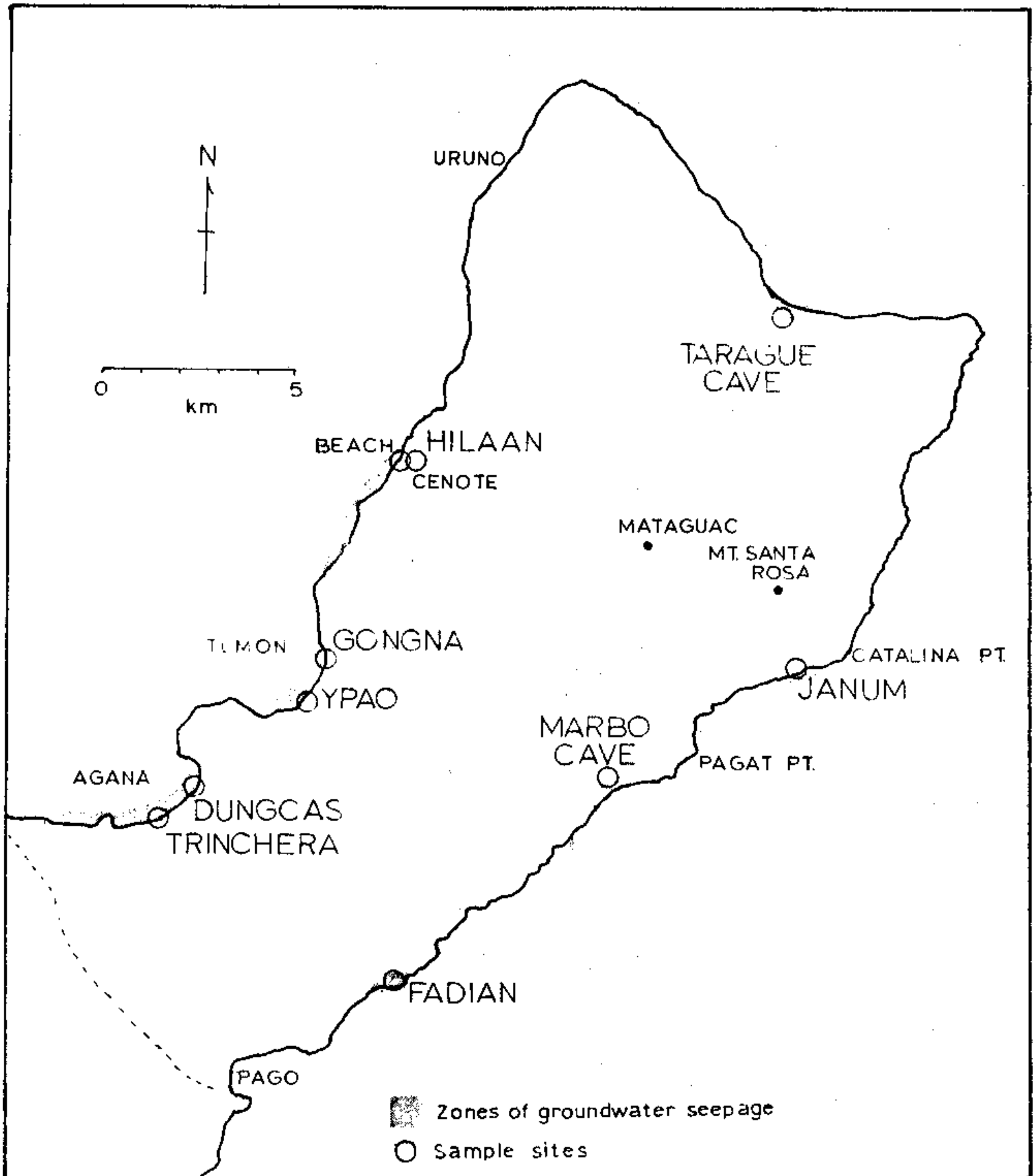

Figure 3. Map of Northern Guam showing beach areas with major groundwater seepage areas and sampling locations (circles). (Smaller seepages occur at Pago Bay, Uruno and Tarague Beaches.)

The Dungcas Beach station consists of a large spring site situated about 50m north of the sewage pumpstation below Camp Watkins Road at the Alupang Street turnoff. The spring wells up in a large flat delta pan (Figure 4) formed by the spring and a stream adjacent to the pumpstation. Many springs exist in the area, particularly in the channelized stream, 80 to 100m upstream from the pumpstation. The stream flow is similar to that of NAS storm drain. The stream was not sampled because of significant surface water flow resulting from recent modifications in the storm drain system. It was initially expected that the springs at Dungcas Beach would be of reduced water quality because of their location directly on the reef flat.

The Ypao site was selected from many possible sampling points running from the Pacific Islands Hotel beachfront to the Dai-ichi Hotel. Several large spring sources lie off the beach in marine water and could not be sampled (Figure 5). Beach rivulet seepage (Figure 1) was used instead. Sometimes, a pool was formed to collect from several seepage points and then sampled. The main area of sampling was 50m northeast of the Japanese pillbox when surf and tide conditions permitted. The Hilaan Point sampling site resembles the Ypao Beach sampling site in that it consists of small seeps. Because of the relatively steep beach angle at the site, the seepage points were close to the marine water edge, even during low tides.

The Gongna Beach station is located at the far northern edge of the beach fronting the Okura Hotel. Water forms a pool in a boulderous area and then flows to the sea (on lower low tides). The seepage points are significantly above the sea during these low tides. As a consequence, it was expected that water quality at this station would be considerably better than observed at Ypao and Hilaan point.

To observe how the proximity of the seepage points to marine waters affected marine water quality, four sampling points were selected that were close to the coast but physically cut off from the sea at the surface. These sampling sites consisted of pooled water in caves or cenote. The sites selected included the cave near Fadian Point, Marbo Cave, the Tarague Cave once used for drinking water supply, and the Hilaan Cenote. All of these sites are formations derived from solution of the limestone substrata in northern Guam and are along the coast. The Tarague site houses an old pumpstation that was abandoned by the Air Force in the late 1960's as a source for drinking water. Marbo Cave was also once used for drinking water but was likewise abandoned in the 1950's when better quality water was developed from surface sources and groundwater.

The Hilaan Cenote (Figure 6) is 34m in diameter and approximately 2.3m deep (Muniappan, 1976). It is directly inshore from a similar sink hole in the fringing reef just north of Hilaan Point. The level of water responds to tidal action and falls in synchronization with low tides at the shore line. The cenote supports a rich and distinct flora assemblage around its margin (Figure 6). Samples were collected on the western side of the cenote.

Figure 4. Dungcas Beach sampling site with exposed delta pan.

Figure 5. Large springs south of Hilaan Pt. Similar springs also occur at several places along the Tumon shoreline.

Figure 6. Hilaan cenote. The cenote lies in a basin about 5m below the level of the surrounding terrain on the north and east sides. The west and southern margins slope gradually upward toward the coconut grove inland from the beach.

Sampling and Water Analyses

Samples were collected at lower spring tides twice a month from December 1980 to August 1981, excluding April when no samples were collected and July when three sets were collected. Grab samples were collected at the spring or seepage source(s). At Ypao, Hilaan Point, and Gongna beaches, a small hole was excavated at the spring source by hand to allow enough water to collect for sampling. Sufficient time (approximately two minutes) was allowed for the pool to flush prior to taking a sample. Dissolved oxygen samples were fixed immediately upon collection and transported to the lab along with other samples for analyses. Because spring low tides occur from 2300 to 0400 during the months of December through April, sampling was conducted at night during this period. This complicated the sampling procedure since a few sites were 10 to 20 minute walks from the nearest road.

Sampling at the caves was conducted during daylight hours irrespective of tidal state and followed approximately the same schedule as the beach collections. Janum spring was sampled on three occasions (it can only be safely reached during periods of extreme low tides and calm surf). This spring was included to evaluate changes in water quality caused by changing seasons. Observers had reported dramatic increases in the silt load of the spring after heavy rains.

Starting in May and continuously through August, additional samples for chlorophylls *a*, *b*, *c*, carotenoid pigments, ammonia-nitrogen, nitrate-nitrogen, and phosphate-phosphorus were collected from marine waters in front of groundwater springs at the beach stations. These grab samples were collected approximately five meters from the spring source. Variations in the offshore sample collection distances between sampling dates were sometimes necessary because of the variations in tidal heights. Samples were collected from waters 0.1 to 0.3 meters deep, regardless. A list of all the parameters and methods used for analyses is presented in Table 1.

Some earlier inconsistent and dubious results from specific ion-probe analyses of waters for nitrate-nitrogen are not presented. The cadmium reduction method of analysis was used exclusively for nitrate-nitrogen analyses in the later three-fourths of the study. Chauvenet's criterion (Neville and Kennedy, 1964) was used to delete data that were an erroneous reading or an extreme outlier. Appendix D lists all data so rejected.

RESULTS AND DISCUSSION

The seeps, springs, and the cenote along the northern coast of Guam have water of fairly consistent quality (Table 2). Because the influences of tidal height and surf conditions were not a constant, fluctuations in quality were expected at those stations influenced by those factors. The shoreline seeps (Ypao Beach, Gongna Beach, and Hilaan Point) had the greatest variability in quality. The Trinchera Beach and Dungca Beach sampling stations are at larger springs and gave more consistent results. Springs, because of their greater volume of discharge are less affected by tidal fluctuation, and particularly, wave-surge.

Table 1. Methodology of parameters measured during the study.

PARAMETER	METHOD	REFERENCE
pH	glass electrode method	Standard Methods, 15th edition
Temperature	mercury thermometer	" "
Turbidity	nephelometric method, Hach 2100 Model turbidimeter	" "
Total Residue	evaporation at 105°C	" "
Filterable Residue	glassfiber filter	" "
Total Non-Filterable Residue	total residue minus fiterable residue	" "
Total Alkalinity	potentiometric titration	" "
Chloride	mercuric nitrate	" "
Sulfate	turbidimetric method	" "
Hardness	EDTA titrametric method	" "
Calcium Hardness	EDTA titrametric method	" "
Dissolved Oxygen	iodometric-azide titration	" "
Orthophosphorus	ascorbic acid reduction	A Practical Handbook for Seawater Analysis
Nitrite-Nitrogen	sulfanilamide diazotization	A Practical Method for Seawater Analysis
Nitrate-Nitrogen	cadmium reduction	A Practical Method for Seawater Analysis
Total Coliform	membrane filter	Standard Methods, 15th edition
Fecal Coliform	membrane filter	" " " "
Chlorophylls a, b, c, and carotenoids	acetone extraction, spectrophotometric	A Practical Handbook of Seawater Analysis
Silica-Silicon	molybdosilicate	Standard Methods, 15th edition
Ammonia-Nitrogen	phenol-hypochlorite	" " " "

Table 2. Results of water quality analyses. Concentrations are in mg/ℓ unless noted otherwise. The mean concentration for coliform bacteria are geometric means.

Parameter $\bar{x}$ Mean S Std. deviation R Range N No. of samples		STATIONS Trinchera Beach	Dungcas Beach	Ypao Beach	Gongna Beach	Hilaan Point
pH	$\bar{x}$	7.34	7.24	7.48	7.44	7.59
	S	0.35	0.22	0.25	0.20	0.21
	R	7.04-7.72	6.78-7.57	7.06-7.97	7.10-7.74	7.27-7.89
	N	13	14	14	14	13
Temp °C	$\bar{x}$	27.6	27.8	26.7	26.8	27.0
	S	1.6	1.5	1.4	1.2	1.4
	R	24.0-30.0	25.0-30.0	24.0-29.0	25.0-29.0	24.0-29.0
	N	13	12	12	13	10
Filterable Residue	$\bar{x}$	1020	1190	2800	5950	3760
	S	410	370	460	1870	2280
	R	190-1520	800-2140	2080-3380	3770-9150	2220-9920
	N	12	12	12	13	11
Total Alkalinity	$\bar{x}$	510	626	479	464	422
	S	52	31	46	24	18
	R	138-622	586-686	417-614	429-519	390-454
	N	13	13	14	14	13
Total Hardness	$\bar{x}$	393	473	656	1110	731
	S	96	56	76	204	168
	R	92-470	407-610	519-767	840-1450	572-1100
	N	12	14	14	14	13
Calcium Hardness	$\bar{x}$	297	344	328	412	321
	S	46	41	36	50	31
	R	234-388	243-384	258-382	380-504	264-360
	N	11	13	13	13	12
Dissolved Oxygen	$\bar{x}$	5.2	2.7	1.2	5.0	5.1
	S	1.2	0.6	0.6	0.9	0.8
	R	3.1-8.2	1.6-3.9	0.5-2.5	3.1-6.9	3.4-6.6
	N	13	14	14	14	12
Chloride	$\bar{x}$	451	358	1190	2840	1450
	S	125	80	187	948	470
	R	123-579	305-469	919-1460	1730-4350	1000-2700
	N	11	12	12	12	10
Sulfate	$\bar{x}$	69	51	167	355	189
	S	8.4	7.2	42	88	65
	R	57-84	38-61	114-238	250-532	110-346
	N	12	10	12	11	9
Nitrite-N	$\bar{x}$	.015	.028	.003	.005	.006
	S	.025	.072	.004	.008	.009
	R	.001-.099	<.001-.267	<.001-.012	<.001-.022	<.001-.028
	N	14	15	14	14	13
Nitrate-N	$\bar{x}$	2.19	2.23	1.49	2.27	1.77
	S	.580	.402	.721	.608	.668
	R	.831-2.91	1.78-3.01	.415-2.36	1.49-3.13	1.05-2.73
	N	9	10	10	11	9

Table 2. Con't.

Parameter x̄ Mean S Std. deviation R Range N No. of samples		Trinchera Beach	Dungcas Beach	Ypao Beach	Gongna Beach	Hilaan Point
Ammonia-N	x̄	.086	.051	.048	.051	.045
	S	.088	.040	.028	.040	.048
	R	.002-.356	<.001-.124	.002-.084	<.001-.120	<.001-.167
	N	14	13	14	14	12
Phosphate-P	x̄	.016	.011	.006	.018	.013
	S	.014	.010	.005	.006	.006
	R	.002-.059	<.001-.027	.001-.019	.004-.029	<.001-.021
	N	14	15	13	14	12
Silica-Silicon	x̄	.005, .004*	.044	.012	.014	.014
	S	----	.028	.007	.006	.002
	R	----	.024-.063	.007-.017	.009-.018	.013-.016
	N	1	2	2	2	2
Total Coliform (col./100 mℓ)	x̄g	14	10	2	9	3
	S	----	----	----	----	----
	R	0-60,000	0-<2,000	0-10	0-100	0-11
	N	8	8	8	8	7
Fecal Coliform (col./100 mℓ)	x̄g	7	3	1	1	1
	S	----	----	----	----	----
	R	0-1,000	0-17	0-3	0-8	0-7
	N	8	8	8	8	7
Shore waters Nitrate-N	x̄	.227	.327	.063	.679	.317
	S	.224	.316	.042	.565	.255
	R	.008-.543	.008->.860	.004-.110	.014-1.71	.022-.656
	N	6	6	6	6	6
Shore waters Ammonia-N	x̄	.080	.108	.087	.078	.082
	S	.015	.027	.048	.039	.020
	R	.052-.096	.072-.155	.040-.161	.049-.164	.052-.114
	N	6		6	6	6
Shore waters Phosphate-P	x̄	.005	.080	.008	.030	.022
	S	.005	.122	.007	.026	.025
	R	<.001-.013	.005-.298	<.001-.012	.009-.068	.006-.066
	N	5	5	5	5	5
Shore waters Chlorophyll a (mg/m³)	x̄	1.21	7.09	1.10	0.86	0.87
	S	0.58	8.07	0.50	0.40	0.26
	R	0.46-2.00	0.67-22.6	0.55-1.96	0.58-1.82	0.50-1.38
	N	8	8	8	8	8
Shore waters Chlorophyll b	x̄	0.59	3.82	0.83	0.66	0.45
	S	0.35	3.50	0.31	0.34	0.36
	R	<0.10-0.67	0.58-10.5	0.40-1.34	<0.10-1.06	<0.10-0.96
	N	8	8	8	8	8
Shore waters Chlorophyll c	x̄	0.30	0.79	0.14	0.14	0.23
	S	0.79	2.14	0.40	0.29	0.60
	R	<0.10-2.09	<0.10-6.09	<0.10-1.12	<0.10-0.80	<0.10-1.58
	N	7	8	8	8	7
Shore waters Carotenoids (mg/m³)	x̄	0.80	6.68	0.71	0.54	0.55
	S	0.51	8.58	0.45	0.39	0.43
	R	<0.10-1.39	0.46-24.8	<0.10-1.60	<0.10-1.31	<0.10-1.28
	N	8	8	8	8	8

* Surface runoff

Table 2. Con't.

Parameter x̄ Mean S Std. deviation R Range N No. of samples		STATIONS Hilaan Cenote	Perez Bros. Fadian Cave	Marbo Cave	Tarague Cave	Janum Sp.
pH	x̄	7.53	7.77	7.59	7.57	7.30
	S	0.22	0.29	0.21	0.24	0.08
	R	7.20-7.89	7.28-8.27	7.30-7.92	7.20-7.91	7.24-7.39
	N	14	12	11	11	3
Temp °C	x̄	27.3	27.2	27.5	27.0	25.8
	S	1.4	0.6	1.0	1.2	3.5
	R	25.0-30.0	26.0-28.0	26.0-29.5	26.0-29.0	22.0-29.0
	N	13	11	11	9	3
Total Nonfilterable Residue	x̄	6.2	7.4	3.8	6.5	3.2
	S	11	8.5	5.5	6.7	2.6
	R	0.2-35.4	0.3-28.8	0.1-18.3	0.1-22.2	0.6-5.9
	N	9	11	10	9	3
Filterable Residue	x̄	1240	1530	1350	550	199
	S	190	800	550	120	132
	R	860-1530	320-2830	540-2630	360-772	52-310
	N	12	12	13	11	3
Total Alkalinity	x̄	407	304	340	366	447
	S	38	147	6.3	8.0	27
	R	284-431	217-493	327-349	348-375	431-478
	N	14	12	11	11	3
Total Hardness	x̄	413	398	363	258	233
	S	65	202	26	20	-----
	R	337-584	134-693	315-420	238-298	1
	N	13	12	11	11	-----
Calcium Hardness	x̄	266	247	206	214	156
	S	29	129	24	23	-----
	R	234-281	86-421	173-251	176-240	1
	N	13	11	10	10	-----
Dissolved Oxygen	x̄	5.5	6.6	7.2	7.4	6.9
	S	1.1	0.9	0.4	0.3	0.3
	R	3.8-7.3	4.9-7.7	6.5-8.0	7.2-7.9	6.7-7.3
	N	13	12	11	11	3
Chloride	x̄	486	672	545	173	88
	S	120	399	54	27	95
	R	186-607	176-1250	464-631	132-212	30-198
	N	12	11	11	11	3
Sulfate	x̄	74	94	72	17	1.7
	S	12	58	10	4.0	0.2
	R	54-90	19-173	49-85	12-22	1.5-1.9
	N	10	10	11	8	2
Nitrite-N	x̄	.017	.009	.002	.005	<.001
	S	.020	.010	.002	.008	
	R	<.001-.060	<.001-.035	<.001-.009	<.001-.024	<.001-<.001
	N	14	13	11	11	3
Nitrate-N	x̄	1.44	2.03	1.85	1.44	1.49
	S	.274	.484	.036	.061	.046
	R	1.17-1.92	1.47-2.79	1.80-1.90	1.34-1.54	1.45-1.54
	N	8	9	6	8	3

Table 2. Con't.

Parameter x̄ Mean S Std. deviation R Range N No. of samples		STATIONS Hilaan Cenote	Perez Bros. Fadian Cave	Marbo Cave	Tarague Cave	Janum Sp.
Ammonia-N	$\bar{x}$	.047	.064	.052	.060	.044
	S	.042	.057	.021	.030	.008
	R	.001-.127	.001-.222	.022-.094	.003-.111	.040-.053
	N	12	13	10	10	3
Phosphate-P	$\bar{x}$	.010	.018	.009	.012	.017
	S	.005	.018	.004	.008	.019
	R	<.001-.019	.003-.074	.004-.015	.004-.024	.004-.039
	N	13	13	11	11	3
Silica-Si	$\bar{x}$	.012	.022	.008	.009	.233
	S	.008	.008	.006	.004	-----
	R	.006-.017	.016-.027	.004-.012	.006-.012	-----
	N	2	2	2	2	1

Because the spring at the Trinchera Beach is diverted into a storm drain system it is influenced by surface runoff when it rains (Table A-1). A couple of samples appear to have been so influenced (the March 16th and July 17th samples). A separate sample of strictly surface runoff collected August 17th from an adjacent drainage pipe shows the characteristics of exclusively surface runoff for comparison with normal spring water. Surface runoff contributes bacterial contamination and results in dilution of inorganic chemical parameters.

Precipitation did not affect the water quality of the seepage waters when the rainfall activity (Appendix B) of the previous day and the five days previous to sampling date are compared to the water quality of groundwater seepage. A longer lag time may occur between rainfall activity and a change in water quality.

The caves and the cenote at Hilaan produced water of the most consistent quality. However, the cave at Fadian Point which is pumped intermittantly by Perez Bros. and Guam Aqua Research varied considerably in quality (Tables 1, A-7). At times, this pumpage exceeds 60 gallons per minute.

In comparison to Guam potable drinking water standards (GEPA, 1981) only waters from the Tarague cave were potable. Chloride concentrations at Tarague ranged from 132 to 212 mg/ℓ which are below the 250 mg/ℓ standard for potable waters. These results compare favorably with the results of chloride analyses performed in the late 1960's when pumping had stopped (Appendix C). Mean chloride concentrations of other stations ranged from 358 mg/ℓ at Dungcas Beach to 2840 mg/ℓ at the Gongna Beach station (Table 2). The Hilaan cenote, which is associated with prehistoric chamorro habitation, had a mean chloride concentration of 486 mg/ℓ. While undesirable by present standards, the waters continuous availability during dry weather makes it a valuable resource in an area devoid of other surface water resources. The other cave sites at Tarague and Fadian have also been associated with pre-contact (i.e., before contact with western civilization) settlements (Guam Historic Preservation Plan, 1976).

The presence of seawater in the groundwater was found to produce higher filterable residue, total alkalinity, hardness, chloride and sulfate in the tested groundwater. Other parameters such as pH, nitrate-nitrogen phosphate-phosphorus appear close to normal groundwater concentrations found in production wells (Appendix C).

Dissolved oxygen concentrations varied according to the site. The Hilaan cenote and cave waters were high in dissolved oxygen though the cenote was below saturation. The Trinchera Beach springs were also well-oxygenated but this could have occurred after its appearance at the surface. Seeps at Hilaan Point and Gongna Beach both had mean dissolved oxygen concentrations in excess of 5 mg/ℓ. The Ypao and Dungca Beach seeps were low in oxygen with some samples below 1 mg/ℓ. How the Hilaan Point and Gongna Beach seeps managed to have higher dissolved oxygen levels when they resembled, physically, the Ypao seeps is not known.

Input of nitrite-nitrogen occurs in the Trinchera Beach and Dungcas Beach springs from some unknown source. At Dungcas Beach, a well-developed and stable reducing environment in the delta pan sediments exists. This may account for the nitrites in these waters. As the sediments of the other shoreline stations were more disturbed by wave and current action, the anaerobic zone in the sediments there may not be as strong a reducing element. The pH of the Dungcas Beach springs was the lowest of any station studied. However, ammonia concentrations at the Dungcas Beach site did not differ much from other stations.

Phosphate-phosphorus concentrations in the seeps were slightly higher than those found in groundwater. Well groundwater concentrations of phosphate-phosphorus are usually below .010 mg/ℓ. Mean concentrations of phosphate-phosphorus in the seeps ranged from .009 to .018 mg/ℓ at all stations except Ypao where the mean concentration was .006 mg/ℓ. This increased phosphorus level may indicate that the thinness of the limestone and soil layers over the water table in the shoreline areas may allow some pollutants in the local percolating waters to reach the water table.

Based on the amount of chloride in the samples, the stations had, at most (Gongna Beach), twenty per cent seawater composition on any particular sampling. On an average, the amount of seawater was much lower at all stations. Trinchera Beach and Dungcas Beach waters, which are springs, along with the Hilaan cenote, were comprised of about two per cent seawater. The beach seeps (except Gongna) ranged from six to seven percent seawater composition. Both Fadian and Marbo Cave, perhaps because they reach lower in elevation, had slightly higher salt content (three per cent) than the shoreline springs at Trinchera and Dungcas beaches. One would expect, therefore, that the nitrate levels in the seeps would be relatively unaffected by dilution and be at high concentrations. Nitrate-nitrogen concentrations in the groundwater seepage zone did reflect the levels commonly observed in groundwater production wells (i.e., 1-2 mg/ℓ). The combined result of elevated phosphorus concentrations (zero to six times the ambient seawater concentrations) and high nitrate concentrations (nearly 300 times ambient) results in the nutrient enrichment of the nearshore waters as pointed out by Marsh (1977).

Coliform bacteria (total and fecal) tests were conducted on the shoreline seep water to observe if the groundwater is bacterially contaminated as it rises to the surface. Results show that some minor contamination does exist (Tables 2 and A-1 to A-5). However, the bacterial concentrations are usually well below water quality limits placed on these marine waters (70 colonies/100 mℓ). This is the case even at Dungcas Beach were bacterial contamination of marine surface waters is chronic due to an overloaded (and poorly located) sewage disposal system. Only one of eight Dungcas samples showed gross total coliform contamination. This would indicate that current urban development and activities along the shoreline do not contribute much bacterial contamination to the groundwater prior to its discharge at the surface. Surface runoff via storm drains, streams, and wash out from the beaches themselves are the only significant causes for bacterial contamination of near-shore marine waters. Hilaan cenote and cave waters were not tested for bacterial contamination because they are frequently visited by persons for recreation and in the case of Hilaan cenote, wild deer, boar and birds are probable visitors as well.

Nutrients and chlorophyll concentrations in nearshore waters were obtained five meters from the discharge point. The near-shore nutrient and chlorophyll samples were obtained well beyond five meters at the Dungcas Beach site because the entire area within five meters is usually exposed during low tide. All stations showed concentrations of nitrogen and phosphorus at levels in excess of those found in marine waters removed from shore. Nitrate levels were frequently well above the water quality standards of 0.2 mg/ℓ for nitrate-nitrogen (GEPA, 1981). Unexpectedly, both phosphate-phosphorus and particularly ammonia-nitrogen were above seepage water concentrations for these nutrients (Tables A-1 to A-5). Unless there is some breakdown of organic material in marine waters occurring as a result of isolation during low tides in combination with the effects of higher temperatures and lower salinities, the only other source of these higher nutrient concentrations are the sediments themselves. This may occur continuously but is not observed when currents are flowing and diluting these waters more effectively. The sediment deltas deposited in places of nutrient enriched groundwater seepage may serve as nutrient traps which also slowly leak these nutrients back into the water column. These possible explanations need further testing to determine their validity.

The concentration of chlorophylls and carotenoids in the near-shore waters around the seepage areas were highly variable. However, as expected, the results showed concentrations in great excess over the concentrations observed off the fringing reef where concentrations of chlorophyll a average 0.2 mg/m^3 (Birkeland and Kitalong, 1982). Near-shore areas covered in this study ranged from 0.5 to over 22 mg/m^3. Typically, concentrations ranged from 0.6 to 2.0 mg/m^3 except at Dungcas Beach where the extremely higher concentrations occurred. Chlorophyll b concentrations were the next most abundant chlorophyll pigment with chlorophyll c usually least abundant. This would tend to indicate that the phytoplankton crop (and any small fragments of macroalgae) were dominated by green or blue-green algae. Carotenoids, calculated according to the Strickland and Parsons (1972) equation for chlorophyta or cyanophyta dominated crops yielded concentrations below detectable limits (0.1 mg/m^3) to about 2 mg/m^3 excepting Dungcas Beach. At this station, carotenoids ranged from 0.5 to 24.8 mg/m^3. These pigment concentrations indicate that the near-shore zone is relatively productive and/or collects the products of primary production.

The few samples (three) collected from Janum Spring which issues from the limestone cliff above the limestone bench reef east of Mt. Santa Rosa are relatively high in silica (Table A-10) despite its surface association with limestone. This is not typical of the rest of the groundwater in northern Guam and signifies that Janum spring waters contact volcanics prior to reaching the limestone area of coastal discharge. However, the silica concentrations are well below (<10% or less) those observed in small surface streams of southern Guam (Zolan, 1981). The water is similar in nitrate-nitrogen concentration (1.5 mg/ℓ NO_3-N) to the groundwater wells. It was also noticed that turbidity and TNFR increased in the waters after a heavy rainfall (TNFR which was less than 1 rose to nearly 6 mg/ℓ). All this indicates that Janum Spring may be derived from multiple sources. One source lies relatively deep on a volcanic layer below or behind the limestone surface layer. The second source(s) which probably are intermittant and seasonal, consists of runoff which connects with the primary source almost directly from the surface via a sink hole(s) or a crevice above the volcanics or limestone. The first source contributes the observed silica, nitrate (via surface percolation) and other predominant chemical characteristics. The second source(s) contributes sediments and dilutes or temporarily increases the chemical concentrations in the primary source. The oxygenated saturated waters of Janum also show that considerable contact with the atmosphere occurs just prior to the spring discharge point.

SUMMARY

The water quality of groundwater seepage at the surface of beaches in Northern Guam is similar throughout the areas studied. The groundwater of the smaller seeps, most characteristic of shoreline seepage areas, contains six to seven percent seawater. Larger, spring-like flows are purer with only two to three percent seawater. The waters located in caves and cenote, close to the shoreline but cut off from direct marine water contact at the surface, average three percent seawater.

The seepages at the shoreline are variable in quality because of effects from surf and tidal conditions. The spring-like discharges and particularly the caves gave more consistent results. However, Fadian Cave, which is pumped by two business concerns, showed great variability with chloride concentrations ranging from 176 to 1250 mg/ℓ. Chloride concentrations at Marbo Cave and Tarague Cave ranged from 464 to 631 and 132 to 212 mg/ℓ, respectively.

The relatively small dilution effect on the groundwater seepage by seawater renders the seepage practically undiluted with respect to groundwater chemical constituents. Nitrate-nitrogen concentrations fall within the usual 1-2 mg/ℓ NO_3-N average observed in groundwater wells. Any contaminant in the groundwater will be present in shoreline seepage with practically no dilution effect. Because the seawater is very concentrated in filterable residue (dissolved solids), its presence in the groundwater seeps is sufficient to raise filterable residue, total alkalinity, hardness, chlorides and sulfates to objectionable levels in relation to water quality standards for potable water.

Bacterial contamination in the seepages was only minor, indicating that groundwater bacterial contamination via urban developments of the shoreline areas is not a problem. Shorewater bacterial contamination occurs via surface runoff or beach washout by waves or rain.

Marine waters within 5 meters of the seeps and springs show greatly elevated nutrient concentrations (primarily NO_3-N, but also NH_3-N and PO_4-P over reef flat waters removed from groundwater influences). These affected waters were also somewhat higher than the seepage groundwaters in NH_3-N and PO_4-P indicating possibly some sediment nutrient input into surrounding waters. Chlorphylls a, b, and c plus carotenoids were elevated three to twenty fold from concentrations observed at or beyond the reef margin. Sites of _Enteromorpha clathrata_ growth are clearly related to sites of seep areas or springs. However, besides nutrient availability, the growth may also be related to the removal of fine sands from the spring area by groundwater flow and/or wave action, leaving larger substrate particles exposed for algal attachment.

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APPENDIX A

Sampling and Analyses Data for each Station

Table A-1. Sampling and analyses data for Trinchera beach groundwater seepage and receiving marine waters.

DATE	SAMPLING TIME	pH	TEMP C°	FR mg/ℓ	TNFR mg/ℓ	T.Alk. mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ
12-15-80	1050	----	----	---	---	---	----	----	---	---	---	.356	.012	.831
12-26-80	0715	----	28°	---	---	---	----	----	---	---	----	---	----	---
1-12-81	0500	7.41	----	1380	---	526	444	320	4.6	572	72.0	<.005	.003	2.11
1-31-81	2200	7.32	26°	1300	---	528	426	388	5.0	467	76.4	.005	.003	2.10
2-10-81	0420	7.15	27°	844	---	---	470	334	4.7	479	67.6	.018	.014	---
2-18-81	2315	7.27	27°	1210	---	523	420	302	5.0	492	69.1	.150	.016	---
3-6-81	2345	7.44	27°	192	---	505	422	302	4.6	363	63.2	.149	----	2.04
3-20-81	2345	7.44	24°	---	---	512	384	280	4.6	579	60.1	.112	.099	---
5-6-81	1515	7.53	28°	940	---	413	348	242	3.1	---	64.6	.032	.031	---
5-19-81	1330	7.72	28°	1520	---	521	425	313	6.2	494	83.6	.105	.006	---
6-19-81	1330	7.27	---	1050	---	498	432	330	3.9	---	---	.075	.003	2.56
7-1-81	1140	7.16	30°	1210	---	523	436	234	6.2	514	80.1	.087	.005	2.63
7-17-81	1320	7.27	29°	1280	---	526	436	290	5.6	472	57.0	.052	.003	2.38
7-30-81	1215	7.04	26°	292	---	622	92.0	---	8.2	123	---	.029	.001	2.91
*8-17-81	1340	8.48	28°	252	---	138	64.0	35.0	---	155	13.7	.062	.006	.063
8-27-81	1510	7.39	29°	992	---	430	369	234	5.7	411	64.1	.049	.005	2.18

*Surface storm runoff exclusively.

Table A-1. Con't.

						Shorewaters						
DATE	SAMPLING TIME	Po_4-P mg/ℓ	Sio_2-Si mg/ℓ	T. Coli Col/100mℓ	F. Coli Col/100mℓ	NO_3-N mg/ℓ	NH_3-N mg/ℓ	Po_4-P mg/ℓ	Chl *a* mg/m^3	Chl *b* mg/m^3	Chl *c* mg/m^3	Carotenoids mg/m^3
12-15-80	1050	.014	----	----	----	----	----	----	----	----	----	----
12-26-80	0715	----	----	----	----	----	----	----	----	----	----	----
1-12-81	0500	.002	----	----	----	----	----	----	----	----	----	----
1-31-81	2200	.003	----	----	----	----	----	----	----	----	----	----
2-10-81	0420	.014	----	----	----	----	----	----	----	----	----	----
2-18-81	2315	----	----	----	----	----	----	----	----	----	----	----
3-6-81	2345	.012	----	170	9	----	----	----	----	----	----	----
3-20-81	2345	.016	----	----	----	----	----	----	----	----	----	----
5-6-81	1515	.023	----	----	----	.008	.052	----	1.25	.672	2.09	1.39
5-19-81	1330	.011	----	4	7	----	.080	----	1.74	0.54	<0.10	<0.10
6-19-81	1330	.021	----	0	0	----	----	----	0.73	0.77	<0.10	0.96
7-1-81	1140	.006	----	0	0	.121	----	<.001	0.90	<0.10	----	0.80
7-17-81	1320	.011	----	35	5	.139	.078	.003	0.78	0.52	<0.10	0.83
7-30-81	1215	.059	----	0	II	.543	.084	.013	1.86	1.13	<0.10	1.28
*8-17-81	1340	.021	.004	60,000	1,000	.527	.089	.004	2.00	0.83	<0.10	1.07
8-27-81	1510	.013	.055	0	2	.025	.096	.003	0.46	0.25	<0.10	<0.10

*Surface storm runoff exclusively.

Table A-2 . Sampling and analyses data for Dungcas Beach groundwater seepage and receiving marine waters.

DATE	SAMPLING TIME	pH	C TEMP	FR mg/ℓ	TNFR mg/ℓ	T.Alk. mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ
12-15-80	1030	----	----	----	----	----	----	----	----	----	----	<.001	.003	----
12-26-80	0740	----	SURF	----	TOO	----	HIGH	----	TO --	OBTAIN	----	SAMPLE	----	----
1-12-81	0530	7.25	----	828	----	586	407	328	3.2	305	47	----	.009	1.78
1-31-81	2210	7.22	26°	1360	----	609	430	330	2.8	333	51.2	<.005	.005	2.46
2-10-81	0440	7.29	27°	800	----	622	444	376	2.5	469	44.7	<.005	.008	3.01
2-18-81	2325	7.34	27°	1260	----	623	464	368	3.0	410	53.7	.056	<.001	1.84
3-7-81	0000	7.50	28.5	----	----	614	488	360	2.7	338	54.2	.124	.006	----
3-21-81	0000	7.27	25°	----	----	662	581	384	1.6	419	61.2	.092	.110	----
5-6-81	1535	7.18	28°	2140	----	649	610	378	2.0	----	----	.030	.267	----
5-18-81	1345	7.57	28.5	1380	----	650	461	383	2.8	374	----	----	.001	----
6-19-81	~1400	7.54	----	952	----	686	454	356	1.9	----	----	.103	.002	2.06
7-1-81	1152	6.96	30°	956	----	663	467	243	2.8	404	56.4	.059	.001	2.08
7-17-81	1332	7.03	25.5	1320	----	626	470	349	2.3	420	38.0	.050	.002	1.85
7-30-81	1235	7.25	27°	1220	----	604	468	----	2.3	388	58.8	.086	.002	2.14
8-17-81	1405	6.78	29°	1080	----	589	443	330	3.5	363	----	.057	.006	2.68
8-27-81	1455	7.24	29°	936	----	588	436	288	3.9	339	45.7	.045	.001	2.40

Table A-2 . Con't.

DATE	SAMPLING TIME	PO_4-P mg/ℓ	Silica -Si	Total Coliform	Fecal Coliform	Shorewaters NO_3-N mg/ℓ	NH_3-N mg/ℓ	PO_4-P mg/ℓ	Chl *a* mg/m³	Chl *b* mg/m³	Chl *c* mg/m³	Carotenoid mg/m³
12-15-80	1030	<.001	----	----	----	----	----	-----	----	-----	----	-----
12-26-80	0740	<.001	----	----	----	----	----	-----	----	-----	----	-----
1-12-81	0530	.004	----	----	----	----	----	-----	----	-----	----	-----
1-31-81	2210	.005	----	----	----	----	----	-----	----	-----	----	-----
2-10-81	0440	.012	----	----	----	----	----	-----	----	-----	----	-----
2-18-81	2325	----	----	----	----	----	----	-----	----	-----	----	-----
3-7-81	0000	.017	----	10	0	----	----	-----	----	-----	----	-----
3-21-81	0000	.013	----	----	----	----	----	-----	----	-----	----	-----
5-6-81	1535	.019	----	----	----	.008	.091	-----	15.7	7.81	6.09	12.3
5-18-81	1345	.003	----	>2000	0	----	.092	-----	4.60	2.92	0.2	2.61
6-19-81	~1400	.022	----	0	17	----	----	-----	1.75	1.69	<0.10	1.74
7-1-81	1152	.001	----	0	0	>.860	.155	.033	8.41	3.72	<0.10	9.71
7-17-81	1332	.027	----	36	1	.274	.128	.298	22.6	10.5	<0.10	24.8
7-30-81	1235	.004	----	0	10	.422	.105	.025	2.08	2.13	<0.10	0.98
8-17-81	1405	.006	.024	40	17	.385	.115	.040	0.88	1.23	<0.10	0.46
8-27-81	1455	.027	.063	4	2	.014	.072	.005	0.67	0.58	<0.10	0.84

Table A-3 . Sampling and analyses data for Ypao Beach groundwater seepage and receiving marine waters.

DATE	SAMPLING TIME	pH	C TEMP	FR mg/ℓ	TNFR mg/ℓ	T.Alk. mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL⁻ mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ
12-15-80	0715	----	----	----	----	----	----	----	----	----	----	----	.003	----
12-26-80	0750	----	SURF	----	TOO	----	HIGH	----	TO	----	SAMPLE	----	----	----
1-12-81	0550	7.39	26°	3230	----	492	730	347	0.5	1336	----	<.005	.004	----
1-31-81	2250	7.54	25°	2740	----	470	622	272	0.8	1052	159	.005	.003	2.28
2-10-81	0455	7.76	26°	2500	----	483	662	370	0.5	1248	175	.012	.003	2.36
2-18-81	2345	7.97	27°	2700	----	499	657	360	0.9	1129	114	.048	.008	2.32
3-7-81	0020	7.62	26°	2080	----	474	767	338	0.8	1147	165	.036	.008	1.97
3-20-81	0025	7.65	24°	----	----	614	519	382	1.0	1025	132	.066	.012	----
5-6-81	~1600	7.43	27°	3080	----	475	604	338	1.8	----	157	.033	.003	----
5-19-81	1405	7.82	----	3100	----	476	607	331	2.0	1071	168	.088	.001	----
6-19-81	~1430	7.33	----	3150	----	502	672	332	0.8	----	----	.084	.003	.942
7-1-81	1230	7.23	28°	----	----	484	731	258	0.8	1441	238	.062	<.001	.933
7-17-81	1350	7.30	29°	3220	----	434	736	335	1.2	1459	217	.048	<.001	.786
7-30-81	1300	7.27	26°	3380	----	446	732	----	1.4	1464	230	.056	<.001	.415
8-17-81	1435	7.06	28°	2260	----	417	572	301	1.4	1004	116	.084	<.001	1.68
8-27-81	1410	7.43	28°	2140	----	444	570	307	2.5	919	134	.048	<.001	1.20

Table A-3 . Con't.

DATE	SAMPLING TIME	PO_4-P mg/ℓ	Silica -Si	Total Coliform	Fecal Coliform	Shorewaters NO_3-N mg/ℓ	NH_3-N mg/ℓ	PO_4-P mg/ℓ	Chl *a* mg/m³	Chl *b* mg/m³	Chl *c* mg/m³	Carotenoid mg/m³
12-15-80	0715	----	----	----	----	----	----	----	----	----	----	----
12-26-80	0750	----	TOO	----	ROUGH	----	TO	-----	SAMPLE	----	----	----
1-12-81	0550	.001	----	----	----	----	----	----	----	----	----	----
1-31-81	2250	.002	----	----	----	----	----	----	----	----	----	----
2-10-81	0455	.004	----	----	----	----	----	----	----	----	----	----
2-18-81	2345	----	----	----	----	----	----	----	----	----	----	----
3-7-81	0020	.006	----	<10	1	----	----	----	----	----	----	----
3-20-81	0025	.019	----	----	----	----	----	----	----	----	----	----
5-6-81	~1600	.011	----	----	----	.004	.047	----	1.96	.924	1.12	1.60
5-19-81	1405	.003	----	3	3	----	.127	----	1.70	0.40	<0.10	<0.10
6-19-81	~1430	.013	----	0	0	----	----	----	1.07	1.08	<0.10	0.94
7-1-81	1230	.001	----	0	0	.073	.161	.017	1.04	0.66	<0.10	0.72
7-17-81	1350	.009	----	0	0	.107	.040	.012	0.64	0.57	<0.10	0.59
7-30-81	1300	.005	----	2	0	.035	.057	.004	1.16	1.02	<0.10	0.64
8-17-81	1435	.004	.007	10	0	.047	.119	<.001	0.73	1.34	<0.10	0.46
8-27-81	1410	.013	.017	0	0	.110	.057	.005	0.55	0.65	<0.10	0.72

Table A-4 . Sampling and analyses data for Gongna Beach groundwater seepage and receiving marine waters.

DATE	SAMPLING TIME	pH	C TEMP	FR mg/ℓ	TNFR mg/ℓ	T.Alk. mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	Cl^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ
12-15-80	0800	---	---	---	---	---	---	---	---	---	---	<.005	.003	---
12-26-80	0800	---	TOO	----	ROUGH	----	TO	---	SAMPLE	---	---	----	----	----
1-12-81	0625	7.46	26°	5200	---	474	1020	396	4.8	2380	---	.005	.003	3.13
1-31-81	2315	7.39	26°	5130	---	489	840	430	5.2	1730	250	<.005	---	2.04
2-10-81	0525	7.69	26°	4330	---	476	962	504	5.1	2140	310	<.005	.002	3.10
2-19-81	0005	7.55	26°	4730	---	483	985	416	5.2	2430	286	.120	.022	2.74
3-7-81	0040	7.43	26°	3770	---	470	1050	396	4.7	2260	324	.047	.017	2.86
3-21-81	0045	7.64	25°	---	---	471	1080	380	3.1	2680	368	.084	.016	----
5-6-81	~1600	7.42	27°	6610	---	429	1250	416	4.7	---	>375	.031	.004	----
5-19-81	1425	7.74	28°	9150	---	454	1420	457	4.6	3670	>380	.091	<.001	----
6-19-81	1445	7.45	---	5280	---	519	952	434	4.4	---	---	----	<.001	1.75
7-1-81	1232	7.16	28°	7960	---	460	1450	480	4.5	3710	490	.094	<.001	1.73
7-17-81	1415	7.15	29°	8840	---	439	1310	345	4.8	4350	532	.052	<.001	1.49
7-30-81	1330	7.25	26°	7690	---	439	1340	---	4.9	4130	---	.066	<.001	1.61
8-17-81	1500	7.10	28°	4490	---	438	914	346	6.4	1980	283	.084	<.001	2.37
8-27-81	1345	7.44	28°	4180	---	459	939	352	6.9	1990	309	.039	.001	2.11

Table A-4 . Con't.

DATE	SAMPLING TIME	PO_4-P mg/ℓ	Silica -Si	Total Coliform	Fecal Coliform	Shorewaters NO_3-N mg/ℓ	NH_3-N mg/ℓ	PO_4-P mg/ℓ	Chl *a* mg/m^3	Chl *b* mg/m^3	Chl *c* mg/m^3	Carotenoid mg/m^3
12-15-80	0800	.009	----	----	----	----	----	----	----	----	----	----
12-26-80	0800	----	TOO	----	ROUGH	----	TO	----	SAMPLE	----	----	----
1-12-81	0625	.004	----	----	----	----	----	----	----	----	----	----
1-31-81	2315	.017	----	----	----	----	----	----	----	----	----	----
2-10-81	0525	.021	----	----	----	----	----	----	----	----	----	----
2-19-81	0005	----	----	----	----	----	----	----	----	----	----	----
3-7-81	0040	.020	----	10	2	----	----	----	----	----	----	----
3-21-81	0045	.029	----	----	----	----	----	----	----	----	----	----
5-6-81	~1600	.023	----	----	----	.014	.062	----	1.82	.93	.80	1.31
5-19-81	1425	.022	----	2	0	----	.082	----	0.74	<0.10	<0.10	<0.10
6-19-81	1445	.024	----	8	0	----	----	----	0.89	0.80	<0.10	0.59
7-1-81	1232	.014	----	0	0	.768	.164	.068	0.74	0.45	<0.10	0.43
7-17-81	1415	.018	----	4	0	.433	.049	.048	0.67	0.88	<0.10	0.50
7-30-81	1330	.018	----	100	1	1.71	.067	.014	0.84	1.06	<0.10	0.43
8-17-81	1500	.012	.009	100	8	>.600	.068	.009	0.58	0.75	<0.10	0.27
8-27-81	1345	.017	.018	6	1	.547	.056	.012	0.58	0.45	0.29	0.82

Table A-5 . Sampling and analyses data for Hilaan Pt. shoreline groundwater seepage and receiving marine waters.

DATE	SAMPLING TIME	pH	C TEMP	FR mg/ℓ	TNFR mg/ℓ	T.Alk. mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ
12-15-80	0830	----	----	----	----	----	----	----	----	----	----	<.001	.003	1.28
12-26-80	0920	----	TOO	-----	ROUGH	----	TO	----	SAMPLE	------	---	----	----	-----
1-12-81	0700	7.62	----	3010	----	427	601	293	5.6	1242	----	.006	.003	2.17
2-1-81	0005	7.88	----	3220	----	451	782	360	6.0	1386	190	<.001	.003	2.54
2-10-81	0615	7.86	26°	2216	----	454	640	360	5.2	1169	157	.009	.006	2.36
2-19-81	0030	7.79	27°	3212	----	431	707	328	5.4	1528	176	.167	.011	----
3-7-81	0120	7.55	25.9	2280	----	406	799	328	4.8	1515	209	.077	.024	2.73
3-21-81	0130	7.51	24°	----	----	421	585	----	3.4	1209	----	----	.028	----
5-6-81	1645	7.54	28°	2744	----	390	618	292	----	----	149	.029	.004	----
5-19-81	1445	7.89	28°	3476	----	428	655	315	4.7	1365	182	.061	<.001	----
6-19-81	1515	7.46	----	9920	----	422	726	342	4.3	----	----	.091	<.001	1.05
7-1-81	1345	7.28	29°	----	----	429	1053	320	4.6	----	----	----	----	----
7-17-81	1530	7.40	28°	3132	----	410	672	296	5.9	1361	183	.038	<.001	1.21
7-30-81	~1600		NOT	SAMPLED	DUE	TO HIGH	WATERS							
8-17-81	1545	7.27	27°	5920	----	403	1097	358	5.1	2700	346	.031	<.001	1.18
8-27-81	1255	7.63	27°	2244	----	408	572	264	6.6	1002	110	.034	<.001	1.42

Table A-5 . Con't.

DATE	SAMPLING TIME	PO_4-P mg/ℓ	Silica -Si	Total Coliform	Fecal Coliform	Shorewaters NO_3-N mg/ℓ	NH_3-N mg/ℓ	PO_4-P mg/ℓ	Chl *a* mg/m³	Chl *b* mg/m³	Chl *c* mg/m³	Carotenoid mg/m³
12-15-80	0830	.004	----	----	----	----	----	----	----	----	----	----
12-26-80	0920	----	TOO	----	ROUGH	----	TO	----	SAMPLE	----	----	----
1-12-81	0700	<.001	----	----	----	----	----	----	----	----	----	----
2-1-81	0005	.011	----	----	----	----	----	----	----	----	----	----
2-10-81	0615	.013	----	----	----	----	----	----	----	----	----	----
2-19-81	0030	----	----	----	----	----	----	----	----	----	----	----
3-7-81	0120	.017	----	<10	0	----	----	----	----	----	----	----
3-21-81	0130	.016	----	----	----	----	----	----	----	----	----	----
5-6-81	1645	.019	----	----	----	.022	.064	----	.94	.40	1.58	0.83
5-19-81	1445	.009	----	<10	0	----	.114	----	1.00	<0.10	<0.10	<0.10
6-19-81	1515	.021	----	0	0	----	----	----	0.85	0.89	<0.10	0.77
7-1-81	1345	----	----	0	0	.280	.076	.006	1.38	<0.10	----	1.28
7-17-81	1530	.010	----	8	0	.180	.093	.066	0.83	0.42	<0.10	0.67
7-30-81	~1600	----	NOT	SAMPLED	----	.165	.052	.007	0.78	0.60	<0.10	0.53
8-17-81	1545	.014	.013	10	7	>.600	.088	.016	0.66	0.96	<0.10	<0.10
8-27-81	1255	.017	.016	11	0	.656	.088	.016	0.50	0.32	<0.10	0.35

Table A-6. Sampling and analyses Data for the Hilaan Cenote.

DATE	SAMPLING TIME*	pH	C Temp	FR mg/ℓ	TNFR mg/ℓ	T.Alk mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ	PO_4-P mg/ℓ	Silica -Si
12-26-80	0940		28°	---	---	---	---	---	---	---	---	---	---	---	---	---
1-12-81	0710	7.89	26°	1160	35.4	284	337	281	5.1	404	---	.010	.012	---	<.001	---
2-1-81	0015	7.64	---	1530	---	424	362	260	6.3	590	76.7	.007	.015	1.92	.006	---
2-10-81	0630	7.77	26°	864	---	418	368	318	6.3	580	62.9	≤.005	.014	1.75	.008	---
2-19-81	0050	7.72	27°	1350	2.6	426	410	268	6.4	607	80.6	.034	.044	---	---	---
3-7-81	0135	7.69	25°	---	---	416	418	266	5.9	481	61.7	.127	.029	---	.011	---
3-21-81	0140	7.60	25°	---	---	396	501	320	3.8	186	---	---	.049	---	.012	---
5-6-81	1650	7.55	28°	1310	5.9	405	404	260	---	---	89.7	.033	.060	---	.014	---
5-19-81	1505	7.82	28°	1410	1.2	423	381	264	3.8	514	76.9	---	.003	---	.008	---
6-19-81	1530	7.47	---	1180	---	443	584	276	5.0	---	---	.115	.004	1.25	.019	---
7-1-81	1330	7.24	30°	1096	1.9	431	409	239	4.3	573	87.7	.091	<.001	1.25	.008	---
7-17-81	1520	7.27	29°	1320	1.4	419	386	234	5.9	500	65.3	.060	.002	1.17	.010	---
7-30-81	1600	7.44	27°	1080	5.1	396	---	---	6.5	384	---	.027	<.001	1.31	.006	---
8-17-81	1610	7.20	28°	1390	0.2	415	423	235	5.4	567	79.7	.030	.003	1.58	.006	.006
8-27-81	1235	7.46	27°	1080	2.5	404	381	238	7.3	443	54.2	.034	.002	1.31	.018	.017

Table A-7. Sampling and analyses data for the Perez Brothers Quarry cave water near Fadian Point.

DATE	SAMPLING TIME	pH	C Temp	FR mg/ℓ	TNFR mg/ℓ	T.Alk mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ	Po_4-P mg/ℓ	Silica -Si
12-23-80	1030	---	---	---	---	---	---	---	---	---	---	<.005	.017	2.42	.003	---
1-12-81	0825	7.58	---	1610	28.8	414	383	220	6.7	664	173	<.005	.035	1.52	.017	---
1-31-81	1450	7.73	26°	2210	3.5	394	504	302	6.8	919	93.7	.007	.019	1.64	.006	---
2-14-81	1010	7.87	27°	2830	15.0	493	638	421	5.4	1250	154	.079	.011	---	.020	---
2-28-81	1010	7.47	27°	2150	13.4	499	624	411	4.9	1220	131	.070	.006	---	.018	---
3-14-81	0915	7.28	27°	2300	---	490	693	350	5.2	1140	153	.048	.012	---	.023	---
5-18-81	0930	8.07	27°	980	0.3	232	260	180	7.0	383	---	.106	.006	---	.012	---
6-11-81	0930	7.68	27°	2200	4.4	341	589	378	6.8	---	98.2	.222	<.001	2.79	.017	---
6-30-81	1350	8.16	27°	940	0.6	239	286	150	7.1	410	33.2	.058	.002	1.89	.006	---
7-15-81	0920	8.27	28°	480	4.9	217	174	94.6	7.6	205	---	.050	.001	1.90	.010	---
7-29-81	0855	7.80	28°	1020	4.0	250	294	---	7.0	484	65.8	.075	.003	2.65	.008	---
8-19-81	1400	7.78	28°	320	4.4	223	134	86.3	7.7	534	19.4	.076	<.001	1.47	.074	.016
8-31-81	1400	7.54	28°	1380	2.2	265	196	127	6.9	176	22.9	.041	.001	2.00	.027	.027

Table A-8. Sampling and analyses data for Marbo Cave waters.

DATE	SAMPLING TIME	pH	C Temp	FR mg/ℓ	TNFR mg/ℓ	T.Alk mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ	Po_4-P mg/ℓ	Silica -Si
1-21-81	1400	7.76	23°	1400	0.9	---	---	---	---	---	---	---	---	1.58	---	---
1-31-81	1050	7.92	27°	1590	---	338	364	206	7.1	578	84.6	.022	<.001	---	.004	---
2-14-81	1050	7.67	28°	1550	1.5	339	381	211	7.1	631	80.0	.204	.002	---	.015	---
2-28-81	1000	7.65	27°	1090	18.3	341	357	251	6.7	611	80.2	.075	.004	---	.012	---
3-14-81	1015	7.87	27°	1260	---	342	420	220	6.8	520	72.8	.040	.009	---	.012	---
5-18-81	1030	7.65	27°	1110	0.4	340	339	202	7.3	491	76.0	.094	<.001	---	.008	---
6-11-81	1040	7.45	26°	1770	6.4	345	315	223	6.5	464	77.5	.056	.001	1.87	.009	---
6-30-81	1000	7.50	29.5	604	4.5	331	360	173	8.0	509	69.7	.052	<.001	1.85	.008	---
7-15-81	0940	7.30	29°	2630	0.1	349	357	179	7.4	491	75.0	.055	<.001	1.87	.007	---
7-29-81	1420	7.42	27°	1270	3.3	346	364	---	7.4	562	67.1	.049	<.001	1.90	.007	---
8-17-81	1443	7.31	28.5	1380	1.2	327	356	180	7.2	576	62.0	.040	<.001	1.82	.006	.004
8-31-81			27°	536	1.4	339	379	211	7.3	566	48.6	.033	<.001	1.80	.014	.012

Table A-9. Sampling and analyses data for Tarague Cave waters.

DATE	SAMPLING TIME	pH	C Temp	FR mg/ℓ	TNFR mg/ℓ	T.Alk mg/ℓ	T.Hard mg/ℓ	C.Hard mg/ℓ	DO mg/ℓ	CL^- mg/ℓ	$SO_4^=$ mg/ℓ	NH_3-N mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ	Po_4-P mg/ℓ	Silica -Si
1-31-81	1145	7.81	27	636	-----	363	244	240	7.3	189	22.5	<.005	.024	1.34	.004	
2-14-81	1210	7.91	26	772	9.7	375	261	230	7.5	212	19.4	-----	.006	-----	.023	
2-28-81	1135	7.65	26	532	22.2	370	263	232	7.2	210	21.0	.111	.006	1.54	.019	
3-14-83	1055	7.76	26	480	-----	373	298	236	7.2	202	13.1	.074	.016	-----	.017	
5-18-81	1125	7.78	26	576	0.1	365	238	218	7.8	155	-----	.082	.001	-----	.011	
6-11-81	1115	7.60	26	596	9.8	370	263	234	7.9	132	11.9	.072	<.001	1.44	.017	
6-30-81	1430	7.53	29	360	2.9	358	243	176	7.3	146	13.7	.037	.001	1.41	.004	
7-15-81	1040	7.46	29	448	6.2	370	254	196	7.3	157	19.9	.078	<.001	1.48	.006	
7-30-81	1040	7.20	---	724	3.0	371	244	-----	7.3	168	-----	.059	<.001	1.49	.004	
8-19-81	1500	7.32	---	464	2.8	348	242	192	7.8	166	18.0	.038	<.001	1.41	.005	.006
8-31-81	1535	7.26	27	500	2.4	359	289	193	7.2	170	-----	.044	<.001	1.45	.024	.012

Table A-10. Sampling and analyses data for Janum Spring.

6-18-81	1330	7.39	22	236	0.6	478	----	-----	7.3	198	1.5	.040	<.001	1.48	.039	
6-30-81	1310	7.27	29	52	5.9	432	233	156	6.8	30.0	1.9	.040	<.001	1.45	.009	
7-16-81	1400	7.24	26.5	308	3.0	431	----	-----	6.7	37.7	-----	.053	<.001	1.54	.004	

APPENDIX B

Past Water Analyses Results for Marbo and Tarague Cave (U.S. Geological Survey Auspices) And Production Well H-1 Close to the Study Areas in Tumon and the NCS Area

Appendix B. Past water analyses results for Marbo and Tarague Cave (U.S. Geological Survev auspices) and production well H-1 close to the study areas in Tumon and the NCS area. Data for H-1 is from the Public Utilities Agency of Guam and the Guam Environmental Protection Agency. All concentrations are in milligrams per liter unless noted. Filterable residue (FR) for H-1 was approximated from the ratio (.55) of FR to specific conductance observed at Tarague Cave.

SITE	DATE	TEMP °C	FR	CL	SO_4	NO_3-N	T. HARD	T. ALK.
Marbo Cave	8/64	-----	1228	480	76	2.90	352	190
Tarague Cave	6/67	-----	489	160	25	.814	237	195
" "	6/68	-----	531	179	29	1.52	253	191
" "	8/69	-----	542	155	25	1.52	242	192
" "	3/71	-----	526	180	27	2.01	250	194
H-1	1/81	26.0	350-375	148	-----	----	-----	-----
"	2/81	26.2	450-475	161	-----	1.92	-----	-----
	3/81	26.5	400-425	148	-----	1.99	268	-----
	4/81	26.5	350-375	150	-----	----	-----	-----
	5/81	26.6	400-425					
	6/81	26.5	325-350	104	-----	----	276	-----
	7/81	27.0	425-450	145	-----	----	-----	-----
	8/81	26.5	400-425	148	-----	----	-----	-----

APPENDIX C

Precipitation and Approximate Tidal Heights for the Sample Collection Dates

Appendix C. Precipitation and tidal heights for the sample collection dates. Rainfall totals (in millimeters) are from Naval Air Station, Guam for previous day and previous 5 days prior to the sampling date. Approximate tidal heights are given in meters and were derived from tide tables produced by the National Oceanic and Atmospheric Administration. Postscripts indicate the phase (rising-r or falling-f) of the tidal cycle during the sampling period. No postscript indicates that the cycle was near the trough.

DATE	TIDAL HEIGHTS At Start	TIDAL HEIGHTS At Finish	PRECIPITATION Previous Day	PRECIPITATION 5 Days Previous
12-15-80	0.3 r (H.PT.)*	0.5 f (T.B.)	3	8
12-26-80	0.3 r	0.3 r	0	40
1-12-81	0.0 r	0.2 r	13	32
1-31-81	0.0 r	0.1 r	32	109
2-10-81	0.2 f	0.2 r	2	9
2-18-81	0.2 f	0.1 f	6	10
3-06-81	0.1 f	-0.1	1	16
3-20-81	0.3 f	0.1	2	4
5-06-81	-0.2	0.0 r	2	12
5-19-81	0.0	0.0	2	10
6-19-81	0.0 f	-0.1	2	29
7-01-81	0.0 f	-0.2	6	72
7-17-81	-0.1	0.1 r	6	11.4
7-30-81	-0.1	0.2	30	78
8-17-81	0.0	0.0	4	42
8-27-81	0.0 r (H.PT.)	0.3 r (T.B.)	0	13

*Starting sampling station was Trinchera Beach (T.B.) unless noted as Hilaan Pt. (H.PT.).

Appendix D. Outlying data points rejected by Chavenet's criterion. The concentrations are in mg/ℓ unless noted otherwise.

DATE	SAMPLE STATION	PARAMETER	REPORTED CONCENTRATION (mg/ℓ)
12-26-80	Trinchera Beach	Temperature	22° C
2-10-81	Trinchera Beach	T. Alkalinity	1010
3-06-81	Trinchera Beach	NO_2-N	.323
7-01-81	Trinchera Beach	Chlorophyll C	19.5
1-12-81	Dungcas Beach	Temperature	22° C
6-19-81	Gongna Beach	NH_3-N	.685
3-21-81	Hilaan Point	Calcium Hardness	86
6-19-81	Hilaan Point	Chlorophyll C	18.5
1-12-81	Hilaan Cenote	So_4	147
3-07-81	Hilaan Cenote	Filterable Residue	316
2-14-81	Marbo Cave	NH_3-N	.204
2-14-81	Tarague Cave	NH_3-N	.430
6-18-81	Janum Spring	Temperature	22°

APPENDIX D

Outlying Data Points Rejected by Chavenet's Criterion