WATER QUALITY ASSESSMENT FOR AGANA SPRINGS

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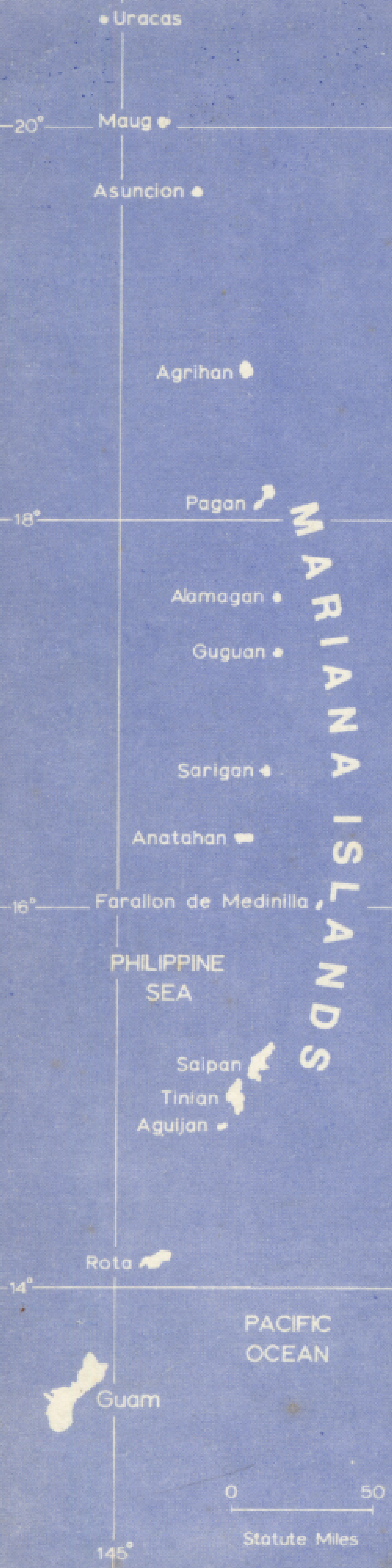

UNIVERSITY OF GUAM
Water and Energy Research Institute of the Western Pacific

Technical Report No. 22

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Completion Report

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Water Quality and Quantity Assessment of Agana Springs

Project No. A-015-Guam, Grant Agreement No. 14-34-001-0112

Principal Investigators: Stephen J. Winter and William J. Zolan

Project Period: October 1, 1979 to March 31, 1981

The work on which this report is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Research and Development Act of 1978.

ABSTRACT

The purpose of this water quality study was to assess the potential of Agana Springs for possible development as a municipal water source. To achieve this objective, Agana Springs was sampled weekly from March to August 1980 and analyzed for common water quality parameters.

Results indicate that Agana Springs water quality is sufficiently high to merit development as a freshwater resource. The chemical and physical quality of Agana Springs water within the impoundment is relatively high compared to standards set by GEPA for "drinking waters" and standing waters utilizable as drinking water resources.

Bacterial contamination appears to be the only problem of any significance. The contamination, however, may not be due to contaminated groundwater. Surface runoff and animal activity in the pond vicinity may be responsible for this contamination.

The Agana Springs source should be developed. Tapping this resource would serve to augment the northern well field with a volume equal to or surpassing four to six high production groundwater wells.

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INTRODUCTION

The territory of Guam is currently assessing groundwater resources for future development. The total amount of developable water from the groundwater aquifer system is unknown. It is hoped the island can rely on the major northern groundwater aquifer to satisfy the increasing demand for freshwater during the remainder of the century. However, alternate supplies to augment the northern well field need to be assessed. Agana Springs, one of the largest springs of freshwater on the island, is such a supply. The springs discharge between 0.5 and 2.5 million gallons of water per day depending upon seasonal rainfall activity (Ward et al., 1965). A volume of 2.0 million gallons is approximately equal to the daily production of seven groundwater production wells now in service.

Agana Springs is located in the Agana River Valley, northeast of the city of Agana and directly north of the village of Sinajana. The springs are situated at the base of the steep slope that rises from the valley floor to Route 4. Spring water flows into a long abandoned reservoir site constructed by the U. S. Navy between 1914 and 1937 (GSTA, 1971). The reservoir and surrounding structures are now barely recognizable. The spring water currently flows from the old reservoir into the Agana River and out to sea. The springs are believed to originate from a juncture of two major limestone members, the Agana argillaceous and the Alifan limestone member which comprise central Guam (Ward et al., 1965).

The Agana area has a long history of problems supplying water to its population (Stephenson, 1979). The U. S. Navy became directly responsible for the island in 1898. The Navy tried to improve the quantity and quality of water needed by the populous central portion of the island by developing several springs, Agana Springs being one of them. Development of Agana Springs began in 1914 and continued sporadically to 1937. A pump house, low level dam and two retaining walls had been built around the Springs by 1937. The Navy redeveloped the springs after World War II. The Agana Springs was supplying the island with water at slightly less than a million to nearly 2.5 million gallons per day as late as the early 1950's (Appendix A). This represented 20% of the water system production at that time (GSTA, 1971). The Fena Reservoir in southern Guam was completed in 1951. With the filling of the reservoir and completion of a water treatment facility in 1957, the islands major water supply problems were temporarily alleviated and Agana Springs was abandoned. The springs were abandoned because the spring water had persistently shown bacterial contamination. The water was believed to be contaminated by the village of Sinajana, directly south of the springs. Centralized sewage collection and treatment was non-existent (outdoor toilets) or consisted of septic tanks. The village of Sinajana is now connected to the island's central wastewater treatment system which collects, treats (primary treatment) and discharges the wastewater in an ocean outfall off Agana Bay.

An attempt was made by the Guam Science Teachers Association (GSTA) to maintain the Agana Springs area for nature study in the early 1970's (GSTA, 1970). This project consisted of cleaning the site, which had overgrown and was cluttered with remnants of the reservoir structures and dumped rubbish. This project succeeded for several years until the project leaders moved off-island or became involved with other activities. Another objective of the teachers association was to obtain Government of Guam control of the springs land from the U. S. Navy. This did not succeed. The major barrier to the springs development has been, and will continue to be, the U. S. Navy, which controls the springs and has no interest in developing this freshwater resource. Only infrequent fishing and swimming at the springs was observed during this study. CETA employees have cleaned the pond of aquatic plants the past two years. The aquatic vegetation however grows back within a few months to choke the pond. The Guam Environmental Protection Agency collects monthly samples (since 1978) from the spillway and tests for fecal coliform bacteria and other water quality parameters as part of their environmental monitoring program.

OBJECTIVE

The objective of the project is to determine the water quality of Agana Springs as it relates to possible development as a municipal water supply.

SITE DESCRIPTION

Agana Springs, at an elevation of 2 meters, is located within the Agana-Choat River Basin on the west coast of Guam, slightly north of the midpoint of the island running north-south (Figure 1). The site consists of the old reservoir, which is barely recognizable as such. Two concrete retaining walls of the reservoir are still in place along the north and west sides. The spillway is located on the north side. The east side of the ponded area is completely overgrown and the pond fades into water hyacinth and various marsh plants. A steep, soil covered limestone slope comprises the southern boundary of the ponded area (Figure 2a).

Agana Springs is described as a "open water" facies (ecological subunit) within a "wet land" biotope (ecological unit) by Randall and Tsuda (1974). The water level within the reservoir fluctuates, flowing over the spillway during the wet season and generally being below the spillway level during the dry season (Figures 2b, c, and 3). From the deepest portion of the reservoir, the height to the top of the spillway is 2.7 meters.

At the beginning of the study (Oct. 1979) the reservoir was free of vegetation except for a narrow fringe of *Hydrilla verticillata* along the northeast margin. Water clarity was excellent; the bottom was clearly visible at any point in the pond. The bottom of Agana Springs is composed of a 1 meter layer of muck overlying calcareous deposits.

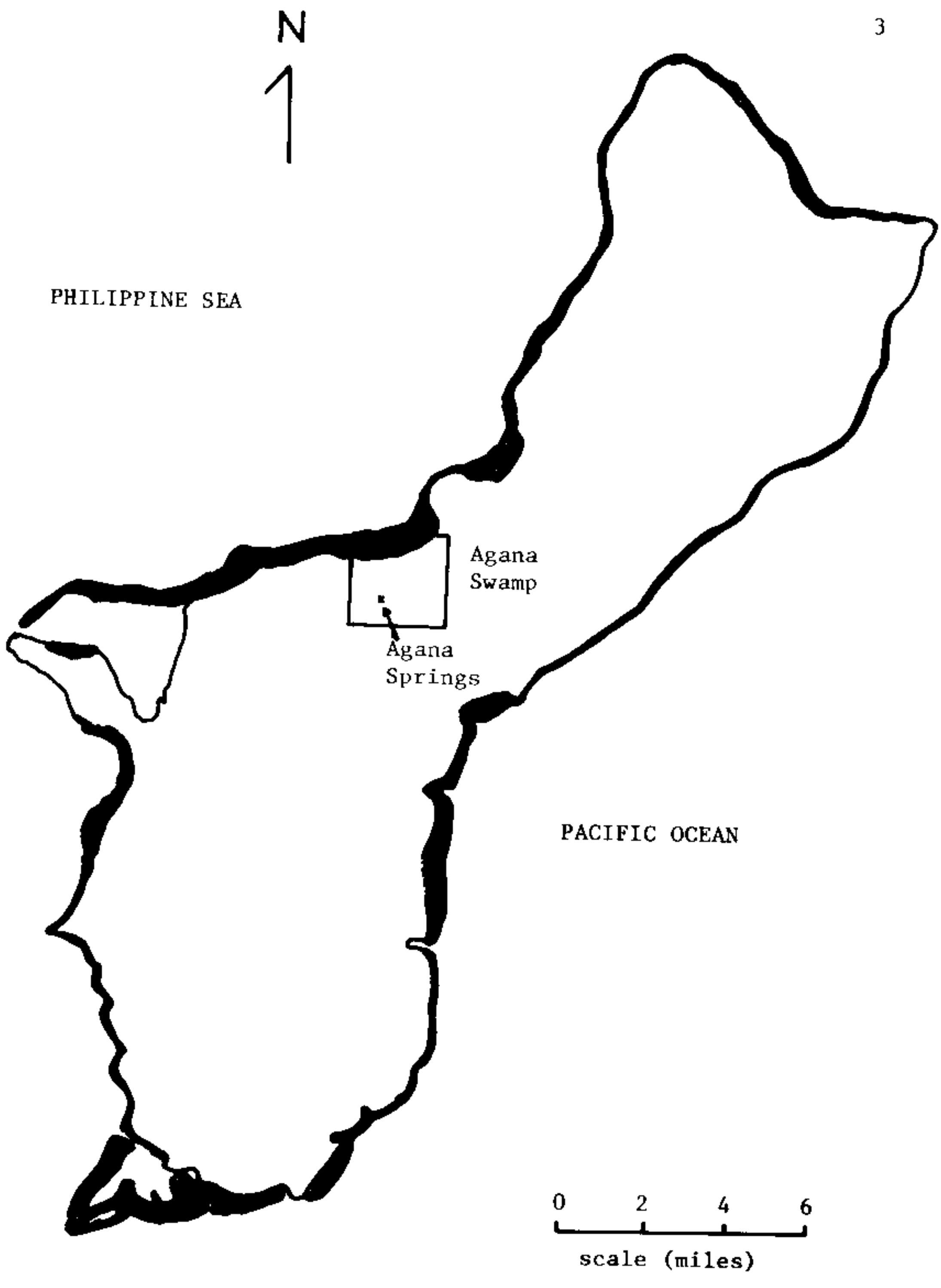

Figure 1. Map of Guam showing location of Agana Swamp and Agana Springs.

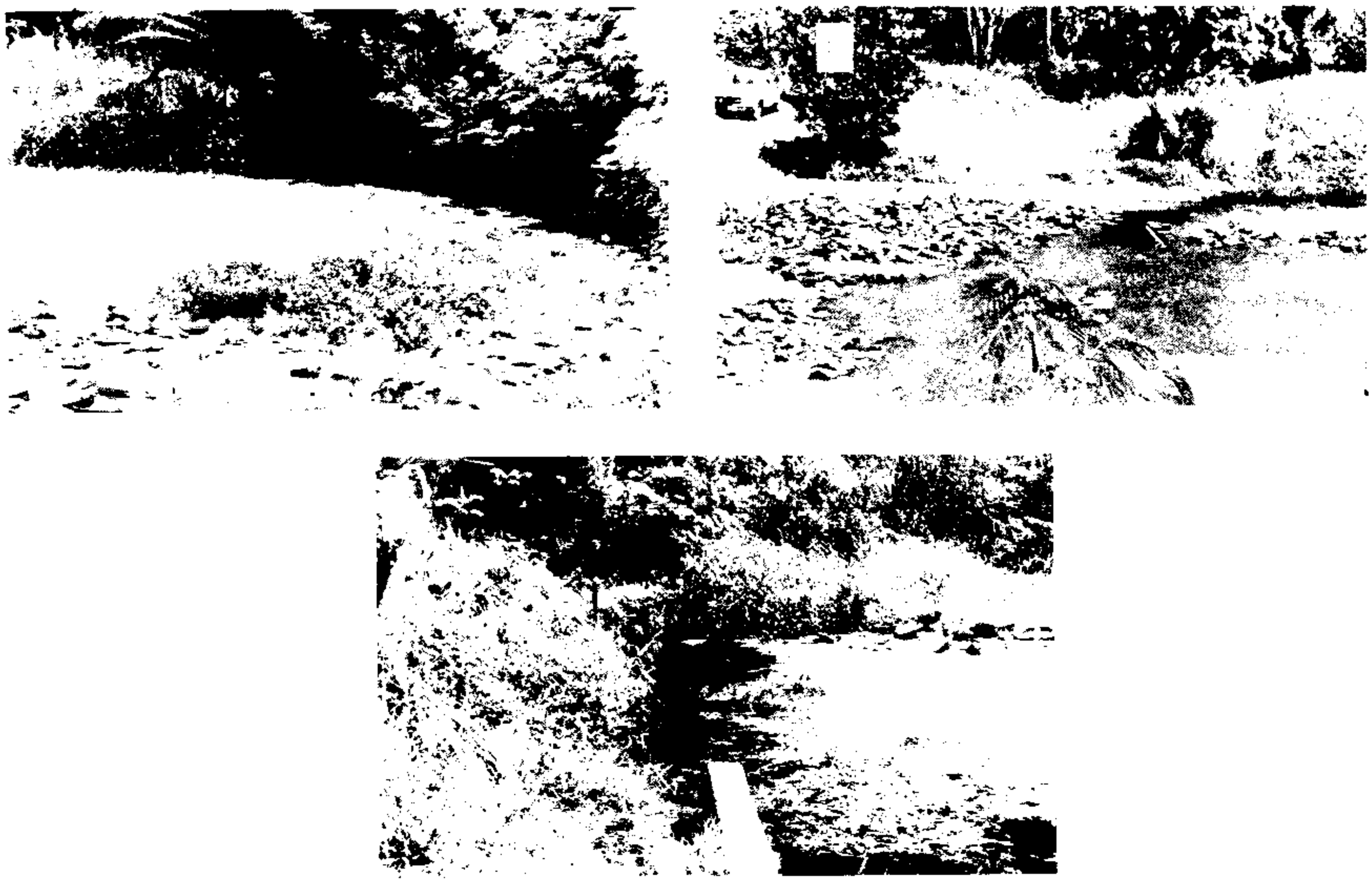

Figure 2. Agana Springs as it appeared in January 1981. a. looking east to the sampling site along the south limestone slope. b. northwest portion of the impoundment with the spillway as seen from the top of the south limestone slope. c. spillway with water flowing over it; bacteria sampling site on spillway.

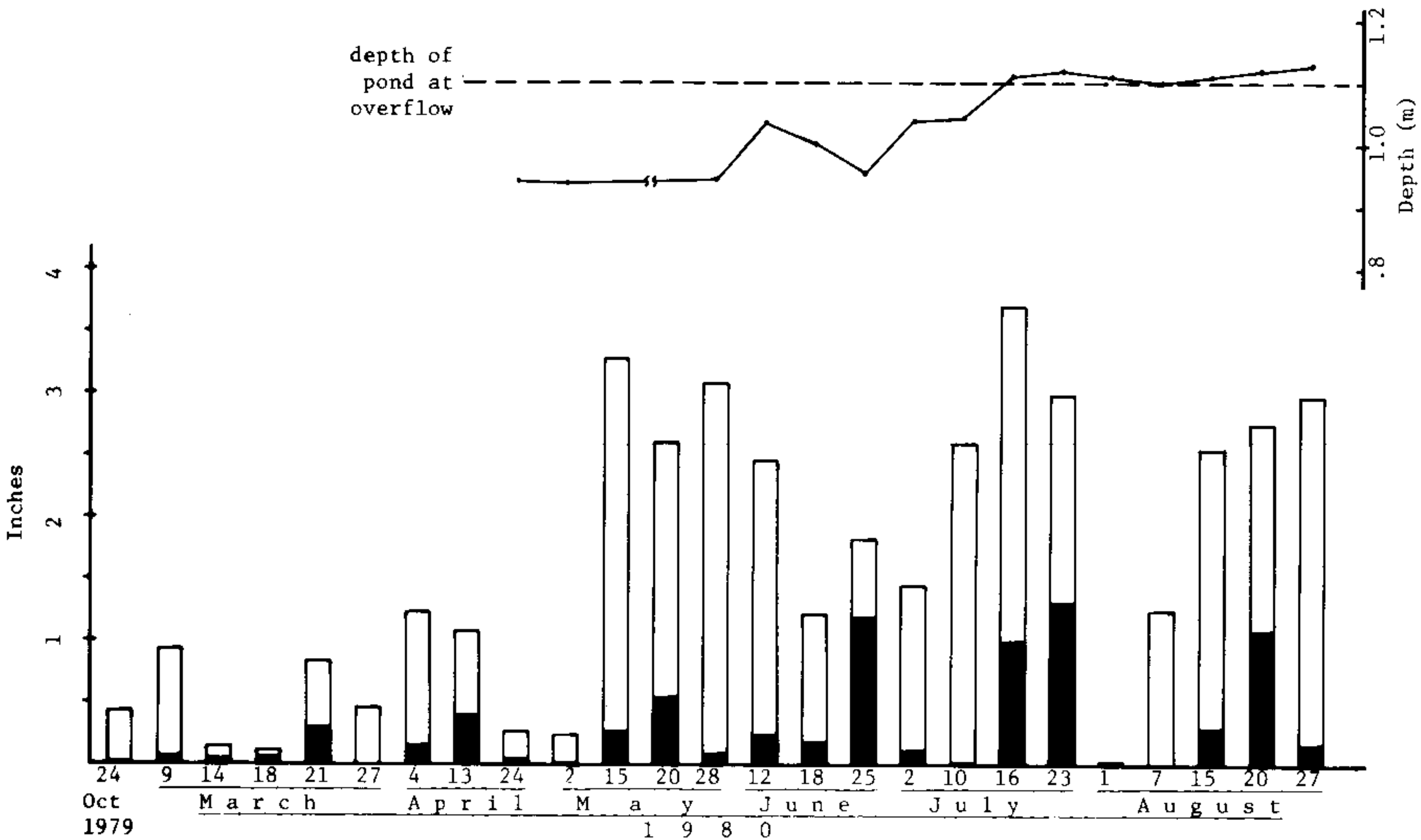

Figure 3. Total rainfall (inches) for week prior to sampling date (unshaded) and for 48 hours before sampling (shaded), and flow (as indicated by pond depth) **versus** sampling date.

The muck is a mixture of black or very dark colored, soft, decomposed plant remains with considerable pale-brown to light yellowish-brown fibers and generally enough clay, silt, and limesand or shell fragments to make the mass soft, sticky, and slightly gritty (Randall and Tsuda, 1974, in part from Stensland, 1959). By May 1980 the entire reservoir was choked by Hydrilla verticillata and Nymphea sp. (See Figure 2).

The actual site of water sampling was at an upwelling located at the east end of the steep limestone slope bordering the south side of the reservoir (Figure 2a).

METHODS

All water samples, with the exception of bacteriological samples, were collected with a Van Dorn sampling bottle. All parameters, again with the exception of bacteria, were measured from weekly samples taken at the same spring upwelling (Figure 2a), as close as possible to its source on the pond bottom. Samples were transported immediately, in an ice chest, to the WRRC laboratory for preservation and analysis. No special treatment (preservation or fixing) was given in the field as the samples could be in the laboratory within 20 minutes of sampling. Upon arrival at the laboratory the samples were treated and analyzed in accordance with "Standard Methods for the Examination of Water and Wastewater" (APHA, 1975) or "A Practical Handbook for Seawater Analysis" (Strickland and Parsons, 1972) (see Table 1). Analyses of phosphate-phosphorus and total phosphorus were modified from Strickland and Parsons (1971) and Standard Methods (1975) respectively. The modification applied to the phosphorus analysis is described in Cowan et al. (1978).

Initially it was attempted to isolate, as much as possible, the upwelling source on the pond bottom in order to obtain water samples as representative of the spring waters as possible. A section of concrete culvert of approximately 36 inches in diameter and 48 inches in length was utilized for this purpose by positioning it in an upright fashion such that the upwelling discharged within the culvert. This allowed for collection of the sample from within the culvert by means of the Van Dorn sampler.

At the outset of the study, water samples from within the confines of the culvert were obtained with ease. As time progressed however, a dense growth of the vascular plant Hydrilla verticillata made sampling within the culvert more and more difficult. Early attempts to remove the Hydrilla from within the culvert and immediately around it soon proved fruitless as removal could not keep pace with the growth of the Hydrilla. Sampling became a matter of locating the culvert, and then gently pushing the Hydrilla clear above the culvert to allow use of the Van Dorn bottle.

Table 1. Parameters Analyzed During the Study.

Parameter	Methods	Source
pH	Glass Electrode	--
Temperature	Mercury Thermometer	--
Turbidity	Nephelometer (NTU)	--
Specific Conductance	Wheatstone Bridge	--
Total Residue (TR)	Evaporation at 98°C	Standard Methods
Total Non-Filterable Residue (TNFR)	Glass Fiber Filter	Standard Methods
Total Filterable Residue (TFR)	TFR = TR - TNFR	Standard Methods
Alkalinity	Potentiometric Titration	Standard Methods
Hardness	EDTA Titrametric Method	Standard Methods
Calcium Hardness	EDTA Titrametric Method	Standard Methods
Chloride	Mercuric Nitrate Titration	Standard Methods
Sulfate	Turbidimetric Method	Standard Methods
Ammonia Nitrogen (NH_3-N)	Indophenol	Standard Methods
Nitrite Nitrogen (NO_2-N)	Sulfanilamide Diazotization	Standard Methods
Nitrate Nitrogen (NO_3-N)	Cadmium Reduction	Standard Methods
Total Kjeldahl Nitrogen (TKN)	Digestion/Distillation/Nesslerization	Standard Methods
Total Nitrogen	TN = (TKN + NO_2 + NO_3)	--
Phosphate Phosphorus	Ascorbic Acid Reduction	Handbook of Seawater Analysis-modified
Total Phosphorus	Persulfate Digestion/Ascorbic Acid Reduc.	Standard Methods-modified
Silica	Molybdosilicate	Handbook of Seawater Analysis
Biochemical Oxygen Demand$_5$	5-Day Incubation at 20°C	Standard Methods
MBAS	Methylene Blue Method	Wang, L. K. 1975
Total Bacteria	Membrane Filter	Standard Methods
Total Coliform	Membrane Filter	Standard Methods
Fecal Coliform	Membrane Filter	Standard Methods
Fecal Streptococcus	Membrane Filter	Standard Methods

Bacteriological samples were collected at the pond spillway (wall) for ease of collection (see Figures 2b and c) with pre-sterilized sample bottles. Bacteria were measured within 6 hours of collecting by the membrane filter technique (APHA, 1975).

All parameters with the exception of temperature were measured in the laboratory. Temperature was determined with a mercury thermometer (20-50°C) in the field.

Physical, chemical and bacteriological parameters measured and the method of analysis are presented in Table 1.

A one time sampling for metal analyses was conducted on October 3, 1980. Concentrations of barium, cadmium, copper, iron, lead, mercury, and silver were determined by flameless atomic absorption according to procedures outlined in Methods for Chemical Analysis of Water and Wastes (USEPA, 1979). All elements except mercury were analyzed with a Perkin-Elmer HGA-2200 graphite furnace. Mercury was analyzed by the cold vapor technique utilizing a Perkin-Elmer MHS-10 mercury hydride generation system.

A crude measure of spring output was attempted by measuring the height of the water level at the spillway (Figures 2b, c and 3) to the nearest centimeter with a meter stick.

RESULTS AND DISCUSSION

The original scope of work called for bi-weekly sampling of all parameters for a period of 12 months (Oct. 1979 to Sept. 1980). Due to a number of difficulties however, a strict sampling program was not initiated until March of 1980. In order to obtain as much data as possible, a weekly sampling schedule was adhered to from March to August. This period coincided with the end of the dry season and the beginning of the wet season.

In the analysis of the results, all parameters were compared against rainfall for short term (48 hour and 7 day) effects. Relationship to rainfall is discussed under the appropriate parameters. Weekly and 48 hour rainfall data are presented in Figure 3.

Some selected parameters are compared with results from previous analyses of Agana Springs (see Appendix B), results obtained on Well No. A-5 (see Appendix C) Sinajana by the Public Utility Agency of Guam (PUAG), and the results of Smith and Hedlund (1978) for Agana Swamp.

Agana Springs appears free of methylene blue active substances as MBAS was not detected in any weekly samples throughout the study.

The weekly results of parameters measured are presented in Table 2. Table 3 presents the mean, standard deviation, range of values and the number of samples for all parameters measured during the study. In addition, geometric means for bacteriological analyses were also calculated (Table 3).

Temperature

Temperature values of Agana Springs ranged from 25.6 to 30.0°C with a mean of 28.0°C. No temperature trends were detected during the period of the study. Variations observed were due to the time of sampling and the closeness of the sample collection to the spring upwelling.

pH

pH values fluctuated between 6.99 and 7.67 with a mean of 7.31. During the period March through August, when all but one of the samples were taken, the pH never fell below 7.02 (Table 2). The observed pH values are normal for groundwater on Guam. Monthly samples of Agana Springs by GEPA yielded a wider range of values, 6.75-8.85, during the same period; however the mean value (7.14) obtained by GEPA was comparable. Well analysis by PUAG yielded a range of 6.97 to 7.53 with a mean value of 7.18 for the same period at well A-5 (Appendix C).

Turbidity

In general, turbidity values were found to be constant and low (Figure 4) with a geometric mean of 0.86 NTU. Values ranged from a low of 0.42 NTU to high of 2.8 NTU. Mean turbidity was 0.97 NTU (Table 3). The mean turbidity of Agana Springs meets the current Guam Water Quality standards for turbidity. The range of values obtained by GEPA for Agana Springs during the same period was slightly lower, being 0.41 to 1.05 NTU with a mean value of 0.72 NTU.

Specific Conductance

Specific Conductance, a parameter which quantifies a water's capacity to carry an electric current, is measured in units of micromhos per centimeter (μmhos/cm). Since conductance varies with temperature, measurements are standardized for comparison at 25°C. The mean specific conductance value was 529 μmhos/cm at 25°C with a range from 430 to 675.

Table 2. Results of Chemical Analyses.

Date	Time	pH Units	Temp. °C	Turb. (NTU's)	Spec. Conduct. (µmho/cm) at 25°C	Total Residue (mg/ℓ)	Total Non-Filt. Residue (mg/ℓ)	Total Filt. Residue (mg/ℓ)	Alkalinity ←(mg/ℓ as $CaCO_3$)	Total Hardness (mg/ℓ as $CaCO_3$)→	Calcium Hardness	Chloride (mg/ℓ)	Sulfate (mg/ℓ)
10/24/79	1130	6.99	25.6	0.45	640	524	2.9	521	--	--	--	--	--
3/9/80	1100	--	--	--	--	320	0.6	319	--	--	--	--	--
3/14/80	1115	--	27.8	--	--	--	--	--	--	--	--	--	--
3/18/80	1145	--	--	--	--	388	1.8	386	291	272	247	19.1	1.6
3/21/80	0830	--	--	--	--	--	--	--	--	--	--	--	--
3/27/80	0830	--	--	--	--	--	--	--	--	--	--	--	--
4/4/80	1215	7.37	28.1	1.2	610	398	--	--	--	206	195	21.1	1.2
4/13/80	1400	7.63	28.5	0.79	590	394	0.2	394	220	285	251	20.5	--
4/24/80	1530	7.05	27.6	0.91	450	240	<0.1	240	269	237	--	--	--
5/2/80	1215	7.67	28.5	0.74	570	354	2.5	351	220	263	248	24.3	2.5
5/15/80	1200	7.02	--	1.1	555	--	5.4	--	--	--	--	--	--
5/20/80	1100	7.20	28.3	0.50	460	268	4.5	263	--	--	--	23.5	--
5/28/80	1100	7.40	28.3	0.80	535	326	5.8	320	--	--	--	23.2	--
6/12/80	0945	7.44	29.0	2.8	440	342	2.6	339	251	200	189	21.5	0.5
6/18/80	0915	7.32	29.0	0.93	440	260	1.6	258	207	207	198	23.0	0.6
6/25/80	0945	7.40	30.0	1.2	450	250	2.1	248	211	202	193	22.8	1.2
7/2/80	0900	7.40	28.0	1.6	430	262	2.2	260	204	201	191	25.8	0.7
7/10/80	0745	7.42	28.0	2.0	430	222	5.4	217	201	200	190	25.5	0.6
7/16/80	0830	7.42	28.0	0.94	430	192	2.0	190	200	193	176	25.8	0.5
7/23/80	0845	7.05	27.0	0.58	600	380	0.5	379	275	234	209	--	0.4
8/1/80	0915	7.22	26.7	0.58	600	336	0.1	336	225	298	--	26.9	1.3
8/7/80	0900	7.46	28.0	0.66	575	284	1.7	282	237	243	229	27.7	2.0
8/15/80	0900	--	29.0	0.91	500	332	2.7	329	224	226	214	--	0.4
8/20/80	0900	7.35	27.5	0.42	595	368	<.1	368	276	291	280	24.3	2.4
8/27/80	0930	7.08	28.0	0.45	675	416	0.5	415	263	281	267	21.2	--

Table 2. Continued.

Date	Time	NH_3-N (mg/ℓ)	NO_2-N (mg/ℓ)	NO_3-N (mg/ℓ)	TKN (mg/ℓ)	Total TN_a (mg/ℓ)	PO_4-P (mg/ℓ)	T-P (mg/ℓ)	SiO_2 (mg/ℓ)	BOD_5 (mg/ℓ)	Total Bact. (col/100 mℓ) (x10^4)	Total Colif. (col/100 mℓ) (x10^3)	Fecal Colif. (col/100 mℓ)	Fecal Strep. (col/100 mℓ)	FC/TC	FC/FS
10/24/79	1130	—	--	--	0.12	--	0.007	--	--	--	--	--	--	--	--	--
3/9/80	1100	0.194	0.003	0.166	--	--	0.003	0.003	1.26	--	--	--	--	--	--	--
3/14/80	1115	--	--	--	--	--	--	--	--	1.2	--	--	--	--	--	--
3/18/80	1145	0.020	--	--	--	--	--	--	2.20	--	--	--	--	--	--	--
3/21/80	0830	--	--	--	--	--	--	--	--	--	Confluent	<0.6	8	22	0.01	--
3/27/80	0830	--	--	--	--	--	--	--	--	--	83	30	12	14	<0.01	--
4/4/80	1215	0.035	0.012	0.108	--	--	0.004	0.011	4.85	--	7	8	17	<10	<0.01	--
4/13/80	1400	0.046	0.017	2.28	--	--	0.003	0.013	5.68	--	36	6	10	<10	<0.01	--
4/24/80	1530	0.072	0.018	2.96	--	--	0.003	0.016	7.50	2.2	35	20	$TNTC_b$	17	--	--
5/2/80	1215	0.078	0.028	1.82	0.40	2.25	0.004	0.017	6.20	1.9	12	2.3	<100	--	0.04	--
5/15/80	1200	0.114	0.058	0.729	0.38	1.17	0.004	0.009	5.70	--	--	--	--	--	--	--
5/20/80	1100	0.028	0.054	--	0.38	--	0.001	0.013	3.30	--	42	--	1200	30	--	--
5/28/80	1100	0.058	0.087	0.770	0.45	1.31	0.004	0.014	2.81	--	--	--	--	--	--	--
6/12/80	0945	0.099	0.025	0.219	0.57	0.81	0.004	0.016	7.21	0.8	25	40	1900	23	0.05	--
6/18/80	0915	0.098	0.022	0.162	0.45	0.63	0.001	0.019	5.88	2.0	28	12	<100	440	<0.01	<0.23
6/25/80	0945	0.076	0.009	0.042	0.24	0.29	0.002	0.019	5.22	1.5	10	1	120	65	0.12	--
7/2/80	0900	0.061	0.002	0.021	0.31	0.33	0.003	0.025	7.56	2.5	18	7	<100	300	0.01	<0.33
7/10/80	0745	0.028	<0.001	0.016	0.26	0.28	0.002	0.026	6.70	1.8	25	7	<100	93	0.01	--
7/16/80	0830	0.037	0.011	0.032	0.55	0.59	0.002	0.018	0.962	1.4	9	1	19	86	0.02	--
7/23/80	0845	0.032	0.024	2.67	0.49	3.18	0.001	0.004	2.05	0.9	18	1.1	14	73	0.01	--
8/1/80	0915	0.025	0.060	2.00	0.52	2.58	0.001	0.015	0.936	--	13	1	34	75	0.03	--
8/7/80	0900	0.030	0.065	0.496	0.12	0.68	0.001	0.009	1.59	1.6	19	0.2	60	50	0.30	--
8/15/80	0900	0.021	0.026	0.124	0.27	0.42	0.002	0.016	2.28	1.9	560	<0.1	$TNTC_c$	10,000	--	--
8/20/80	0900	0.043	0.031	2.17	0.40	2.60	0.001	0.006	2.23	1.5	21	0.9	17	35	0.02	--
8/27/80	0930	0.027	0.008	2.73	0.29	3.03	0.002	0.002	3.52	0.6	16	0.8	50	79	0.06	--

a = Total Nitrogen = $(NO_2 + NO_3)$ + TKN
b = 10 mℓ dilution
c = 1 mℓ dilution

Table 3. Mean ($\bar{Y}$), standard deviation(s), range, and number of samples (N) for parameters measured - Agana Springs: October 1979 - September 1980.

Parameters	$\bar{Y}$	s	Range Low	Range High	N
Temperature, °C	28.0	0.9	25.6	30.0	20
pH	7.31	0.2	6.99	7.67	19
Turbidity, NTU	0.97	0.58	0.42	2.8	20
Specific Conductance, μmho/cm at 25°C	529	81	430	675	20
Total Residue, mg/ℓ	326	78	192	524	21
Total Non-Filterable Residue, mg/ℓ	2.2	1.8	<0.10	5.8	21
Total Filterable Residue, mg/ℓ	321	79	190	521	20
Alkalinity, mg/ℓ as $CaCO_3$	236	31	200	291	16
Total Hardness, mg/ℓ as $CaCO_3$	238	37	193	298	17
Calcium Hardness mg/ℓ as $CaCO_3$	218	32.7	176	280	15
Chloride, mg/ℓ	23.3	2.27	19.1	27.7	16
Sulfate, mg/ℓ	1.1	0.7	0.4	2.5	14
Ammonia-Nitrogen, mg/ℓ	0.058	0.041	0.020	0.194	21
Nitrite-Nitrogen, mg/ℓ	0.028	0.024	<0.001	0.087	20
Nitrate-Nitrogen, mg/ℓ	1.03	1.11	0.016	2.96	19
Total Kjeldahl Nitrogen, mg/ℓ	0.36	0.14	0.13	0.57	17
Total Nitrogen, mg/ℓ	1.34	1.07	0.28	3.18	15
Ortho-phosphorus, mg/ℓ	0.003	0.002	0.001	0.007	21
Total Phosphorus, mg/ℓ	0.014	0.007	0.002	0.026	20
Silica, mg/ℓ	4.08	2.30	0.936	7.56	21
BOD_5, mg/ℓ	1.6	0.5	0.63	2.5	14
Total Bacteria, col/100 mℓ	$2.43x10^5$*	-	$7x10^4$	$5.6x10^6$	18
Total Coliform, col/100 mℓ	$2.50x10^3$*	-	$2x10^2$	$4x10^4$	18
Fecal Coliform, col/100 mℓ	53*	-	8	$1.9x10^3$	17
Fecal Streptoccocus, col/100 mℓ	62*	-	<10	10^4	18

*indicates geometric mean

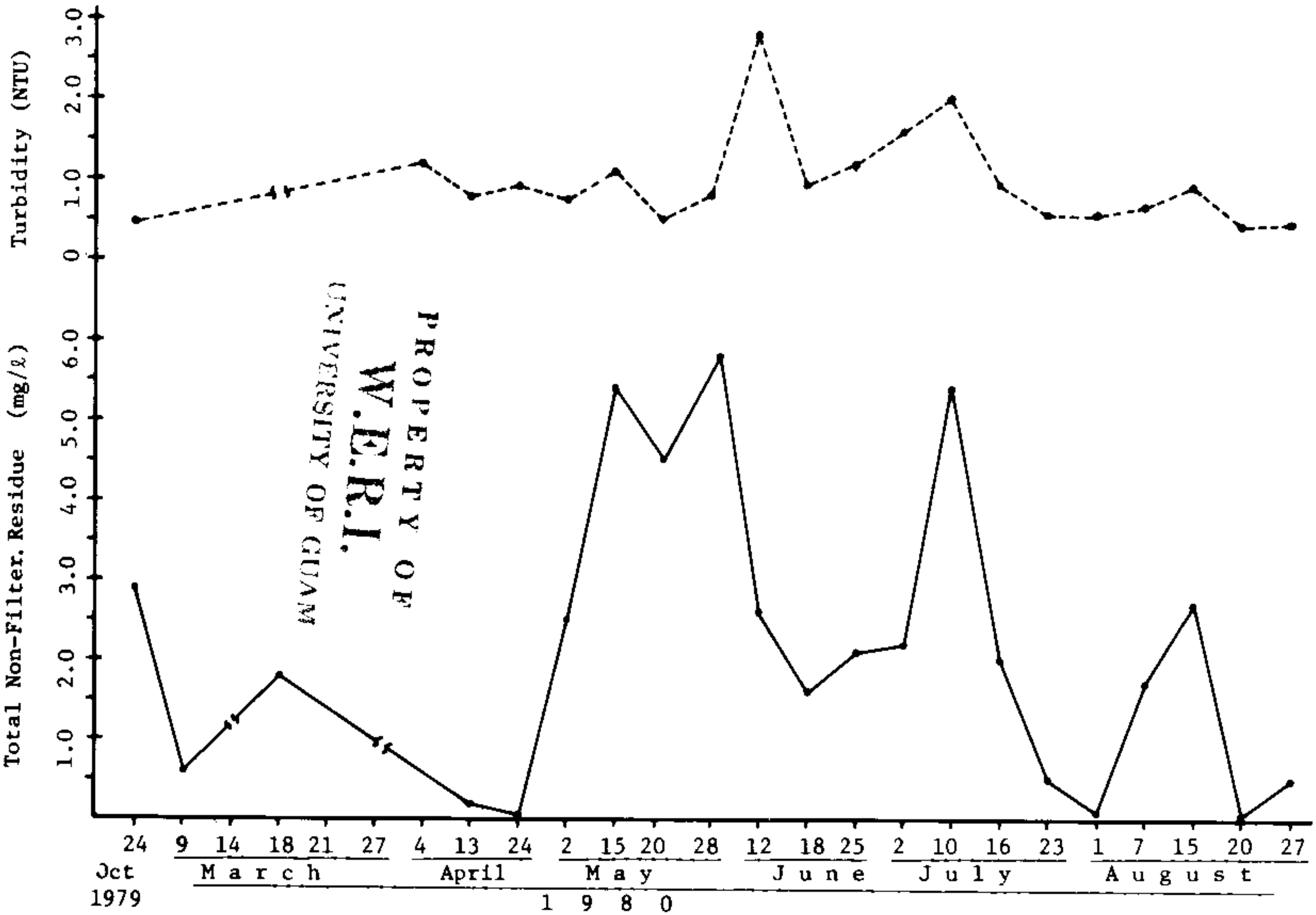

Figure 4. Total Non-Filterable Residue and Turbidity versus Sampling Date.

Residue

Total residue (TR) and total non-filterable residue (TNFR) were measured and total filterable residue (TFR) was calculated as:

$$TFR = TR - TNFR \text{ , mg/ℓ} \quad . \; . \; . \; . \; . \; (1)$$

The TR concentration varied between 192 and 524 mg/ℓ and had a mean value of 326 mg/ℓ. The suspended solids fraction (TNFR) made up less than one percent of the TR concentration. The mean TNFR value was 2.2 mg/ℓ with a range of <0.1 to 5.8 mg/ℓ. These results compare well with values obtained by GEPA for Agana Springs during the study period (mean value 2.8 mg/ℓ, range: 0.2 to 5.4 mg/ℓ). Calculated TFR (Equation 1) concentrations varied from 190 to 521 mg/ℓ with a mean value of 321 mg/ℓ. These mean values (underscored data) do not adhere to Equation 1 because of incomplete data sets on 4 April and 15 May, 1980.

Specific conductance is directly related to the total concentration of ionized substances present in water (TFR). This relationship is depicted in Figure 5 as the similar increases and decreases in these two parameters with time. The direct relationship is expressed as Equation 2:

$$TFR\text{, mg/ℓ} = \text{factor} \times \text{Sp. Cond., } \frac{\mu mhos}{cm} \text{ at } 25°C \quad . \; . \; . \; (2)$$

Given the mean values for TFR and specific conductance the factor for Agana Springs was calculated to be 0.61. Although Equation 2 should be updated occasionally, TFR for the springs can be approximated in the future by measuring specific conductance and water temperature.

Alkalinity-Hardness

The alkalinity and total hardness components are expressed in terms of mg/ℓ as $CaCO_3$. Alkalinity is a measure of the buffering capacity of natural water systems. The alkalinity concentrations ranged from 200 to 291 mg/ℓ with a mean value of 236 mg/ℓ. Since the pH of the springs was always less than 8.3, the sole alkalinity species was bicarbonate. The high alkalinity values quantified in the study are typical of Guam's groundwater. The alkalinity of Well No. A-5 (PUAG: Appendix C) extended over a similar range (234-283 mg/ℓ) and had a comparable mean concentration (255 mg/ℓ).

Total hardness values ranged from 193 to 298 mg/ℓ with a mean concentration of 238 mg/ℓ. Natural waters with total hardness values in this range are described as hard water systems (Sawyer and McCarty, 1967). A significantly greater mean value was reported for Well No. A-5 (310 mg/ℓ as $CaCO_3$: Appendix C). A sample of Agana Springs by GEPA in March 1976 yielded a total hardness of 288 mg/ℓ.

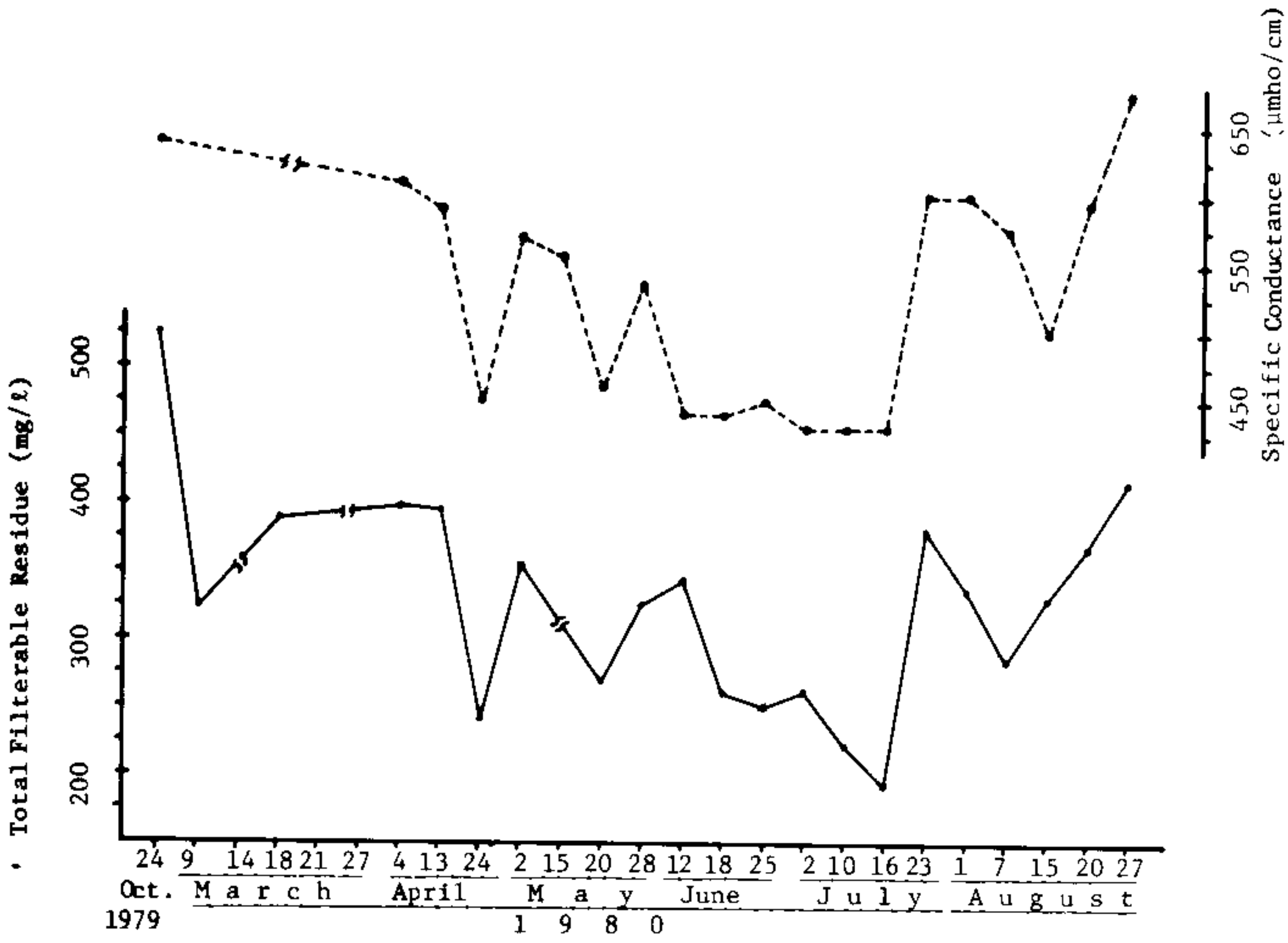

Figure 5. Total Filterable Residue and Specific Conductance versus Sampling Date.

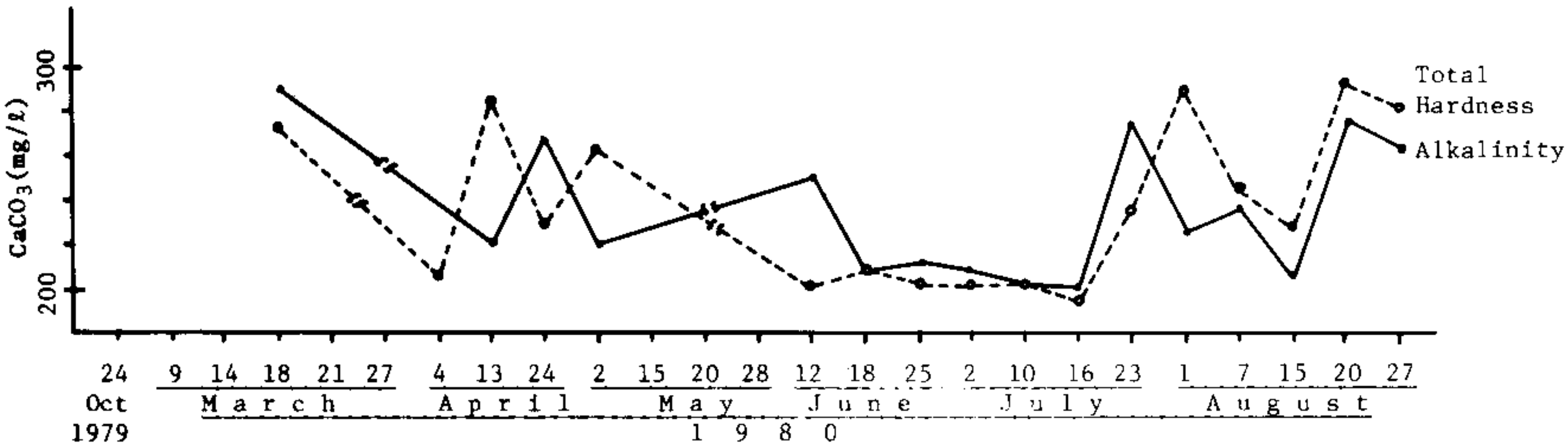

Figure 6. Total Hardness and Alkalinity versus Sampling Date.

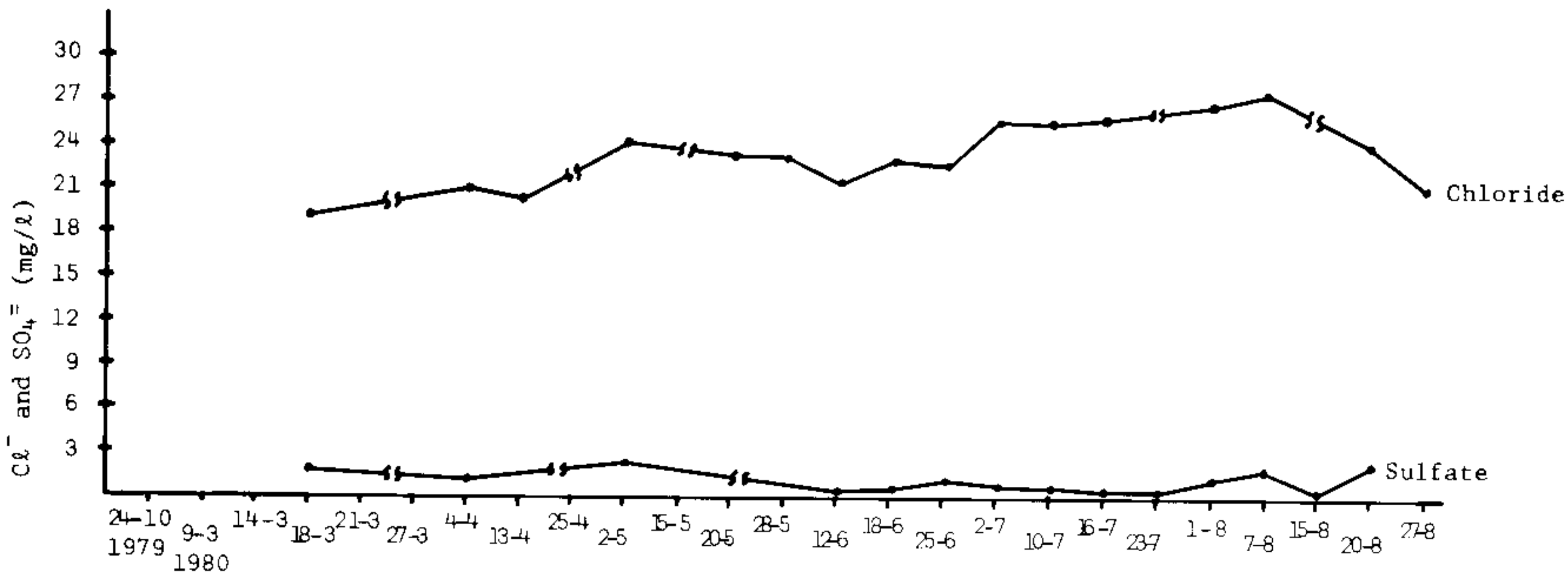

Figure 7. Chloride and Sulfate versus Sampling date.

Changes in alkalinity and total hardness values with time are depicted in Figure 6. No trends were detected in these parameters other than their parallel behavior. The similarity of mean concentrations (underscored data) indicates that all the hardness is bicarbonate hardness with little or no non-carbonate hardness.

Calcium hardness ranged from 176 to 280 mg/ℓ, with a mean of 218 mg/ℓ as $CaCO_3$. These concentrations accounted for 88 to 96 percent of total hardness during the study. For the same period, in Well No. A-5, calcium hardness contributed 80 to 99 percent of total hardness with values ranging from 259 to 291 mg/ℓ and a mean of 278 mg/ℓ.

Chloride-Sulfate

Chloride concentrations during the study ranged from a low of 19.1 mg/ℓ to a high of 27.7 mg/ℓ (Table 2). The mean chloride concentration was 23.3 mg/ℓ. No obvious trend was detectable in the data (Figure 7). Smith and Hedlund (1978) report slightly higher concentrations of approximately 35.0 mg/ℓ for three sites of standing water at the southwest end of the Agana Swamp during the month of January, 1978. Chloride concentrations for Well No. A-5 extended over a slightly wider range, 13.6 mg/ℓ to 29.1 mg/ℓ, than that of Agana Springs and showed a mean concentration at 18.2 mg/ℓ.

Sulfate concentrations ranged from 0.4 to 2.5 mg/ℓ with a mean of 1.1 mg/ℓ. Again no trends were detectable in the data (Figure 7). Results of chloride and sulfate analyses indicate that Agana Springs source water is relatively uncontaminated by seawater and is derived from the same perched aquifer system as the Sinajana A series wells. These results support the same conclusion as stated by Mink and Lau (1977) based on comparative tritium analysis of Agana Springs and other waters.

Nitrogen

Ammonia-nitrogen (NH_3-N) concentrations were very low throughout the study exhibiting little fluctuation with time (Figure 8). Concentrations ranged from a low of 0.020 mg/ℓ to a high of 0.194 mg/ℓ with a mean concentration of 0.058 mg/ℓ

Nitrite-nitrogen (NO_2-N) levels were very low ranging from a minimum of less than 0.001 mg/ℓ to a maximum of 0.087 mg/ℓ with a mean of 0.028 mg/ℓ. On the average, NO_2-N contributed approximately 2 percent to total nitrogen concentration during the study.

Nitrate-nitrogen (NO_3-N) varied over a wide range, from a low of 0.016 mg/ℓ to a high of 2.96 mg/ℓ, with a mean concentration of 1.03 mg/ℓ. Extreme peaks in NO_3-N concentrations (Figure 9) may possibly be due to washing out of nitrate from the soil after periods of rainfall. Lysimeter studies in the laboratory (Cowan and Clayshulte, 1980) highlight this possibility; however, no correlations between NO_3-N peaks and rainfall were apparent (compare Figure 3 and 9).

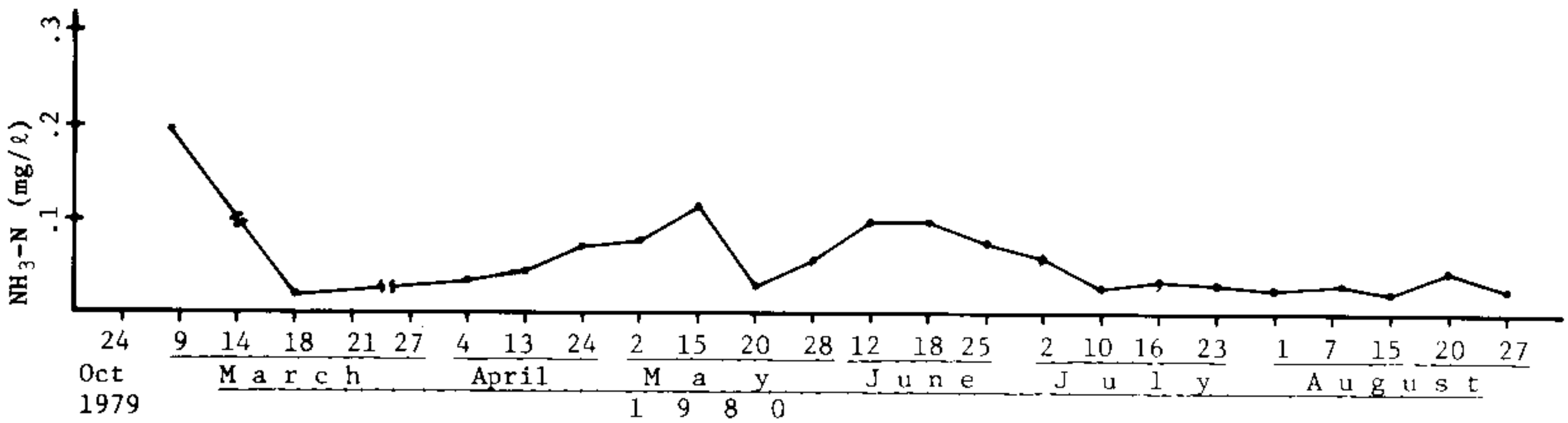

Figure 8. Ammonia Nitrogen versus Sampling Date.

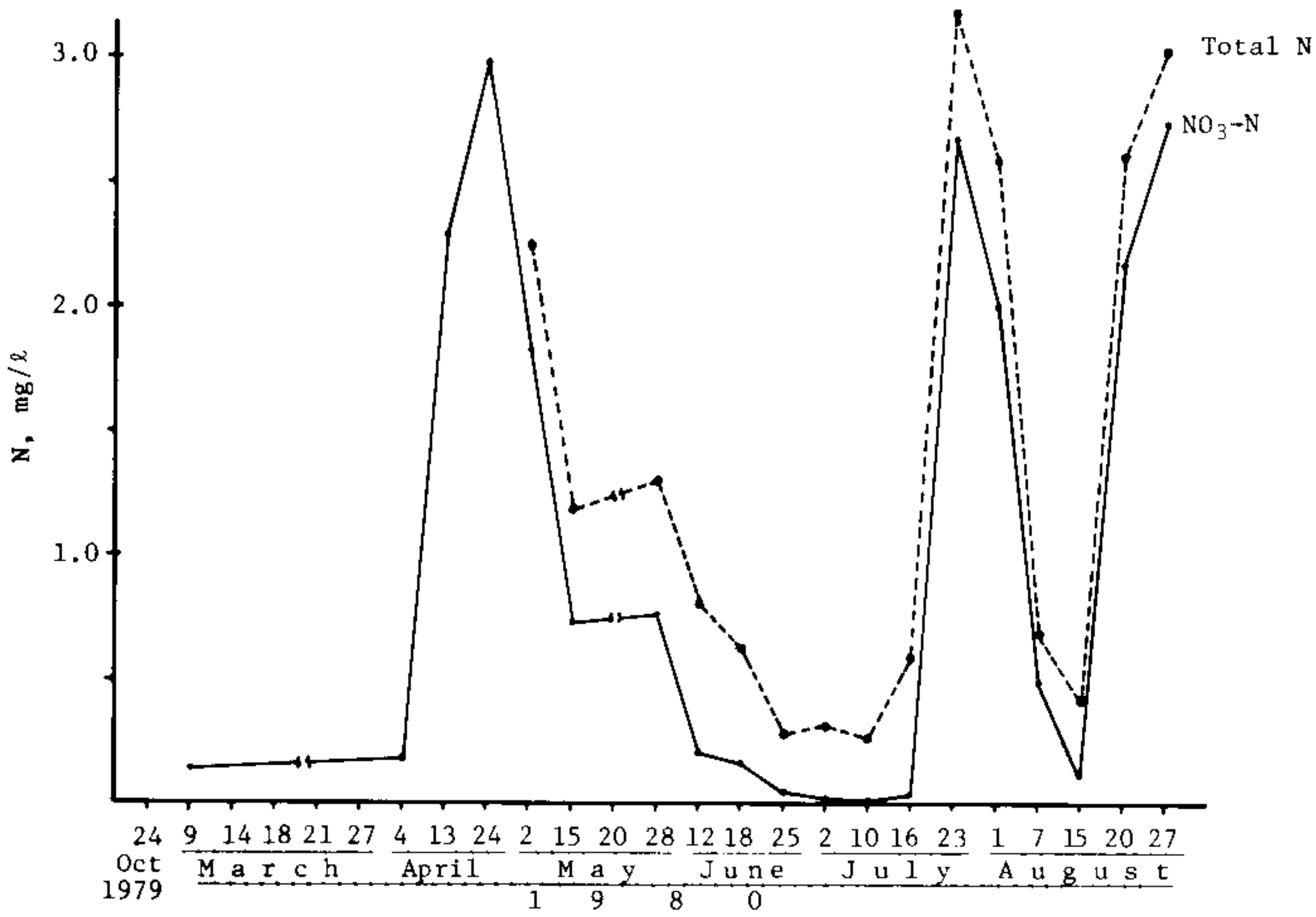

Figure 9. Total Nitrogen and Nitrate Nitrogen versus Sampling Date.

Monthly NO_3-N analysis of Agana Springs by GEPA during the same period also showed wide, unpredictable fluctuations in NO_3-N concentrations, with a slightly lower and narrower range with a minimum concentration of 0.005 mg/ℓ and a maximum of 2.60 mg/ℓ. Mean NO_3-N concentration was slightly lower at 0.83 mg/ℓ. Smith and Hedlund (1978) obtained a NO_3-N concentration at the southwest end of the Agana Swamp, at approximately one tenth the lowest value observed in the reservoir. The wide, unpredictable NO_3-N concentrations observed in this study and GEPA results are interesting as they indicate nitrogen input into the small reservoir formed by Agana Springs. This input may be the result of surface runoff or of NO_3-N leaching into the springs feed water in the water table.

Total Kjeldahl Nitrogen (TKN) in Agana Springs fluctuated between 0.12 and 0.57 mg/ℓ with a mean concentration of 0.36 mg/ℓ during the study period. Total nitrogen was calculated as the sum of oxidized and reduced forms of nitrogen (NO_2-N + NO_3-N + TKN).

Total nitrogen exhibited a mean concentration of 1.34 mg/ℓ and ranged from a low of 0.28 mg/ℓ to a high of 3.18 mg/ℓ. The major nitrogen component was NO_3-N (Figure 9).

Phosphorus

Phosphorus concentrations in Agana Springs were very low during the study. Orthophosphate-phosphorus (PO_4-P) concentrations ranged from 0.001 to 0.007 mg/ℓ showing very little variation with time (Figure 10). Mean PO_4-P concentration from March through August was 0.003 mg/ℓ. During the same period (March-August), samples obtained by GEPA from Agana Springs yielded PO_4-P concentrations with a wider range, 0.004 to 0.035 mg/ℓ. Their mean concentration of PO_4-P was 0.017 mg/ℓ. Analysis of Agana Springs for these months in past years, 1978 and 1979, by GEPA, yielded mean concentrations of 0.047 and 0.217 mg/ℓ respectively.

Total phosphorus (TP) had a mean concentration of 0.014 mg/ℓ with a range from 0.002 to 0.026 mg/ℓ. The consistently low TP concentrations (Figure 10) exhibited no correlation to suspended solids (TNFR) data (compare Figures 4 and 10). A GSTA sample in April 1970 and a sample by GEPA in March 1976 also contained low levels of TP at 0.022 and 0.05 mg/ℓ respectively.

Silica

Silica-Silicon concentrations ranged from a low of 0.94 mg/ℓ to a high of 7.56 mg/ℓ with a mean of 4.08 mg/ℓ. There were no obvious trends in the data (Figure 10). The concentration range exhibited (less than 10 mg/ℓ) is consistent with data from Almagosa Springs. Almagosa Springs is similar to Agana Springs in that both originate in an Alifan limestone contacting volcanics above sea level.

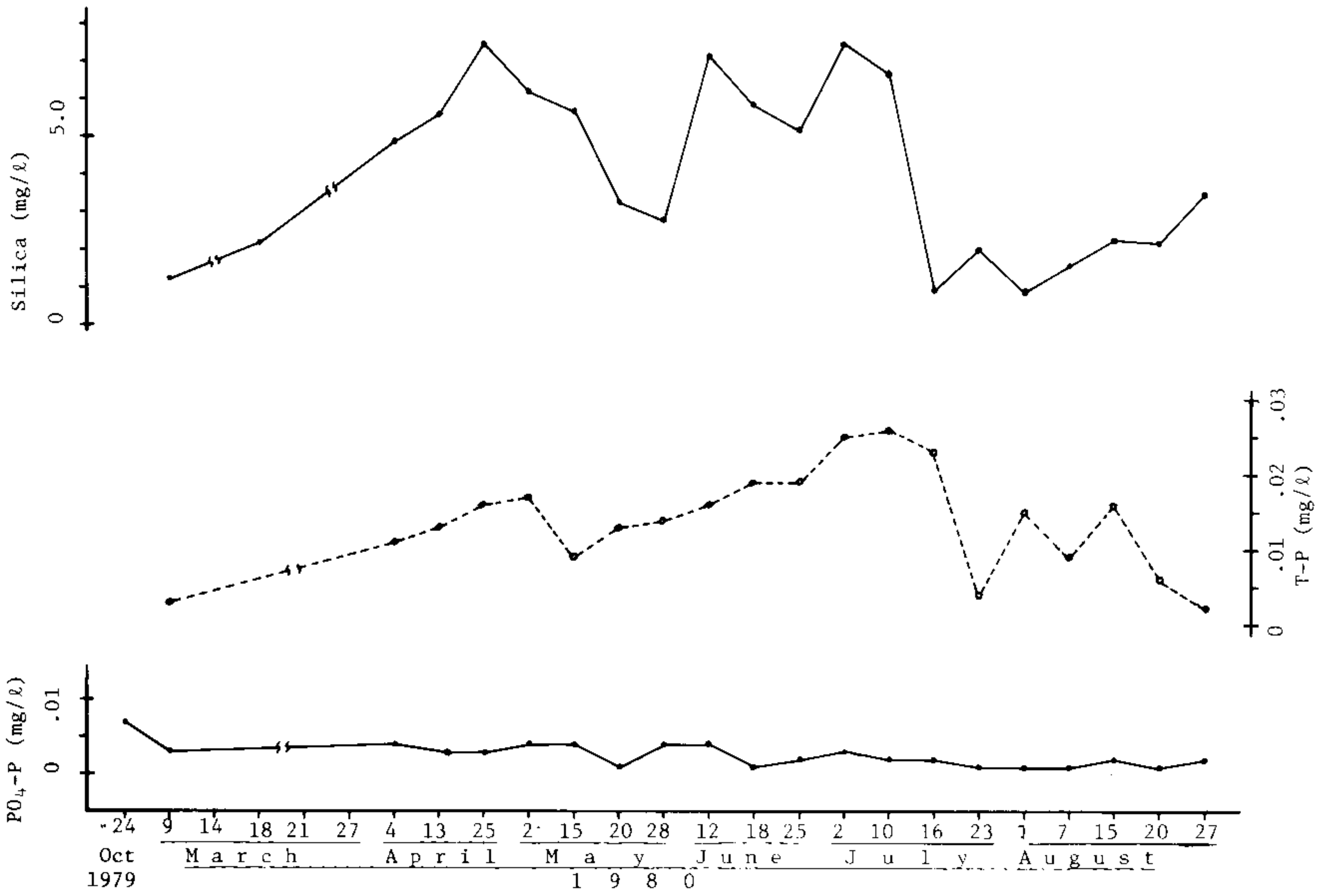

Figure 10. Ortho-Phosphorus, Total Phosphorus, and Silica versus Sampling Date.

Heavy Metals

Barium, cadmium, copper, iron, lead, and silver concentrations in the sample collected on October 3, 1980 were all below the water quality standards for these metals (Table 4). Mercury concentrations were below the detection limit of 0.2 μg/ℓ.

Bacteria

Total bacteria ranged from a low of 70,000 colonies/100 mℓ to a high of 5,600,000 colonies/100 mℓ with a geometric mean of 243,000 colonies/100 mℓ. Total coliform bacteria ranged from 200 to 40,000 colonies/100 mℓ with a geometric mean of 2,500 colonies/100 mℓ. Weekly variations in total coliform (Figure 11) did not appear to follow any observable trend and apparently are not related to rainfall data (compare Figures 3 and 11).

Fecal coliform fluctuated between a low of 8 colonies/100 mℓ to a high of 1900 colonies/100 mℓ with a geometric mean of 53 colonies/100 mℓ. Figure 12 show weekly fluctuations of fecal coliform, and again no trend is discernible in the data. GEPA fecal coliform analyses of samples collected at the spillway were generally higher than the numbers observed closer to the spring source (See Appendix B).

Fecal streptococcus ranged between less than 10 colonies/100 mℓ and 10,000 colonies/100 mℓ with a geometric mean of 62 colonies/100 mℓ.

Fecal coliform to total coliform ratios (FC:TC) ranged from less than 0.01 to 0.3 (Table 3) with a mean value of .05 (S. D. = .07, N = 6). A FC:TC ratio of 0.20 or higher indicates pollution by raw sewage or domestic wastewater (ORSANCO, 1971). The fecal coliform to fecal streptococcus ratio (FC:FS) was calculated in the two instances where fecal streptococcus counts were greater than 100/100 mℓ. For fecal streptococcus counts of less than 100/100 mℓ, the FC:FS ratio should not be applied (Bordner and Winter, 1978). Fecal coliform to fecal streptococcus ratios were calculated at less than 0.23 and less than 0.33 (Table 2) on these two occasions. Ratios (FC:FS) of less than 0.7 are indicative of contamination originating from livestock and poultry wastes while ratios greater than 4.1 are indicative of pollution from domestic wastes (Bordner and Winter, 1978). Heron were occasionally seen leaving the pond on our sampling trips.

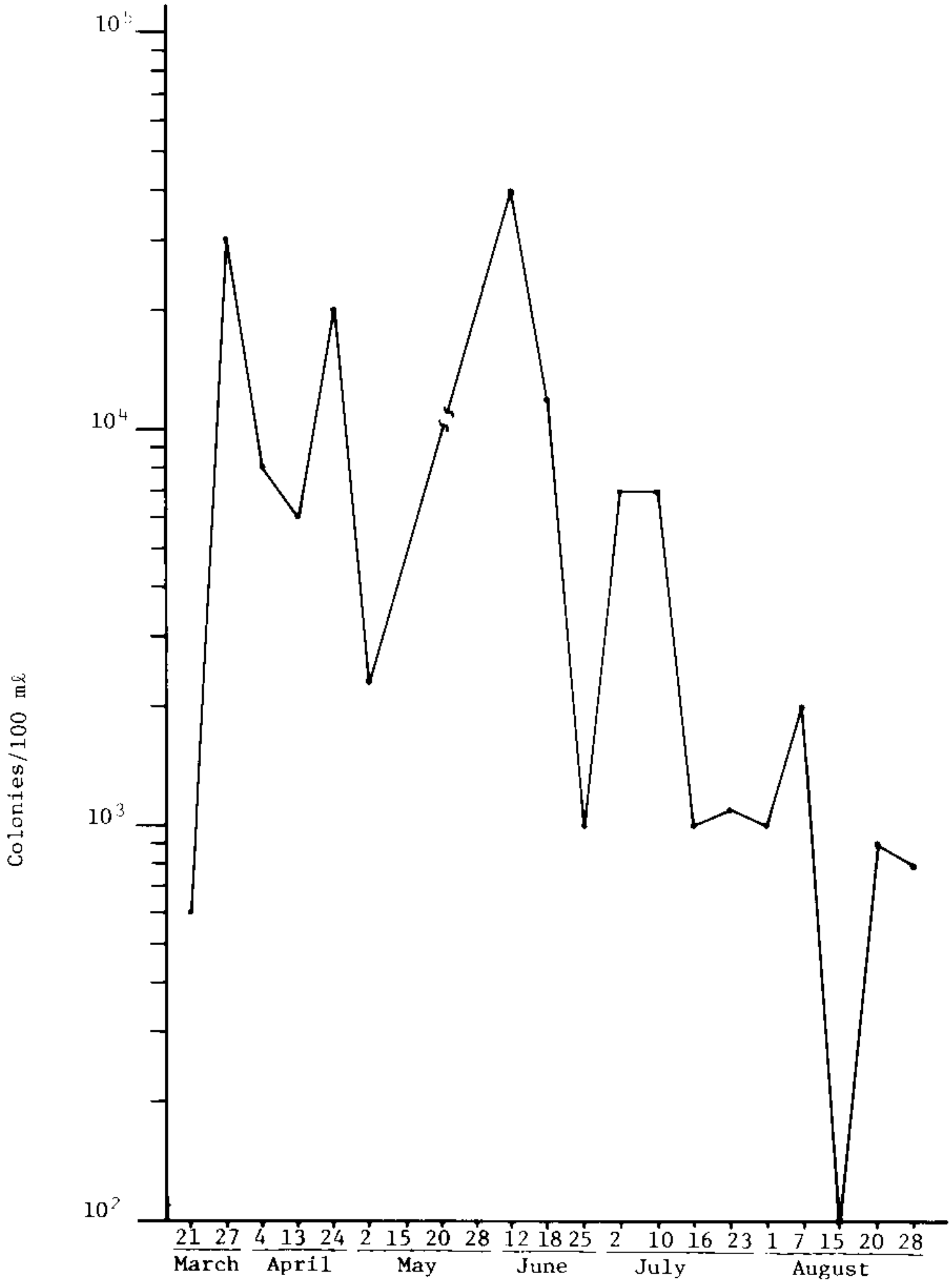

Figure 11. Total Coliform Bacteria versus Sampling Date.

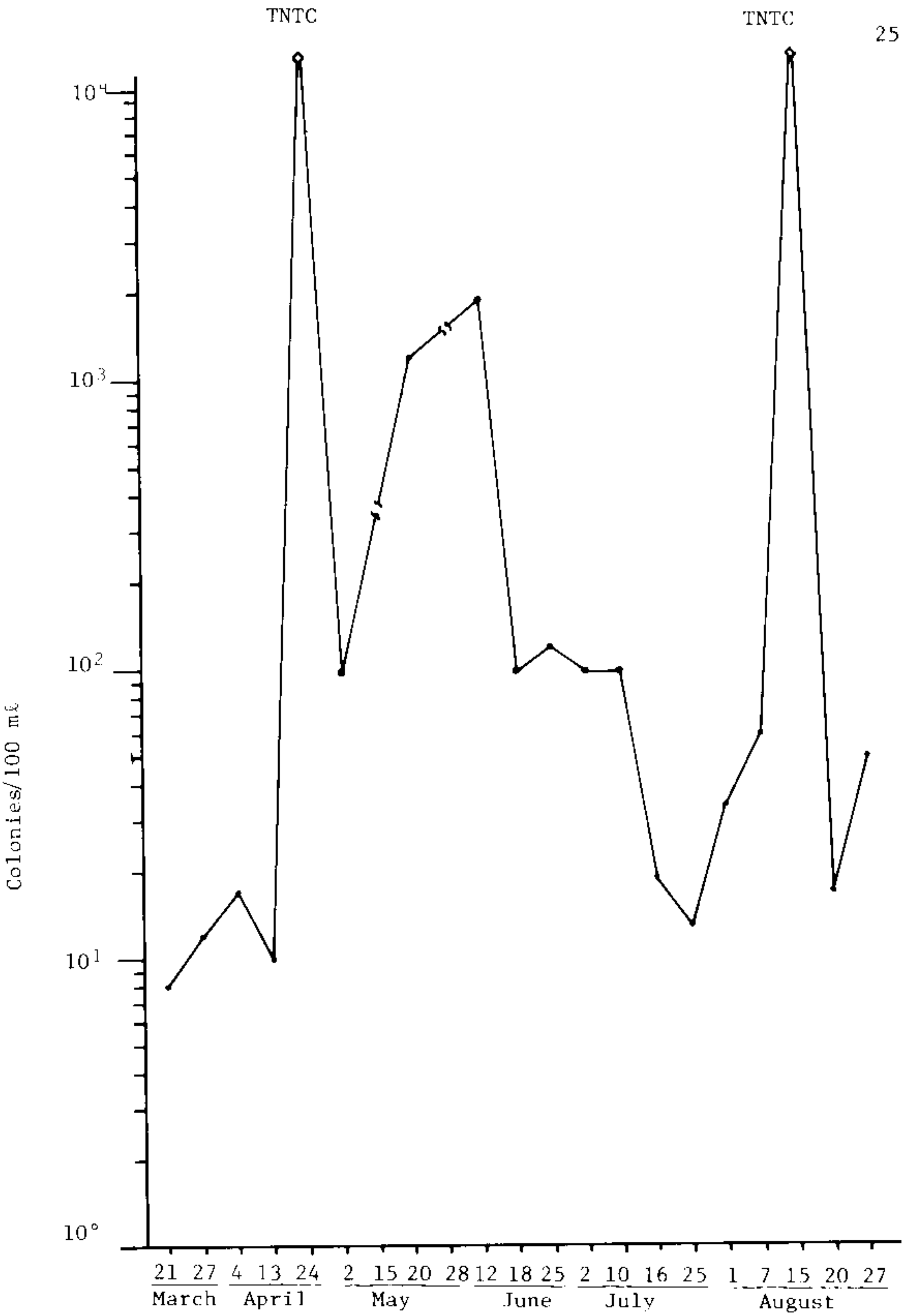

Figure 12. Fecal Coliform Bacteria versus Sampling Date.
° represents <100 counts/100 mℓ.
⊙ represents TNTC (too numerous to count).

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) for Agana Springs was low, varying from a minimum value of 0.6 mg/ℓ to a maximum value of 2.5 mg/ℓ. The mean BOD concentration during the study was 1.6 mg/ℓ. Low BOD concentrations of 1 mg/ℓ or less are characteristic of unpolluted bodies of freshwater (Cross, 1974).

Comparision of Water Quality of Agana Springs with GEPA Water Quality Standards: Chemical and Bacterialogical

The objective of this project was to determine if Agana Springs can be considered a major freshwater resource for development as a municipal water supply from a water quality standpoint. Initially it was attempted to sample spring water or category "1a" water (basal water lens) as described in the GEPA Water Quality Standards. This soon proved infeasible, and subsequent samples were of water above the upwelling, classed as Category "2b" waters (GEPA, 1975). As the objective is to determine if Agana Springs is potentially developable as a drinking water resource, the results are compared against GEPA Water Quality Standards for Zone "2b-I" waters (see Table 4).

Water Quality Standards state that 2b-I waters will not have pH values below 6.5 or higher than 8.5 except as a result of natural causes. Guam tap waters generally range from 7.0-7.8 pH units (Zolan et al., 1978). Agana Springs varied from 6.99-7.67 pH units throughout the study and fall within the suggested range. These fluctuations could not be attributed to anything but natural conditions within the impoundment.

A maximum limit of 1 NTU has been established for drinking waters. For "2b-I" waters "turbidity shall not be increased from ambient conditions at any time" (GEPA Water Quality Standards, 1975). Analyses of Agana Springs yielded a geometric mean of 0.86 NTU with a range of 0.42-2.8 NTU. NTU values greater than 1 NTU occurred on only 6 occasions and there is the possibility that these values were the result of sampling technique due to stirring up of bottom sediment while sampling.

MBAS concentrations, with a limit of .02 mg/ℓ for drinking water, were undetectable throughout the study and are therefore presumed to be absent from the waters of Agana Springs.

Chloride concentration of Agana Springs, ranging from 19.1-27.7 mg/ℓ, is far below the limit of 250 mg/ℓ set by GEPA for drinking waters.

Table 4. Comparison of Agana Springs water quality (this study) to The Guam Water Quality Standards. Metal concentrations are in μg/ℓ, all others are in mg/ℓ unless noted.

	pH	BOD	Turb. (NTU)	TNFR	TP	Sulfate	NO_3-N	NO_2-N	Chloride	MBAS	TC (col/100mℓ)	FC (col/100mℓ)
Agana Springs	7.31		0.97	2.2	0.014	1.1	1.03	0.028	23.3	0	2500*	53*
Guam Water Quality Standards												
Drinking waters	—	—	1	—	—	250	10	1	250	0.5	1	0
Drinking water resource-standing waters (2b-I)	0.5 change from ambient	Ambient	Ambient	Ambient	.05	—	—	—	—	—	Ambient	Ambient

Heavy Metals:	Barium	Cadmium	Copper	Iron	Lead	Mercury	Silver
Agana Springs	3	<0.1	6	9	<1	<0.2	<0.5
Guam Water Quality Standards							
Drinking water	1000	10	1000	300	50	2	50

* indicates geometric mean

Specific numerical criteria are not placed upon phosphorus concentrations from drinking waters by GEPA. Total phosphorus (TP) concentration of category 2b-I waters however, are restricted to values less than or equal to 0.05 mg/ℓ. At no time during the study did TP concentration for Agana Springs exceed 52 percent of the allowable concentration while the mean TP concentration was 28 of that allowed.

Nitrate-nitrogen concentrations throughout the study, ranged from .016-2.96 mg/ℓ, and fell below the maximum allowable limit of 10 mg/ℓ for drinking waters.

Nitrite-nitrogen concentrations also fell well below the maximum limit of 1.0 mg/ℓ, set by GEPA. NO_2-N values never exceeded 10 percent of the maximum allowable value for drinking waters.

A maximum limit of 250 mg/ℓ has been set for sulfate concentrations by GEPA for drinking waters. Analyses of Agana Springs yielded a mean concentration of only 1.1 mg/ℓ.

Microbiological requirements set forth in GEPA Water Quality Standards (1975) state that "fecal coliform concentrations at any point shall not be increased from natural conditions at any time" for 2b-I type waters. Fecal Coliform concentration at Agana Springs ranged from 8 - 1900/100 mℓ with a geometric mean of 53 colonies/100 mℓ. Of 17 samples, six had values greater than the geometric mean. The source water needs to be isolated (by tunneling) then tested in order to state categorically that the groundwater source is not contaminated. Also, testing for virus pathogens should be conducted at that time.

CONCLUSIONS

Agana Springs water quality (and quantity based on past records) is sufficiently high to merit development as a freshwater source for distribution. The only problem of significance is bacterial contamination which for the most part may not be due to contaminated groundwater. The observed fecal coliform bacteria levels indicate light to moderate contamination that could be controlled by chlorination. Surface runoff and animal activity in the pond or along shore undoubtedly contributed to the observed contamination. Agana Springs water should meet potable water quality standards if developed into a completely enclosed concrete reservoir, and the water is chlorinated. An initial project to isolate the main feedwater sources should be undertaken. Bacteriological and virus pathogen testing could then establish the extent of groundwater contamination prior to extensive development.

The chemical and physical quality of Agana Springs water in the current impoundment is relatively high in comparison with standards set by GEPA for "drinking waters" and standing waters in basins utilizable as drinking water resources (2b-I classification: GEPA, 1975). The spring water is also of higher chemical and physical water quality than many wells (the Mangilao A series, and certain F series wells in Dededo) and surface water sources (e.g. Ylig River) currently being utilized by the distribution system.

The Government of Guam should attempt to obtain the Agana Springs resource for development if the Navy does not plan to develop the springs for its own needs.

ACKNOWLEDGEMENTS

We would like to acknowledge all those who lent assistance or advice during this study. We are particularly grateful to Vaughan Tyndzik and Russell N. Clayshulte for field assistance at the begining of the study in placing the culvert. The Public Works Department of Guam provided the section of culvert utilized for the study.

We would also like to thank Dr. Lynn Raulerson of the Biology Department, University of Guam, for identification of vascular plants from the springs and suggestions of previous studies conducted at Agana Springs. Dr. Lucius Eldredge of the University of Guam, Marine Laboratory, provided copies of these studies. Melvin Borja, Biologist II, GEPA, provided well data while Ken Morphew, Environmental Health Supervisor, GEPA, allowed us the use of the GEPA UV sterilizer. The Public Utility Agency of Guam provided well data through Ralph Mesa. Chuck Huxel at the USGS provided flow data for Agana Springs while the U. S. Naval Oceanographic Command Center, Guam, provided us with rainfall data during the period of this study. Dr. Peter Cowan of Water and Energy Resources Institute of the Western Pacific read the manuscript and made many helpful suggestions.

Last but not least we wish to thank our Water Resources secretaries, Terry A. Cruz, Rita Nauta, and Evelyn Paulino, for the many hours put into preparation of this manuscript.

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APPENDIX A

Daily freshwater pumpage in gallons from Agana Spring Reservoir from January to May 1953. Data are from the Guam Office of the U. S Geological Survey.

Day	January	February	March	April	May
1	2,144,000	2,159,200	2,015,700	2,071,100	1,597,600
2	2,814,200	2,227,600	3,041,800	2,063,000	1,557,300
3	2,530,800	2,235,600	2,039,600	2,066,200	1,493,600
4	2,475,300	2,238,900	2,042,400	2,046,800	1,674,400
5	2,499,400	2,236,500	2,050,200	1,938,500	1,571,000
6	2,589,100	2,264,200	2,061,800	1,918,900	1,596,100
7	2,516,200	2,285,100	2,081,300	1,690,600	1,612,800
8	2,460,400	2,227,900	2,009,100	2,103,500	1,578,600
9	2,056,600	2,251,200	2,054,400	1,748,400	1,554,000
10	1,417,700	2,092,000	2,034,400	1,728,600	1,474,500
11	1,294,900	2,061,800	2,030,100	1,854,400	1,545,400
12	1,338,400	2,013,400	2,023,200	1,899,700	1,512,200
13	1,332,900	1,890,400	2,031,700	1,887,200	1,526,000
14	1,329,200	1,940,800	2,018,800	1,876,500	1,480,800
15	1,337,100	2,137,800	1,976,700	1,632,000	1,493,200
16	1,883,800	1,759,300	2,012,600	1,603,300	1,496,900
17	2,126,800	1,932,100	2,021,600	1,601,100	1,459,500
18	2,050,700	1,922,000	2,022,400	1,571,200	1,513,400
19	2,083,600	1,664,700	2,033,900	1,587,500	1,500,700
20	1,437,300	1,876,100	2,028,000	1,588,000	1,438,800
21	969,200	1,896,700	2,012,800	1,522,100	1,430,000
22	954,400	1,843,700	1,975,600	1,624,900	1,413,400
23	941,700	1,886,200	2,012,800	1,643,200	1,397,600
24	1,420,500	1,727,300	2,030,700	1,608,700	1,445,100
25	2,123,700	2,061,800	2,030,200	1,577,500	1,398,400
26	2,153,200	1,904,500	2,033,200	1,550,300	1,434,700
27	2,205,400	2,064,900	2,037,800	1,569,900	1,354,700
28	2,234,300	2,043,000	2,076,700	1,605,600	1,309,200
29	2,224,000		2,054,000	1,575,400	1,348,100
30	2,225,100		2,098,800	1,645,700	1,297,800
31	2,229,300		2,029,900		1,332,800
Total	59,399,200	56,844,700	64,021,700	52,399,800	45,818,600

APPENDIX B

Results of Guam Environmental Protection Agency analyses of Agana Springs waters March 1978-August 1980. Water samples were collected from the Spillway (downstream and across the pond from the WERI sampling location).

Date	pH	T°C	Turb. (Jackson units)	NO_3-N (mg/ℓ)	PO_4-P (mg/ℓ)	F.C. (col/100mℓ)
3/7/78	7.2	28.0	13.5	0.07	0.036	460
4/3/78	7.2	28.5	2.8	0.75	0.069	250
5/1/78	6.8	28.5	0.52	0.05	0.061	180
6/8/78	7.4	30.2	0.08	0.04	0.012	1220
2/1/79	6.9	26.0	2.5	3.00	0.000	1630
6/6/79	7.0	28.0	1.4	0.03	0.149	1360
7/3/79	6.8	27.0	1.7	<0.01	0.099	164
8/7/79	7.4	31.5	2.8	0.01	0.402	114
9/10/79	7.6	31.8	0.69	<0.01	0.487	690
10/2/79	7.0	27.2	2.1	0.20	0.325	295
11/8/79	7.0	27.2	0.39	2.50	0.140	70
12/3/79	7.7	26.0	0.34	3.10	0.063	180
1/2/80	8.5	28.5	0.42	3.02	0.011	3300
1/29/80	7.1	--	0.81	1.77	0.022	200
2/26/80	7.3	26.0	9.1	0.81	0.021	2400
3/25/80	6.9	28.0	0.41	2.60	0.004	470
4/29/80	7.1	24.5	0.42	0.67	0.014	630
5/28/80	6.8	30.0	1.0	<0.01	0.035	860
7/1/80	8.8	28.4	1.0	0.06	0.013	920
8/5/80	7.6	26.9	1.1	0.51	0.215	confluent
$\bar{y}$	7.3	28.0	2.2	0.96	0.109	810
s	0.5	1.9	3.3	1.20	0.142	862
N	20	19	20	20	20	19

APPENDIX C

Mean ($\overline{Y}$), Standard Deviation (s), Range, and Number of Samples (N) for Parameters Measured at Well No. A-5, Sinajana, by the Public Utility Agency of Guam from March to August 1980.

Parameter	$\overline{Y}$	s	Range Low	Range High	N
Temperature °C	27.9	0.20	27.5	28.0	6
pH	7.18	0.20	6.97	7.53	6
Turbidity NTU	0.19	0.04	0.15	0.24	6
Specific Conductance μmho/cm	588	16	560	600	6
Alkalinity mg/ℓ CaCO	254.7	20.3	234.0	283.0	6
Calcium Hardness mg/ℓ CaCO	277.6	11.4	259.2	291.0	6
Total Hardness mg/ℓ CaCO	310.2	25.4	286.8	351.0	6
Chloride mg/ℓ	18.2	5.8	13.6	29.1	6