CONCENTRATIONS OF ALUMINUM, MANGANESE, IRON AND CALCIUM IN FOUR SOUTHERN GUAM RIVERS

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Water and Energy Research Institute
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Technical Report No. 64

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Project Completion Report

for

Seasonal Aspects of Metal Concentrations in a Tropical Stream
Project No. 05 Grant No. 14-08-0001-G901
Principal Investigator: Lynn Raulerson
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The incidence and prevalence of Lytico and Bodig are higher on Guam than anywhere else. Many health professionals suggest that the concentration of aluminum, manganese, iron and calcium are directly related to these diseases, and the source of these minerals is in our rivers. The Water & Energy Research Institute initiated this study in part to investigate the extent to which such assertion might be true. We are confident that the data and finding of this report will prove helpful to the effort to discover the cause and cure of these dreaded diseases.

The Institute, Mr. Zolan, and Ms. Ellis-Neill would like to acknowledge and thank our publishers The Guam Lytico and Bodig Association.

Through the Association's support, this worthwhile project has been printed and distributed.

Abstract

The Water and Energy Research Institute of the University of Guam has conducted an intensive water sampling program of four southern Guam rivers to investigate dissolved and total aluminum concentration variability. Besides aluminum, calcium, iron, and manganese were also measured along with and thirteen other water quality parameters. The study began in June, 1984 and ended in June, 1985. The samples for metal analyses were filtered in the field to separate dissolved from particulate metal fractions.

The results of the study show that the concentrations of dissolved and total metal concentrations, particularly of aluminum and iron, were quite variable with ranges from hundredths to tenths of parts per million. Mean aluminum concentrations in the La Sa Fua, Umatac, Geus and Pigua Rivers exceeded the reported mean concentration for the rivers of the continental United States. Individually, the Guam rivers exceeded the U.S. continental mean river aluminum concentration by 27% to 285%. However, the median concentrations were close to the observed U.S. mean concentration of 0.07 to 0.08 mg/l. Calcium concentrations were moderate to high, characteristic of borderline hard waters. While dissolved aluminum and iron were higher than the reported mean concentrations of these metals in the continental United States, the total metal concentrations of these metals were lower than reported U.S. mean concentrations. Manganese concentrations were much lower than reported U.S. continental mean river manganese concentration; both dissolved and total fractions.

Rainfall activity usually increased dissolved and total concentrations of metals. The amount of algae biomass in the streams appeared to influence flux of manganese with algae die off resulting in increased dissolved manganese concentrations.

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INTRODUCTION

The intense interest of the neurological disease research community in Guam's water quality, particularly in regards to southern Guam rivers stems from the extraordinary high incidence of the neurological disease amyotrophic lateral sclerosis/parkinsonism dementia (ALS/PD) in the residents of Guam. The study of this disease and the search for causitive agents has resulted in over 200 journal publications (Garruto et al., 1983). As the theories for explaining the etiology of this disease has changed from genetic-cultural (dominant in the 1950 and 1960's) toward emphasis on environmental factors in the 1970's, the realm of natural water chemistry began to receive increasing attention. The finding that elevated aluminum concentrations in water used in hemodialysis produces a dementia in patients (Alfrey et al., 1976 and Caster and Wong, 1980) also led to increased suspicion of environmental trace metals, particularly aluminum, as a possible cause of the disease.

Chen and Yase (1984) have edited a series of papers which provide a complete account of the historical development and the current state of affairs with regard to description of the disease and the predominant theories for it's great prevalence on Guam and in certain other localities in the Western Pacific region. Yase (1972) was the first to publish suspicions that the role of metals in Guam's water, soil and foods may be critical in the development of this disease. Yase postulated that a high content of divalent cations including manganese and calcium which occurred in soils and waters in endemic ALS/PD foci caused an accelerated aging in certain systems of nervous tissue and caused the disease.

Interest shifted to the possible role of aluminum in the pathogenisis of ALS/PD in the early 1980's. Since the work of the Klatzo et al. in 1965 it was known that aluminum injected directly into the brains of experimental animals caused a specific type of neurofibrilary degeneration (NFD).

Patients with ALS/PD also had this form of nerve cell degeneration and investigators speculated that aluminum might be causing it. This possibility seemed even greater when Perl et al., 1982, Yase 1983, and Garruto et al in 1984 demonstrated aluminum existing within effected nerve cells undergoing NFD.

When calcium and magnesium concentrations of the soils and waters of the ALS endemic foci were discovered to the unusually low, Gajdusek et al. (1984) hypothesized that chronic nutritional deficiency of calcium provoked secondary hyperparathyroidism and that led to increased intestinal adsorption of and deposition of certain divalent metals in the nervous system.

The first detailed survey of the Guam environment for suspect metals in the etiology of ALS/PD was completed in 1978 (Iwata et al.). At that time, aluminum was not thought to be a possible factor and was not measured in water samples collected. Iwata et al. did report higher than average manganese concentrations in Guam's water and a higher than average aluminum to calcium ratio in Guam soil. However, average figures were based on a world wide base and not based on tropical soils. Tropical soils are typically higher in aluminum and iron than temperate regions because the increased rainfall and weathering action in the tropics deplete surface soils of the more loosely bound cations, such as calcium.

Garruto et al. (1984) carried out a more detailed survey of 30 element concentrations in drinking water and 64 elements in soils from the three ALS/PD incidence foci; Guam, Kii Peninsula of Japan, and Auyu-Jatai, Western New Guinea. Similar types of samples were included from the Northern Mariana Islands, and from Ilocos Norte and Ilocos Sur-Philippines as control locations. The findings were presented but not discussed or interpeted. Calcium and magnesium concentrations in the endemic areas were compared to world wide and average values. Significantly no similar comparisons were made for the aluminum findings.

In human daily living the normal average daily diet intake of aluminum is approximately 45 milligrams from all sources (Tsalev and Zaprinov, 1983). Less than 15% of the aluminum is retained by the body. The estimated contribution of waterborn aluminum is 0.026 milligrams. Most aluminum is normally stored in the lung tissue (19 ppm) nails (13-16 ppm), teeth (66 ppm) and bone (2-4 ppm). Brain tissue and cerebrospinal fluids usually carry much lower amounts 0.5-2 ppm in the tissue and 0.01 to 0.02 ppm in the cerebrospinal fluid (Tsalev, 1984).

Aluminum water chemistry is very complex and it has not been shown what chemical monomers of aluminum in water are the most biologically active though it appears that Al^{+3} is more toxic to organisms in streams affected by low pH leaching of aluminum from soil and sediments. Campbell (1983) and La Zerte (1984) presented methods for determining the inorganic aluminum monomeric species based on recoveries of fast reactive aluminum. However, the methods presented have limitations and conditions as to make their wide spread use unlikely.

Factors influencing aluminum solubility have been studied exhaustively by J. D. Hem whose findings have been published in a number of U. S. Geological Survey publications (e.g. Robertson and Hem, 1969, and Brown and Hem, 1975 and Hem et al., 1973). Field studies have linked aluminum solubility to the toxicity problems caused by acid rain (Budd et al., 1981). The principal factor in determining solubility of aluminum in most natural fresh waters (as from parent Gibbsite, $Al(OH_3)$ is pH (Robertson and Hem, 1969).

A major aspect of the environmental metal metabolism theory as explained by Gajdusek (1984) as an etiological explanation for ALS/PD incidence is that not only must environmental Al, Mn and other metals be available but that dietary intake of calcium must be low. For this reason, measurements of calcium along with manganese (a former suspected metal) and iron (a major element of the soil groups in the area) were included in this present study.

OBJECTIVES

The principal objective of this research was to determine the ambient concentrations of aluminum in the four major southern Guam rivers which are (or have been) potable water sources. Because the rivers are small and suspected to be greatly affected by seasonal factors, such as rainfall, collections of water from the rivers were analyzed every two weeks over a period of one year to observe natural variations and to obtain true ranges and valid mean, and median concentrations. Since manganese, iron and, in particular, calcium have figured prominently in the theories explaining the etiology of the ALS/PD disease, these metals were determined concommitantly with aluminum. Other water quality characteristics which influence the species of those metals in water, or water quality in general were also determined. These parameters were pH, hardness, alkalinity, dissolved oxygen, sulfate, chloride, total dissolved and total solids, suspended and suspended volatile solids, phosphate-phosphorus and nitrate-nitrogen.

The secondary objective of this project was to document the natural variability of water quality as determined by the above parameters, in small perennial tropic rivers and to derive conclusions on the impact of rainfall on these rivers water quality.

STUDY SITES

All rivers in this study are located in southwestern Guam. Their locations are illustrated in Figure 1-5. The watersheds (Figures 6-9) are volcanic in origin, predominately regosol and latosol clays. Soils were collected from eight locations in the study site areas and analyzed for soil cation exchange capacity, pH, exchangeable acidity, exchangeable bases and exchangeable aluminum. The results of these tests, and the description of the soils, the methods of analyses, is in Appendix C.

The La Sa Fua River (Figure 3) drains four major tributaries: The Alatque, Laguan, Chagame, and San Nicolas Rivers. The drainage area is approximately 318 ha, average slope (%) is 6.8 and length is 3,261 m (Best and Davidson, 1981). The La Sa Fua has been reported to have an average discharge (over 10 yr) of 0.13 m^3/sec and discharges into Fouha Bay.

The Geus River (Figure 3) discharges into Cocos lagoon. This river has a drainage area of approximately 324 ha, an average slope (%) of 7.1 and the length is 3,840 m (Best and Davidson, 1981).

The Umatac River has two major tributaries: the Laelae and Madog Rivers (Figure 4). The drainage are is approximately 544 ha, the length is 2,987 m and the average discharge has been estimated as 0.24 m^3/sec (Best and Davidson, 1981). Land adjacent to the Umatac River and is used more extensively for agriculture and grazing than at the other rivers studied. The Umatac River discharges into Umatac Bay.

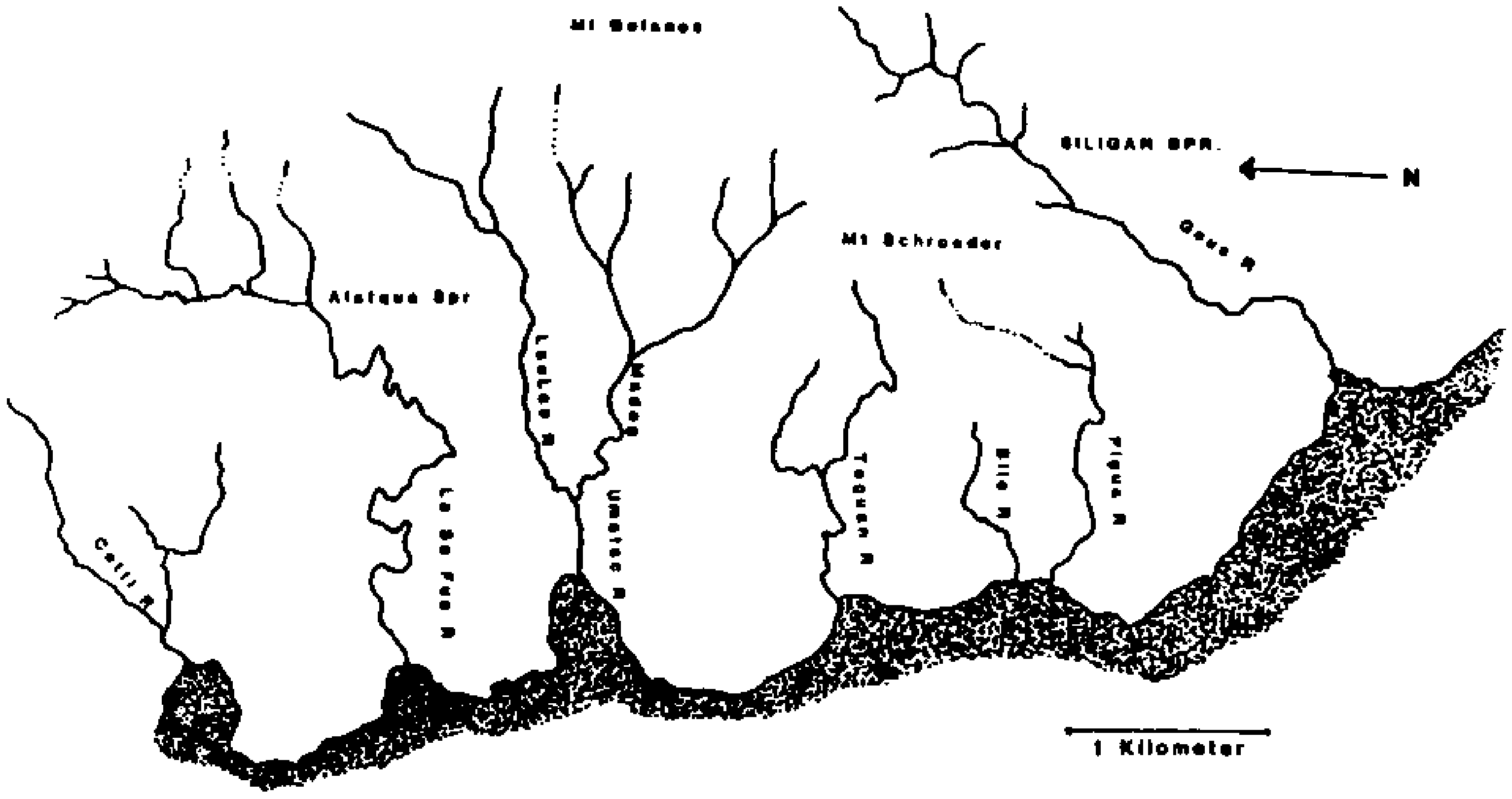

Figure 1. Southwest coast of Guam, showing the four rivers studied and others in the area.

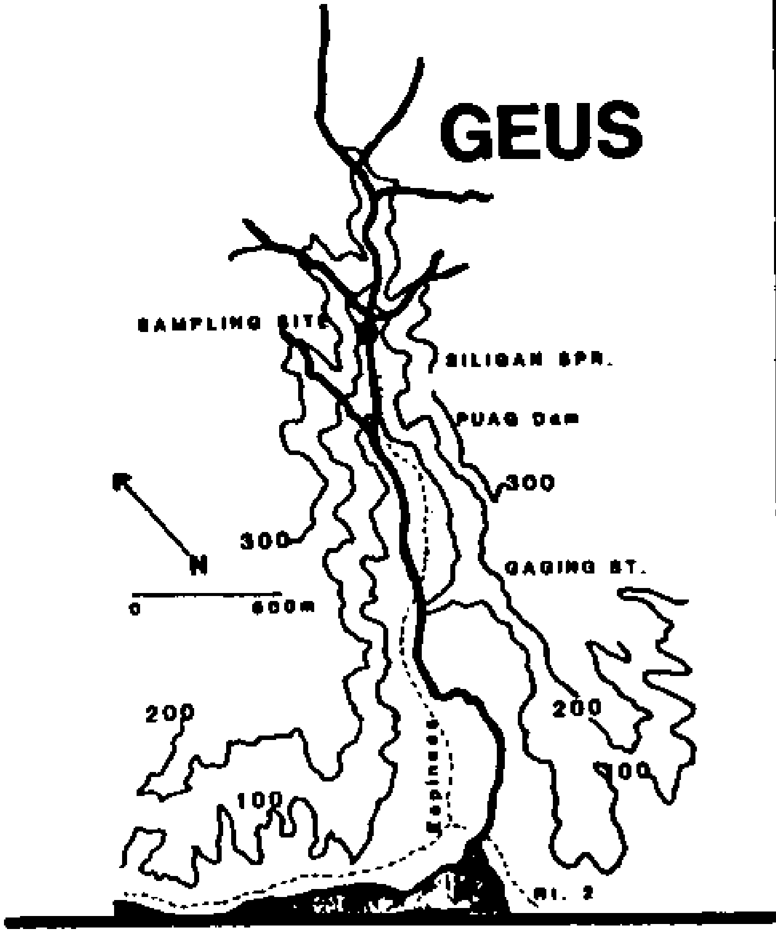

Figure 2. Topographic map of the Geus River showing sampling location above PUAG Dam (adapted from Zolan, 1981).

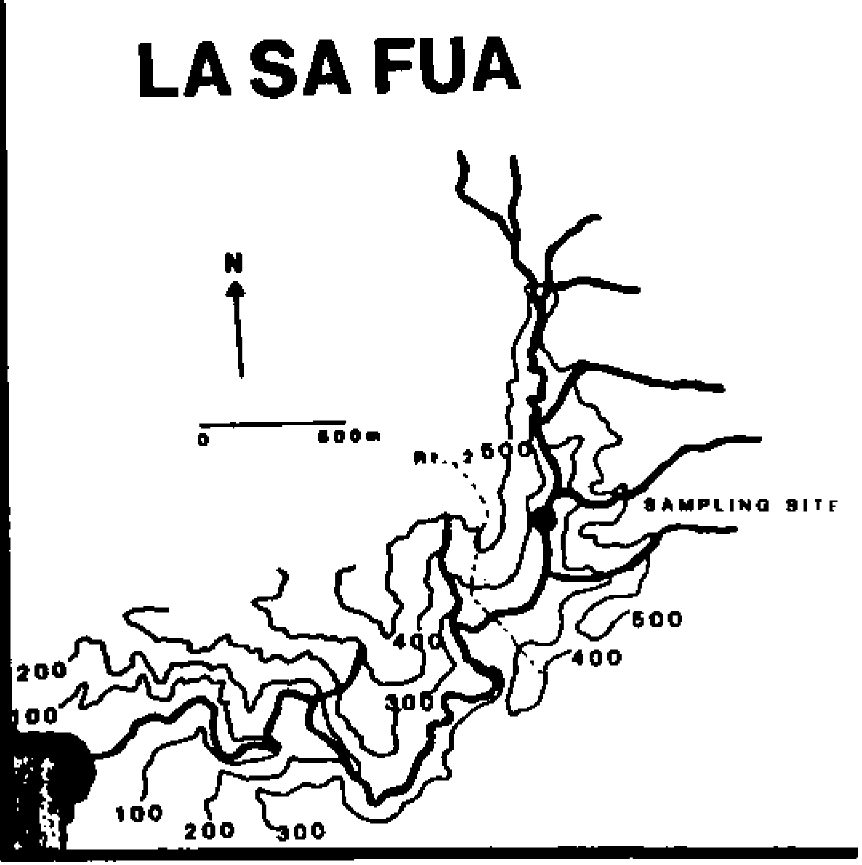

Figure 3. Topographic map of the La Sa Fua River showing sampling location (Adapted from Zolan, 1981).

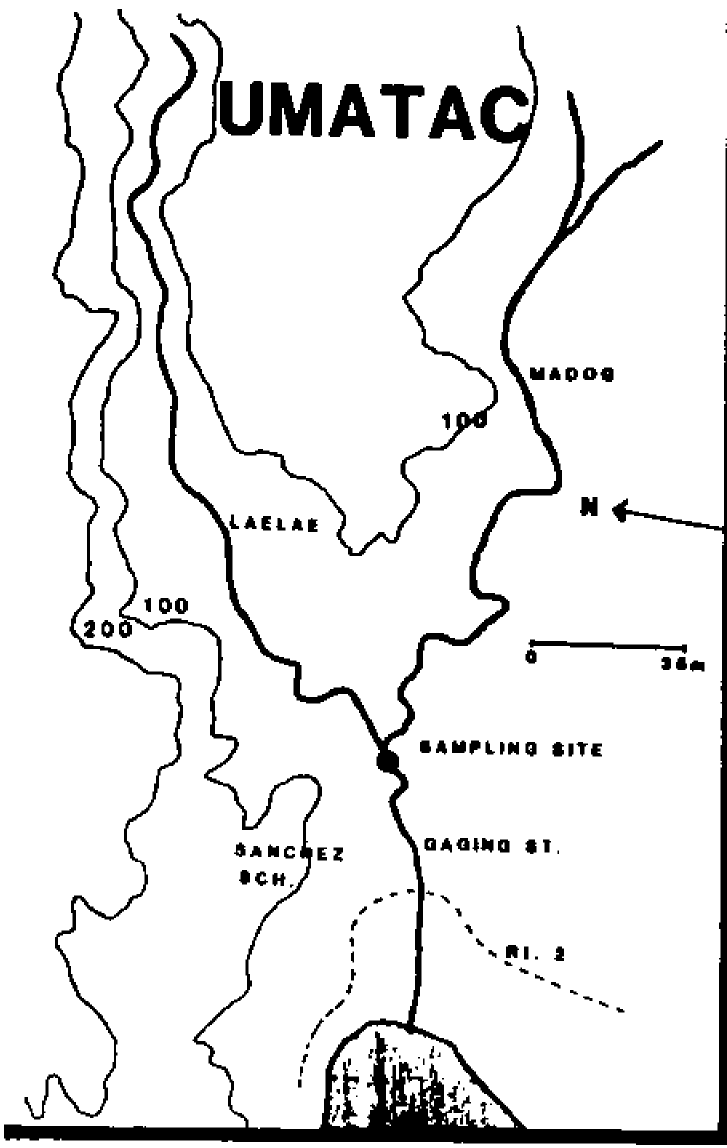

Figure 4. Topographic map of the Umatac River showing sampling locations.

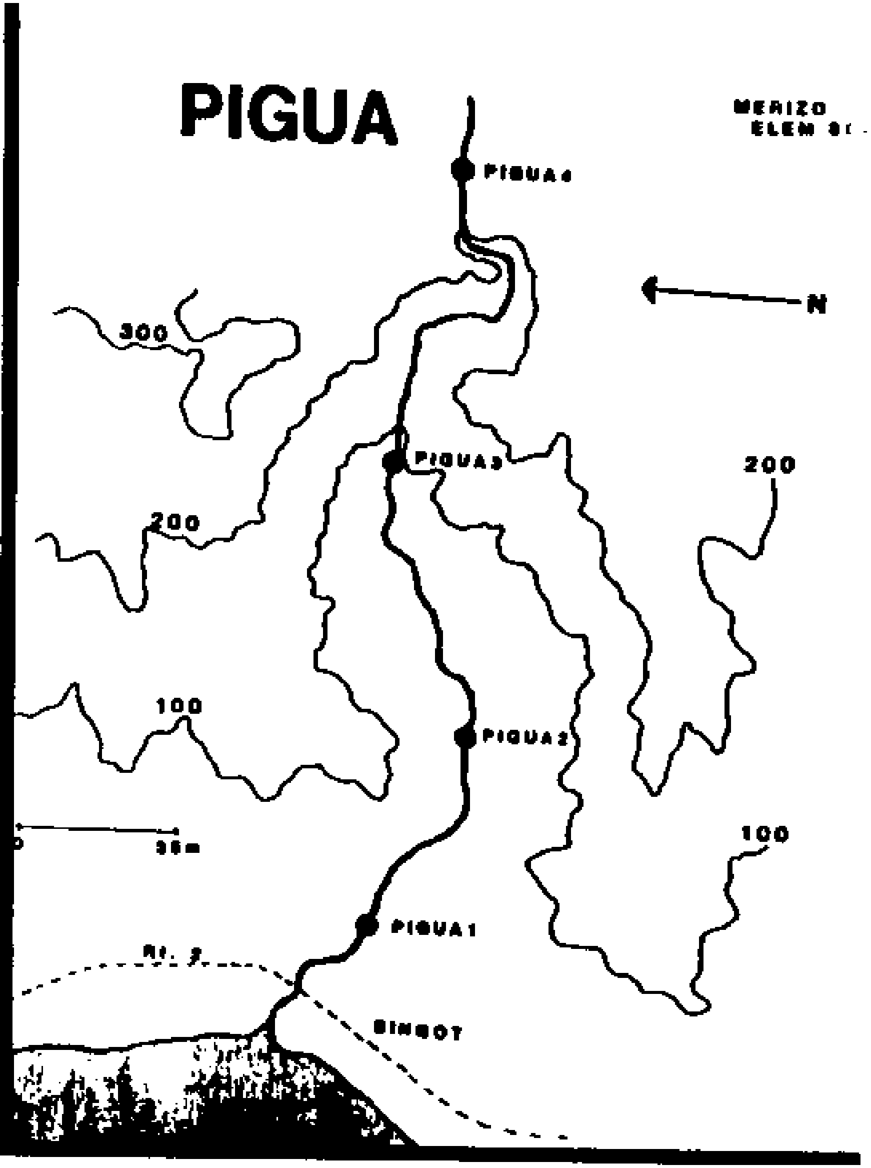

Figure 5. Topographic map of the Pigua River showing sampling locations.

Figure 6. La Sa Fua River basin, looking east from Route 2.

Figure 7. Umatac River watershed, showing confluence of Madog and Laelae tributaries.

Figure 8. Pigua River basin looking west from sampling site 4.

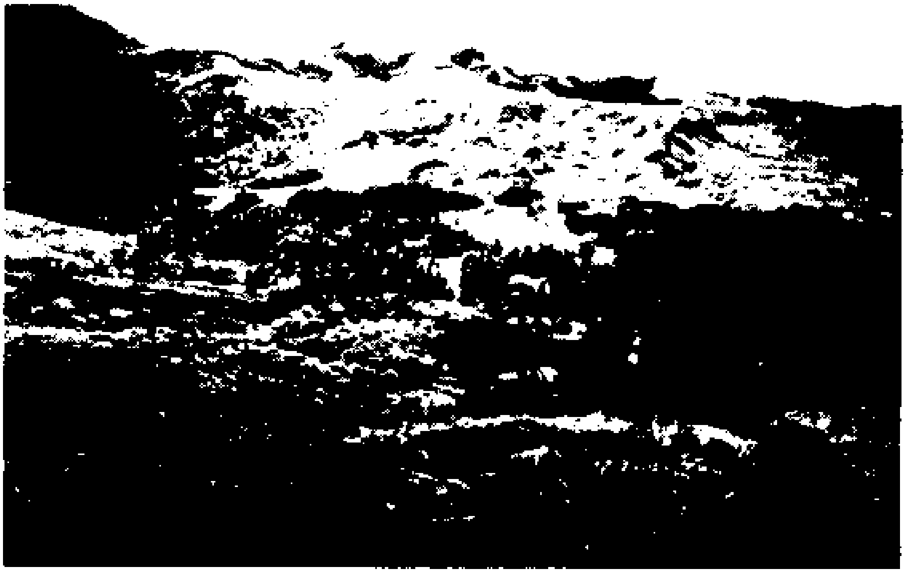

Figure 9. Geus River valley looking south. Area shown is below sampling station.

The Pigua River (Figure 5) has two perennial tributaries. The drainage area is approximately 99 ha, average slope (%) is 11.9 and the length is 1,585 m (Best and Davidson, 1981). The Pigua River discharges into Bile Bay.

MATERIALS AND METHODS

Water samples were collected twice a month (from June 17, 1984 to June 27, 1985) from the Geus River, Umatac River, La Sa Fua River and the Pigua River. Two sites were sampled on the Pigua River; additionally, once a month, two intermediate sites on the Pigua River were sampled. Extra sampling of the Pigua was obtained as an adjunct to other work being performed at the site by one of the authors (Ellis-Neil, M.S. Thesis, in progress). During the time of collection, field measurements of temperature, dissolved oxygen, and pH were determined with a YSI model 51B dissolved oxygen and temperature meter and a Corning 610A portable pH meter, respectively.

Water samples for non-metal analyses were collected in 10% HCL acid-washed linear polyethylene bottles, and placed on ice during transportation to the lab. These samples were analyzed for sulfates, chlorides, total dissolved solids, suspended solids, alkalinity, total hardness, and titratable calcium as outlined by "Standard Methods" (American Public Health Association, 1980). All sample treatment and holding time limitations were followed according to the same reference. Water samples collected from the Pigua River were also analyzed for nitrate-nitrogen and reactive phosphate. A cadmium reduction method was used to determine nitrate-nitrogen (Stickland and Parsons, 1972) and reactive phosphate was determined utilizing the ascorbic acid reduction method of "Standard Methods" (American Public Health Association, 1980). Stream discharge was estimated at the lowest site on the Pigua River following the methods of Robins and Crawford (1954) using a portable Teledyne-Gurley Pygmy water current meter. Rainfall was measured daily between the Pigua and Geus Rivers close to shore (Figure 1). Rainfall was recorded to the nearest 0.01 of an inch but rounded to the nearest 0.1 inch in reporting results to account for loss of accurracy due to evaporation.

Water samples for analyses of chromium, iron and manganese were collected at all sites. All bottles and glassware used for the preparation and analyses were presoaked in No-Chromix brand acid cleaning solution for 12 to 24 hours then rinsed repeatedly with deionized then deionized-distilled water. Samples were collected by hand-held grab sampling at the same location at each study site (Figures 2-5). Sample bottles were held a few cm below the surface, facing upstream from the sampler. The samples were collected in the following sequence; for metals, two 125 ml bottle were filled, then, two 500 ml bottles were filled for other inorganic parameter. After sample collection field measurements were made for dissolved oxygen. Volume transport was measured only at the Pigua river.

Samples for metals were filtered immediately after collection, by a hand driven vacuum pump (Nalgene 6130-10), through a borosilicate glass filtration apparatus containing a 10% HNO_3 acid leached 0.45 um membrane filter (Millepore type HA). One hundred ml of sample were filtered per filter. The filtrate was transferred back to the emptied 125 ml bottle and acidified with 2 ml of concentrated HNO_3 (J.T. Baker, trace metal grade). The filter was placed into its individual, labeled, acid washed, plastic petri plate that was used for storing and transporting each filter. The filtration was repeated with the second sample bottle, however, only the filter from the replicate was retained for analysis.

Filters were digested in 2.5 ml refluxing concentrated HNO_3 at a hot plate temperature of 150° for 4 hours in 100 ml borosilicate glass beakers with teflon watch glasses. This digestion time was sufficient for the samples to have cleared one hour before digestion was terminated. Samples were then allowed to evaporate to near dryness and cool. Concentrated HNO_3 (1.5 ml) was then added to the samples and they were diluted with distilled water to 50 ml. This procedure, as described, is a modification of the official method utilized by the U.S. Environmental Protection Agency (U.S. EPA, 1979). Control blanks; filters both filtered in the field with distilled water or filtered in the lab after sample collection using the filtration apparatus were utilized each sampling trip to monitor stray contamination and serve as blanks for dissolved and suspended metal analyses. The fitration apparatus was rinsed with distilled deionized water between sample filtrations. The filtrate from the control filtration was used as a blank to correct the dissolved metal absorbances.

Sediment samples were collected at the lower three sites on the Pigua River on the December 10, 1984 and on the May 17, 1985. Sediments were dried and stored in teflon containers until the digestion was conducted. Two gram samples (in duplicate) were digested by methods modified from Adams et al. (1980) as follows: Four ml of concentrated HNO_3 were added to the sediment samples. Sediments were then digested for 5 hours at 95° C. Samples were filtered and diluted to 100 ml then stored in teflon bottles until metal analyses were completed.

Epiphytic algae (Spirogyra sp.) was collected on the July 22, 1984, November 10, 1984 and April 11, 1985 for metal analyses and stored in pre-washed (10% HNO_3) plastic bags. This algae was then rinsed with distilled water to remove most of the detritus trapped among the filaments. Following the rinsing, the algae was placed in 200 ml of distilled water and mixed. Two 50 ml aliquots were filtered through pre-weighed glass fiber filters (Whatman GFA) and dried to estimate dry weights. The remaining two 50 ml aliquots were digested separately in concentrated HNO_3 as described above for the digestion of filters. Control blank filters were carried through the entire digestion procedure for blank correction.

Five specimens of the shrimp Machobrachium lar and one specimen of an identified atyid shrimp were collected from the Geus River for Al, Mn, Fe metal analyses. The shrimp were collected and stored similarly to the algae collection except they were frozen until the day of digestion. One to 2 gram samples of abdominal sections were digested following the methods outlined above. Carapace length was also recorded for all crustaceans dissected and used in metal analyses.

Metal concentrations in samples was determined by electrothermal atomic absorption spectoroscopy using a Perkin Elmer model 560 atomic absorption spectrometer equipped with a HGA 2200 graphite furnace. The instrument and furnace programs for each element are in Appendix D.

Throughout the year of analyses checks were made of the analytical proceedures in addition to the standards carried through the entire procedure on each analyses. These analytical checks included standard additions tests, spike recovery tests and checks on background absorbances. Background absorbance was automatically corrected for by the instrument. Periodic checks of the background in prepared samples showed it to normally be from 0.000 to 0.015 absorbance units for all the metals tested, well within the instrument capacity for adequate correction. Spike/recovery tests varied from very good recoveries; 99.1% to 112% (10/4/84) for all the metals to mediocre 83.8% to 113% (12/20/84). In some instances recoveries for individual metals dropped in spiked samples to as low as 60%. The reason for their poor recoveries was not determined.

No unexpected problems were encountered in the analyses. Aluminium usually required more injections (from three to seven) of sample to get a representative population from which to compute a mean absorbance. This was due to sample heterogeneity and to stray contamination of the injection tip pipet or introduction of contamination into the furnace during injection. These problems have been commented on by others (Tsalev, 1984). It was found that rinsing the outer surface of the pipet tip prior to injection increased the consistency of injection absorbances. Also, no deleterious effects were noted from slightly dabbing the pipet tip with a cleaning tissue prior to injection. Confidence in, and, use of this technique varied from technician to technician.

A few field filtration blanks carried through the entire sample handling and preparation procedure showed extraordinary high absorbances. These blanks were still used to correct the raw metal sample absorbances. Blank absorbances, particularly with respect to aluminium were readily improvable upon greater concern for contamination on the part of the sample collector/preparer. Field conditions varied from rainy to oppressive tropical heat. These variable conditions make consistency in field filtration of samples a real test of dedication. On one or two dates a portion of sample sets were filtered upon return to the lab since field conditions (continuous rain) made it more likely that the samples would be contaminated or altered by the field processing.

The number of sample analyses varied for the metal analyses because on two separate dates samples were mistakenly discarded prior to completing analyses by atomic absorption. The dates of these samples were April 1, April 17 and May 30, 1985. Also, sampling of the Geus, La Sa Fua and Umatac River was initiated on the third sampling trip resulting in fewer sampling dates than Pigua River stations 1 and 4. Pigua station 2 and 3 were sampled on every other sampling trip.

RESULTS

Aluminum in Guam River Waters

The yearly mean aluminum concentration for individual rivers ranged from 0.258 mg/l to 0.959 mg/l total aluminum and from 0.094 mg/l to 0.211

mg/l dissolved aluminum (Table 1). The Geus River had the highest aluminum concentrations in both total and dissolved aluminum. The water from the Pigua River had the lowest concentrations. Standard deviations of the yearly means were high (Table 1) and this reflects the large amount of variation encountered from one sampling period to the next.

The median concentration from the rivers shows the same pattern as the means. Thus, the Pigua shows the least amount of dissolved and total aluminum, the Umatac and La Sa Fua River clumped together in the middle range and the Geus River has much higher dissolved and total aluminum concentrations (Table 1). For dissolved aluminum, the median concentrations were 0.082 mg/l, 0.062 mg/l, 0.074 mg/l and 0.178 mg/l for the Pigua, Umatac, La Su Fua and Geus Rivers respectively. For total aluminum concentrations the medians were 0.162 mg/l, 0.218, 0.237, and 0.335 mg/l for the Pigua, Umatac, La Sa Fua and Geus River respectively.

The median Al concentrations are lower and more closely grouped than the mean values which were affected by a few extremely high values obtained with samples collected close in time to rainfall events. Increased suspended solids during this time greatly increased the load of total aluminum and iron in the water. A marked increase in dissolved aluminum was also noted in these cases. For this reason, the median values may be more representative of ambient concentrations than the mean concentrations.

Figure 10a and 10b show the temporal distribution of aluminum concentrations totals from all four rivers. The periods of greatest variation in aluminum concentrations correspond with the wettest periods of the year (Figure 11). Correlation analyses (Pearson's correlation) of aluminum concentrations and rainfall from the previous 48 hours sampling were weakly correlated for total concentrations (r=.21, p=.0177, n-126) but not significantly for dissolved concentrations (r=.13, p=.1456, n=132). This indicates that increases in aluminum concentrations with rainfall are the result of an increase in suspended solids bearing aluminum. A positive correlation was also found between total aluminum and dissolved aluminum concentrations (r=.61, p=.0001, n=135).

Manganese in Guam River Waters

The yearly mean manganese concentrations in river water samples ranged from 0.019 mg/l to 0.128 mg/l for total manganese and 0.008 to 0.100 mg/l for dissolved manganese. Water from the Pigua River was consistently higher in both total and dissolved manganese concentrations. Yearly mean concentrations for the Geus River, Umatac River and La Su Fua River were not significantly different from each other.

The temporal distributions of mean manganese concentrations from all the rivers samples are illustrated in Figure 12a and 12b. Manganese concentrations were not as variable as iron or aluminum with the exception of one peak. This peak in manganese was only observed in the Pigua River. Additionally, the peak is the result of an increase in dissolved manganese as opposed to suspended manganese concentrations. Prior to this sampling date (31 March 1985), an extensive portion of the Pigua watershed burned. This was the first sampling after rainfall and this peak may be a result of the burn releasing organically bound manganese in plant tissues. No

Table 1. Mean concentrations (milligrams per liter) of dissolved and total aluminum, iron, manganese and calcium in the Geus, La Sa Fua, Umatac and Pigua Rivers. Median concentrations are in parenthesis.

Metal	Total Samples Analyzed	Mean	(Median)	S.D.	Minimum	Maximum
Geus River						
Al (Total)	22	0.959	(0.335)	1.61	0.118	6.12
Al (Diss.)	23	0.211	(0.178)	0.204	0.014	0.920
Mn (Total)	23	0.019	(0.013)	0.019	0.005	0.091
Mn (Diss.)	24	0.008	(0.004)	0.014	0.002	0.074
Fe (Total)	24	0.660	(0.226)	1.068	0.032	3.55
Fe (Diss.)	24	0.111	(0.033)	0.209	0.002	0.873
Ca (Diss.)	24	41	(44)	7.8	19	51
La Sa Fua River						
Al (Total)	22	0.454	(0.237)	0.535	0.048	1.93
Al (Diss.)	23	0.205	(0.074)	0.280	0.010	1.19
Mn (Total)	22	0.029	(0.021)	0.021	0.010	0.087
Mn (Diss.)	23	0.018	(0.013)	0.015	0.003	0.068
Fe (Total)	23	0.352	(0.109)	0.609	0.010	1.96
Fe (Diss.)	24	0.053	(0.013	0.093	0.004	0.327
Ca (Diss.)	24	42	(44)	7.6	20	55
Umatac						
Al (Total)	22	0.504	(0.218)	1.07	0.076	5.12
Al (Diss.)	22	0.125	(0.062)	0.148	0.001	0.655
Mn (Total)	22	0.022	(0.021)	0.010	0.002	0.041
Mn (Diss.)	23	0.014	(0.014)	0.006	0.001	0.028
Fe (Total)	23	0.501	(0.112)	1.02	0.019	3.55
Fe (Diss.)	24	0.065	(0.009)	0.147	0.001	0.665
Ca (Diss.)	24	53	(56)	8.8	32	68

Table 1. Continued.

Pigua River, Station 1						
Al (Total)	25	0.319	(0.160)	0.325	0.076	1.33
Al (Diss.)	26	0.102	(0.094)	0.088	0.001	0.369
Mn (Total)	26	0.107	(0.067)	0.177	0.025	0.918
Mn (Diss.)	26	0.086	(0.048)	0.158	0.001	0.839
Fe (Total)	26	0.288	(0.155)	0.389	0.026	1.69
Fe (Diss.)	26	0.056	(0.045)	0.043	0.004	0.162
Ca (Diss.)	27	34	(33)	4.3	28	45
Pigua River, Station 2						
Al (Total)	10	0.377	(0.159)	0.369	0.077	1.15
Al (Diss.)	11	0.094	(0.059)	0.137	0.005	0.494
Mn (Total)	10	0.066	(0.050)	0.034	0.037	0.132
Mn (Diss.)	11	0.054	(0.043)	0.035	0.012	0.117
Fe (Total)	11	0.257	(0.179)	0.235	0.101	0.921
Fe (Diss.)	12	0.049	(0.034)	0.031	0.024	0.125
Ca (Diss.)	12	36	(36)	3.4	30	43
Pigua River, Station 3						
Al (Total)	10	0.258	(0.264)	0.174	0.047	0.581
Al (Diss.)	11	0.095	(0.082)	0.084	0.006	0.298
Mn (Total)	10	0.023	(0.020)	0.008	0.011	0.035
Mn (Diss.)	11	0.013	(0.012)	0.004	0.006	0.019
Fe (Total)	11	0.189	(0.120)	0.027	0.082	0.482
Fe (Diss.)	12	0.038	(0.029)	0.027	0.019	0.113
Ca (Diss.)	12	34	(34)	4.6	28	47
Pigua River, Station 4						
Al (Total)	26	0.318	(0.196)	0.264	0.077	1.21
Al (Diss.)	27	0.106	(0.097)	0.128	0.001	0.608
Mn (Total)	25	0.128	(0.093)	0.164	0.012	0.844
Mn (Diss.)	26	0.100	(0.072)	0.148	0.006	0.774
Fe (Total)	26	0.315	(0.237)	0.245	0.087	1.29
Fe (Diss.)	27	0.060	(0.039)	0.044	0.008	0.191
Ca (Diss.)	27	35	(36)	7.5	20	58

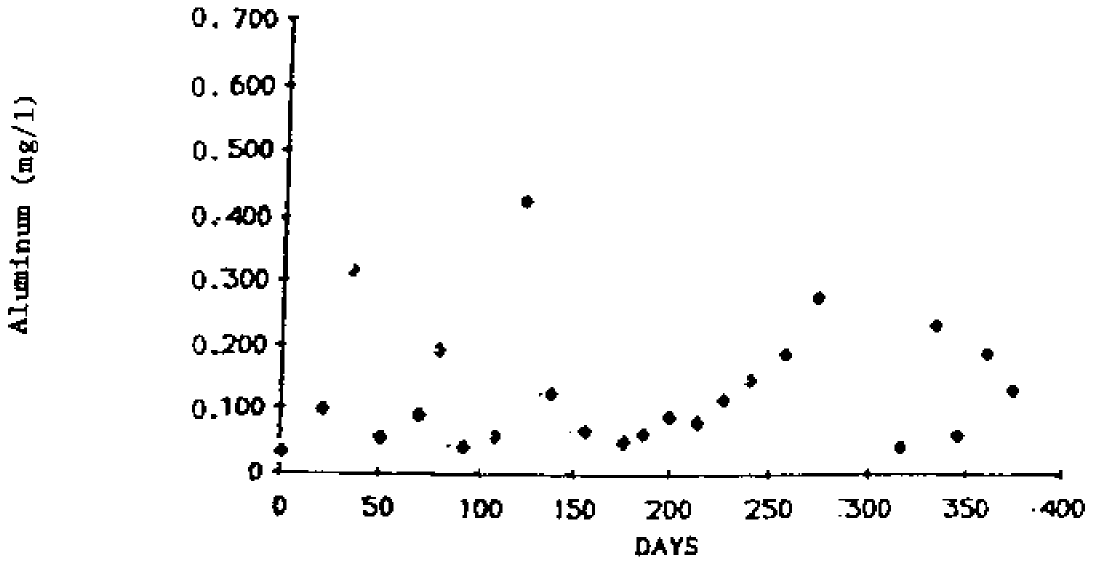

Figure 10a. Averaged dissolved aluminum concentrations for the La Sa Fua, Umatac, Pigua and Geus Rivers over the course of the study.

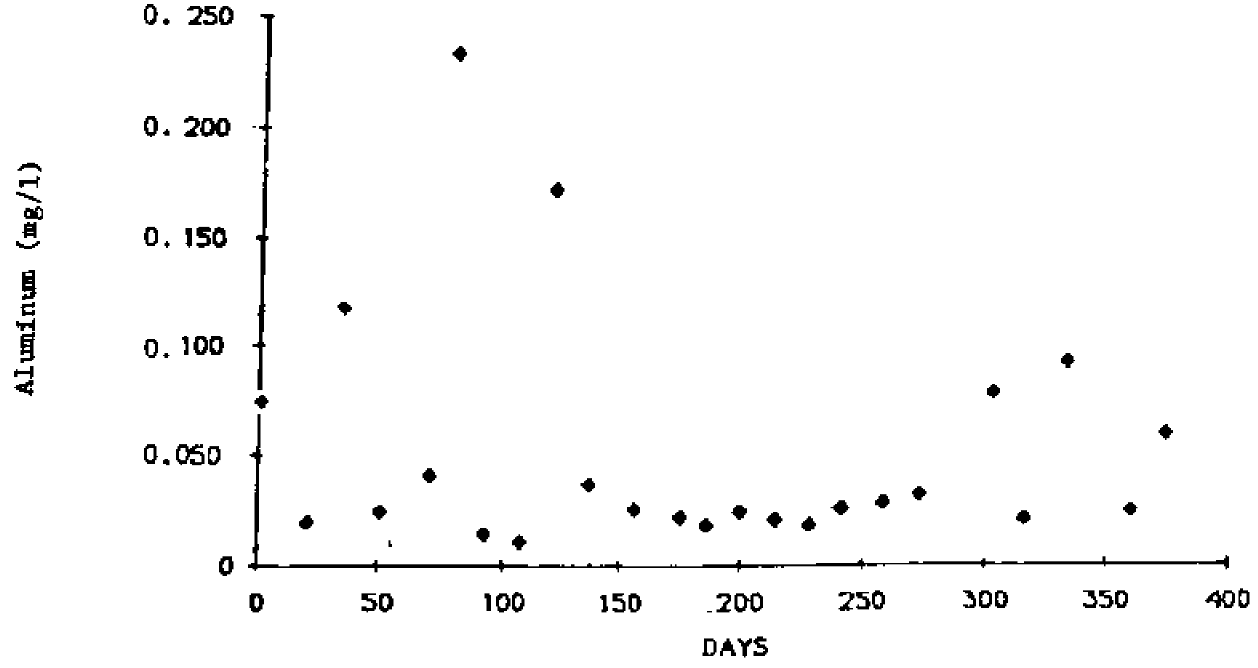

Figure 10b. Averaged total aluminum concentrations for the La Sa Fua, Umatac, Pigua and Geus Rivers.

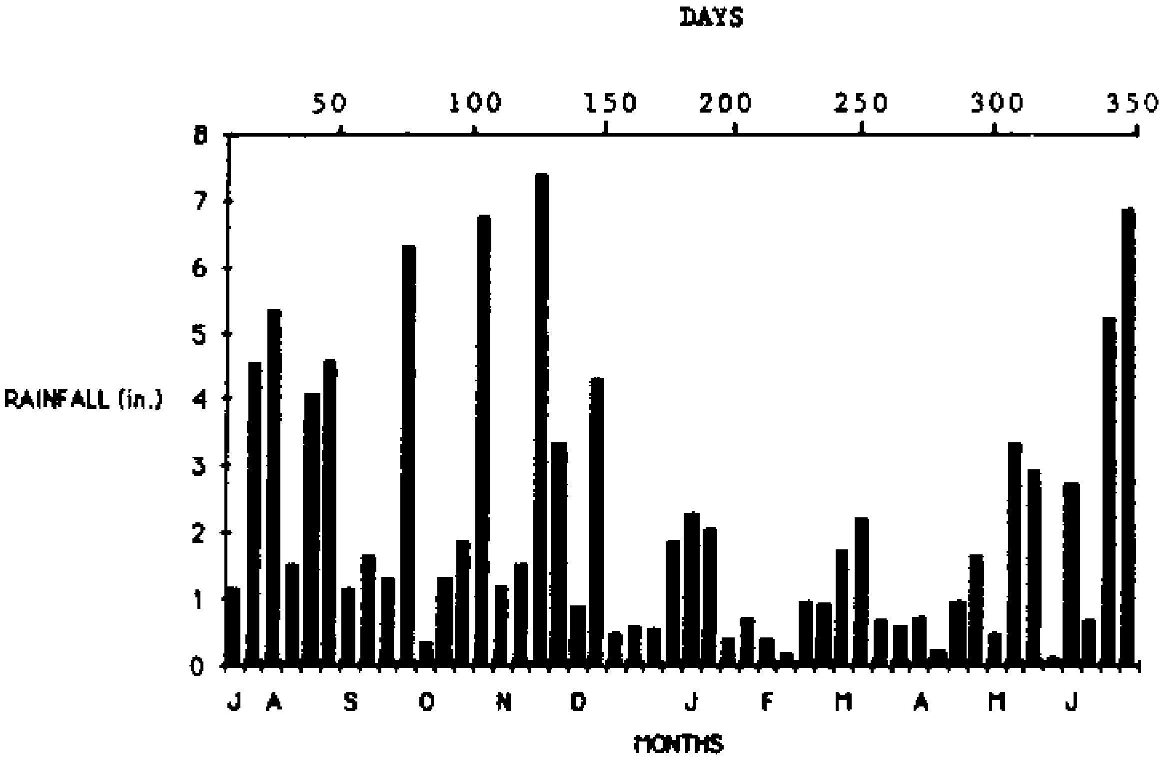

Figure 11. Weekly rainfall totals for the period July 17, 1984 through June 30, 1985.

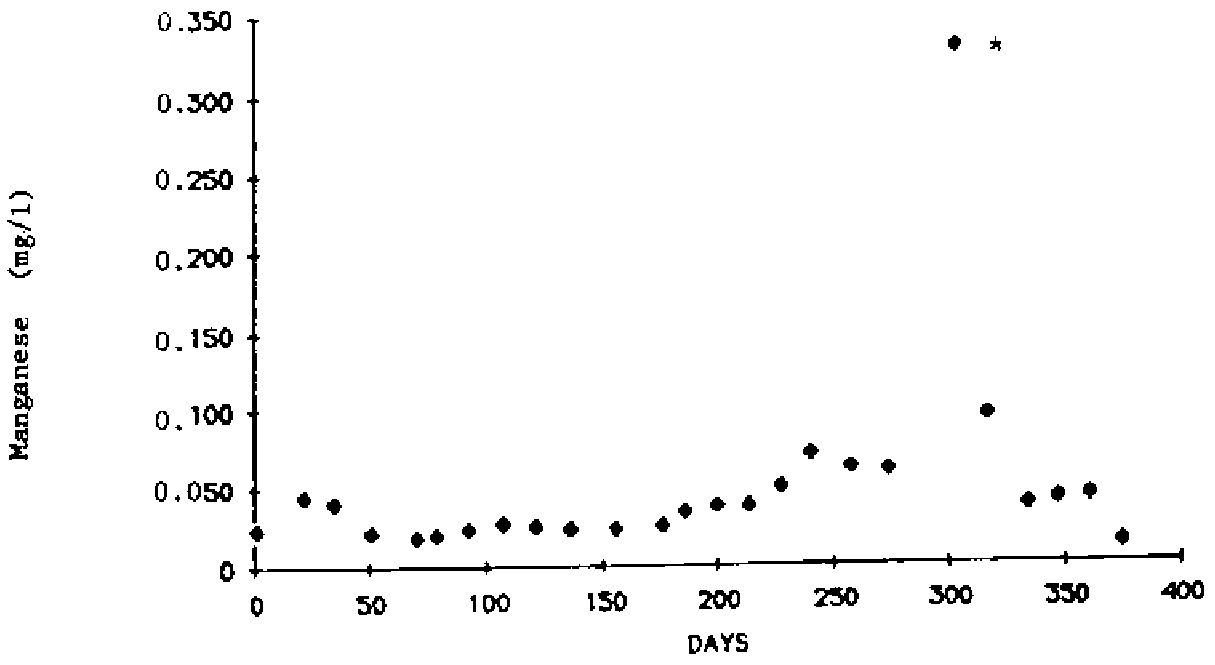

Figure 12a. Averaged dissolved manganese concentrations from the La Sa Fua, Umatac, Pigua and Geus Rivers. Manganese reading with asterisk is sample collected immediately after watershed fire.

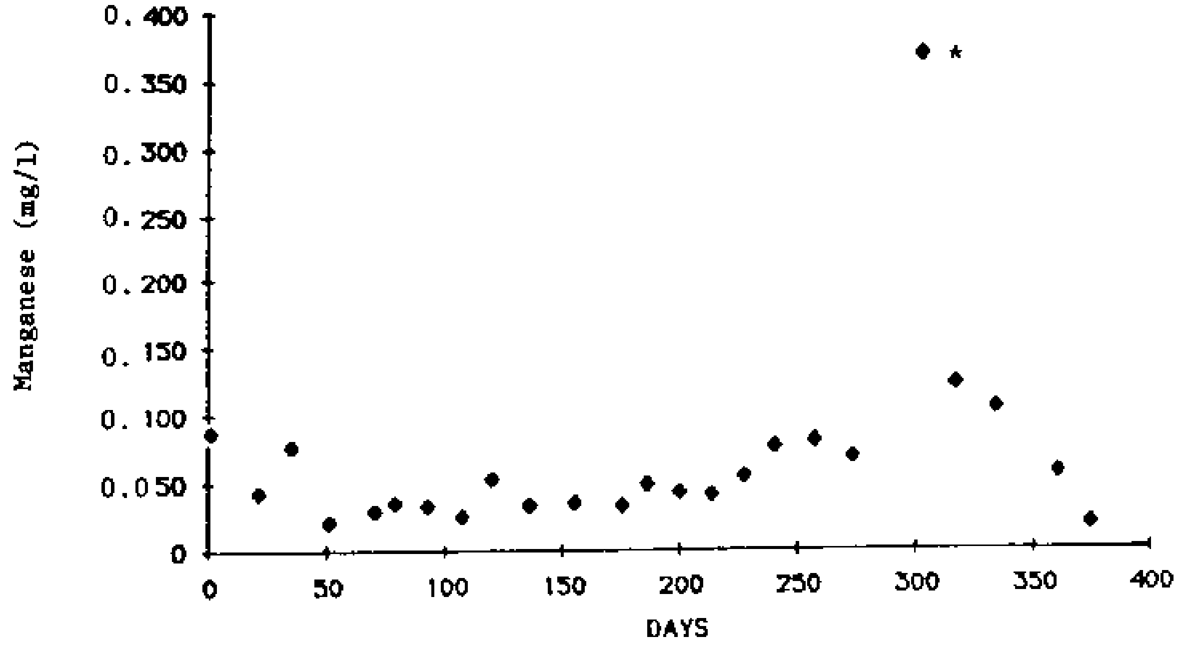

Figure 12b. Averaged total manganese concentrations for the La Sa Fua, Umatac, Pigua and Geus Rivers. Manganese reading with asterisk is sample collected immediately after watershed fire.

significant correlation was found between manganese concentrations and rainfall (48 hours before sampling period).

Iron in Guam River Waters

The yearly mean iron concentrations for river water ranged from 0.189 mg/l to 0.660 mg/l for total iron concentrations and 0.038 mg/l to 0.111 mg/l for dissolved concentrations (Table 1). Like aluminum, iron concentrations were highest in the Geus River and lowest from the Pigua River. Standard deviation of the yearly means were quite high (Table 1).

The temporal distribution of iron concentrations within the four rivers sampled is illustrated in Figure 13a and 13b. Both total concentrations and dissolved concentrations are more variable during periods of greater rainfall (Figure 11). A weak correlation was found between total iron concentrations and rainfall ($r=.36$, $p=0.37$, $n=134$); correlations were also found between dissolved iron and rainfall ($r=0.18$, $p=.0287$, $n=141$).

A strong correlation was observed between aluminum concentrations and iron concentrations ($r=0.83$, $p=.0001$, $n=136$) and is illustrated in Figure 14. This suggests that factors influencing iron and aluminum concentrations are similar in nature. Total and dissolved iron concentrations were positively correlated ($r=0.80$, $p=.0001$, $n=144$).

Calcium in Guam River Waters

EDTA calcium concentrations in filtered river water ranged from 34 mg/l to 53 mg/l (Table 1). The Umatac River was consistently higher in calcium concentrations throughout the period of study. The Pigua River had slightly lower concentrations of calcium than the Geus and La Sa Fua Rivers. The standard deviation of calcium was much smaller in relation to the mean compared to the standard variations observed with other metals.

The temporal distribution of mean calcium concentrations from all four rivers is illustrated in Figure 15. As observed for aluminum and iron, the greatest variations in calcium occurred during the wettest periods of the year but unlike aluminum and iron, periods of heavy rainfall and increased surface runoff are associated with lower concentrations of calcium ($r=0.24$, $p=.004$, $n=141$). During the drier periods, stream water is predominantly derived from groundwater, and, calcium concentrations are higher and more stable.

A significant correlation was found between total dissolved solids (TDS) and calcium concentrations ($r=.64$, $p=.0001$, $n=134$). Calcium concentrations were negatively correlated with iron, aluminum and manganese concentrations (both total and dissolved).

Metal Concentrations in River Sediments

Aluminium, iron and manganese concentrations within the sediments in the Pigua River were determined during the wet season and dry season. In addition, calcium concentrations were measured in the dry season. Results

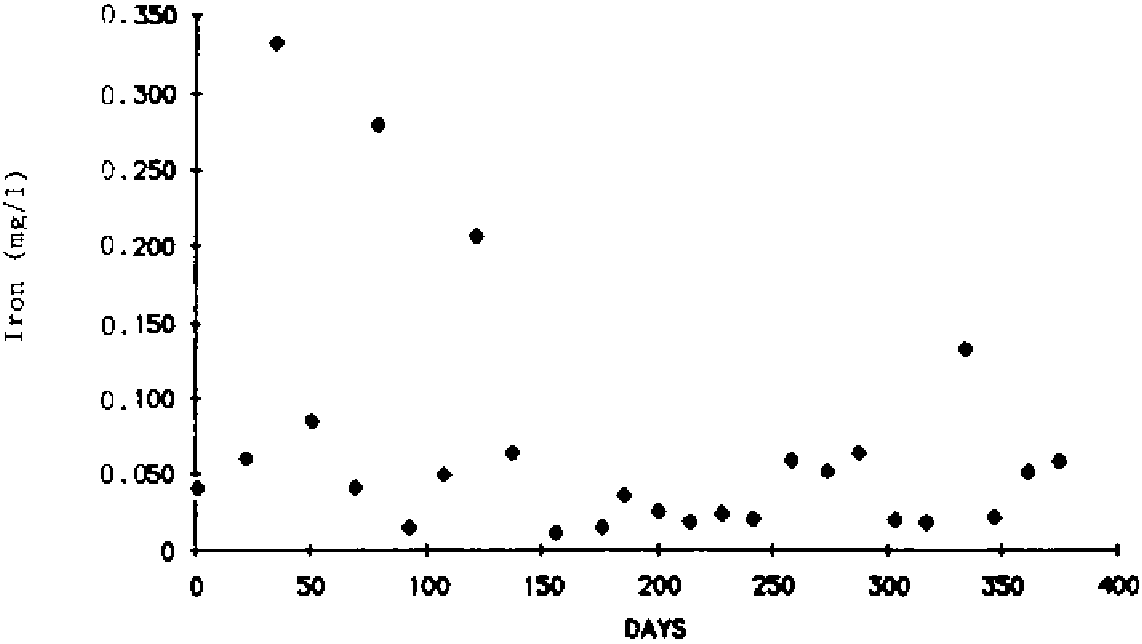

Figure 13a. Averaged dissolved iron concentrations from the La Sa Fua, Umatac, Pigua and Geus Rivers.

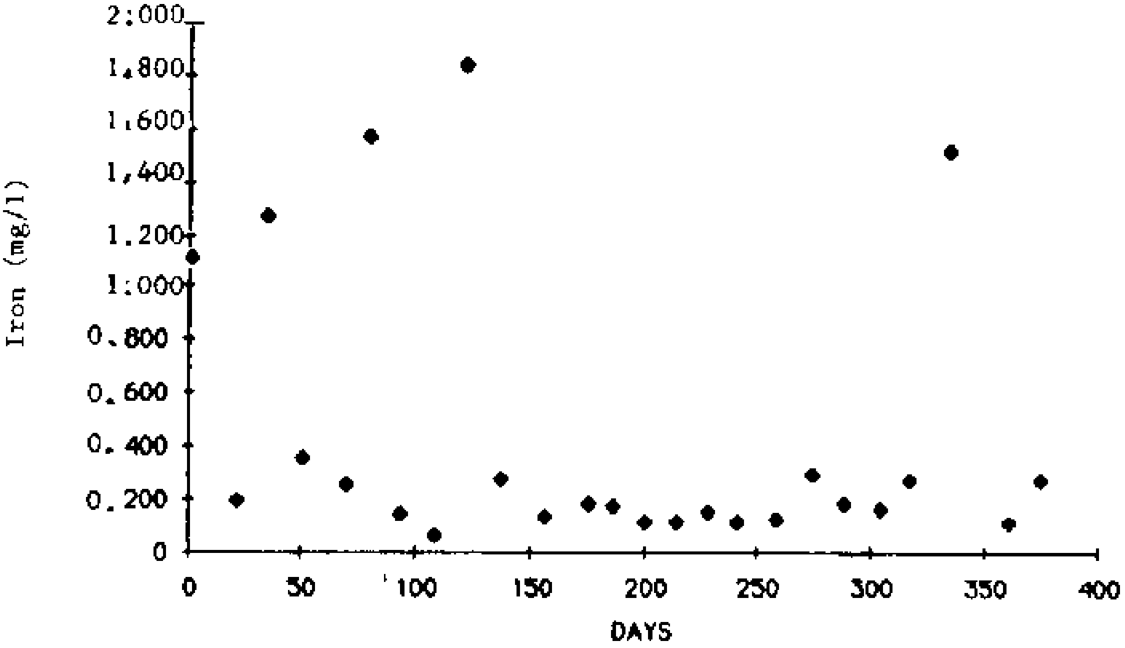

Figure 13b. Averaged total iron concentrations from the La Sa Fua, Umatac, Pigua and Geus Rivers.

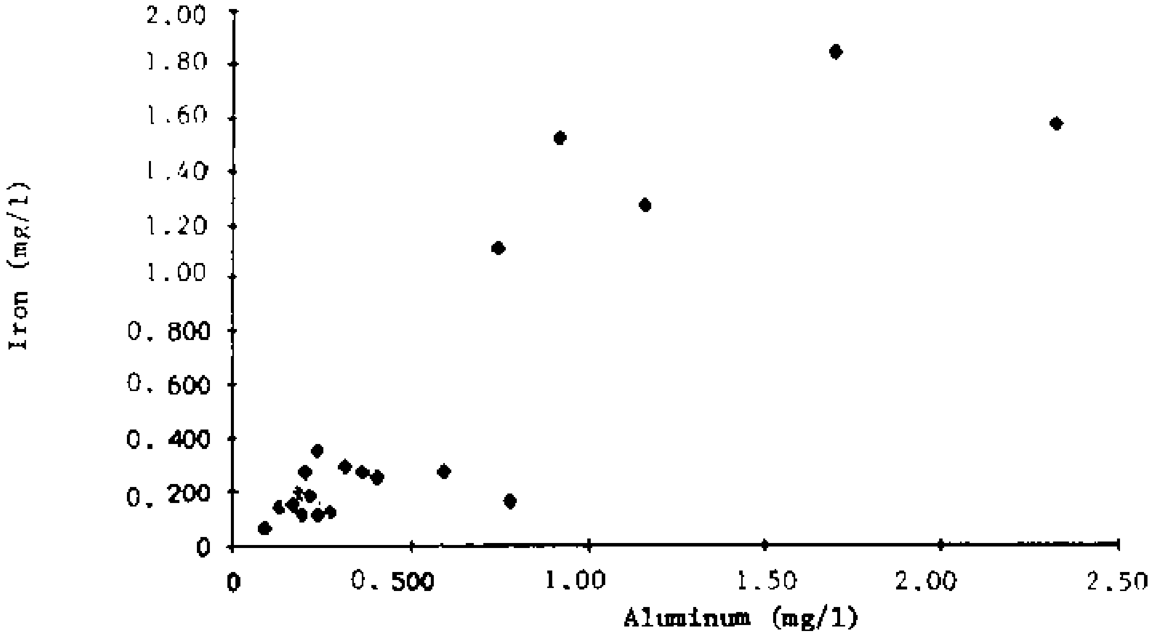

Figure 14. Plot of averaged aluminum versus iron concentrations in the La Sa Fua, Umatac, Pigua and Geus Rivers.

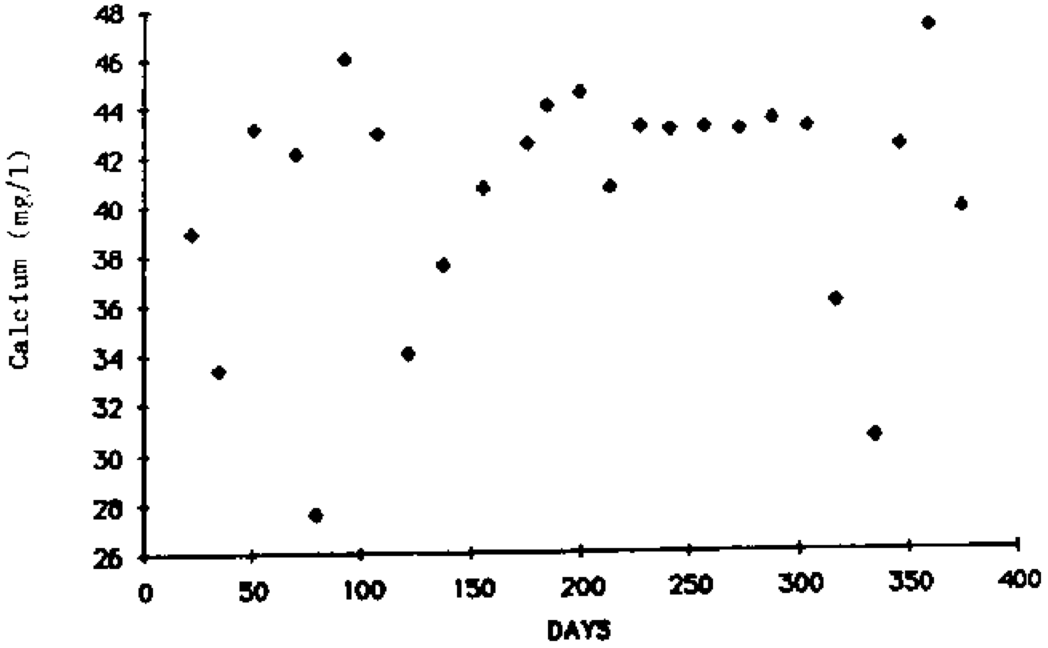

Figure 15. Averaged concentrations of calcium in the La Sa Fua, Umatac, Pigua and Geus Rivers over the course of the study.

of these analyses are shown in Table 2. Manganese concentrations ranged from 0.485 to 2.02 mg/g, aluminum concentrations ranged from 29.4 to 75.0 mg/g, iron concentrations ranged from 15.1 to 65.0 mg/g and calcium ranged from 0.711 to 2.60 mg/g.

Higher metal concentrations were observed for all metals during the dry season. Manganese increased from 0.807 mg/g to 1.52 mg/g, aluminum concentrations increased from 3.43 mg/g to 6.11 mg/g and iron concentrations increased from 2.7 mg/g to 3.50 mg/g. This observed difference could be a function of greater retention of silt-sized particles and organic materials during the dry season.

Manganese, iron and calcium concentrations within the sediments increased downstream (from Pigua 3 to Pigua 1). Increasing metal concentrations downstream indicate that extractable concentrations of these metals are a function of sediment particle size. Metal concentrations in the river water also increased from Pigua 3 to Pigua 1 (Table 1).

On the May 17 1985 sampling date, one sample was taken in a clay bank at Pigua 2 site (Table 9). This sample was higher in manganese and iron and much lower in calcium than the detrital river sediments.

Metal Concentrations in Epiphytic Algae

Filamentous green algae (predominately Spirogyra sp.) is an abundant component of the stream biota on Guam. Dense stands of algae accumulate periodically within the streams and are generally depleted when heavy rains and subsequent sediment transport scours the streambed. In terms of metals, green algae has significately greater concentrations of aluminum, iron and manganese than is observed in river water (Table 3). Mean manganese concentrations were 6.11 mg/g, mean aluminum concentrations were 2.61 mg/g and mean iron concentrations were 4.57 mg/g. This high concentration of metals should influence the dissolved and particulate concentrations within streams which support a large biomass of algae. Attempts were made to correlate organic materials on filters used in the determination of suspended solids with metal fluxes. Filters were ashed at 500°C and algae was noted when present on filters. No correlations were detected between these observations and suspended or dissolved metal concentrations. With the exception of periods of high turbidity, the rivers generally had low quantities of suspended materials (mean = 3.6 mg/l S.D. 10.6 mg/l). The quantity of filterable particles was probably inadequate to draw any conclusions from these comparisons. As discussed earlier, manganese concentrations within the rivers ranged from 0.019 mg/l to 0.128 mg/l, (mean = 0.061 mg/l). Algae therefore concentrated manganese 100,000x that detected in river water. It is suggested that the absence of significant correlations between the flux of manganese and other metals may be the result of the influence of algae growth and decay on manganese concentrations in the river water.

Metal Concentrations in Stream Shrimp

Macrobrachium lar is a ubiquitous invertebrate in the running waters of Guam and is a source of food for man. Specimens of M. lar were trapped during this investigation and small, medium and large individuals were

Table 2. Metal concentrations in Pigua River sediments.

Station	Mn (µg/g)	Al (mg/g)	Fe (mg/g)	Ca (µg/g)
10 December 1984				
Pigua 1	878	38.98	23.53	
Pigua 1	1020	36.58	26.18	
Pigua 2	1003	35.55	24.73	
Pigua 2	855	29.45	21.60	
Pigua 3	600	33.95	18.95	
Pigua 3	485	31.48	15.13	
	$\bar{x}$ = 807	$\bar{x}$ = 34.33	$\bar{x}$ = 21.69	
17 May 1985				
Pigua 1	1441	50.92	29.96	2604
Pigua 1	1890	74.97	30.50	2096
Pigua 2	1363	74.97	30.50	2096
Pigua 2 (clay)	2015	62.24	64.95	711
Pigua 3	1318	60.33	28.88	1166
Pigua 3	1123	64.68	24.50	2527
	$\bar{x}$ = 1525	$\bar{x}$ = 61.10	$\bar{x}$ = 34.96	$\bar{x}$ = 1941

Table 3. Metal concentrations in filamentous algae (*Spirogyra* sp.).

Date	Mn (µg/g)	Al (µg/g)	Fe (µg/g)
22 July	7660	3236	--
10 Nov	5963	2457	1761
11 Apr	4707	2141	2759

analyzed for aluminum, manganese and iron concentrations. These results are listed in Table 4. Aluminum concentrations ranged from 4.16 to 7.22 g/gm, manganese concentrations ranged from 1.28 to 2.98 g/gm and iron ranged from 2.48 to 3.85 g/gm. No difference was detected between smaller and larger prawns and it can be concluded that these shrimp most likely do not concentrate aluminum, manganese or iron with size. Metal concentrations within the small atyid shrimps of the rivers were determined. These filter-feeding shrimps had higher concentrations of all metals investigated than M. lar (Table 4).

Total Hardness and Alkalinity in Guam River Waters

Total hardness analyses of the river waters indicated that the waters were borderline hard (Appendix A). The Figure of 150 mg/l total hardness is usually cited as the concentration over which waters are considered hard (Sawyer and McCarty, 1978). Total hardness of the Pigua River stations ranged from 78 to 187 mg/l with an overall mean of 142 ± 23 mg/l (Tables 5-8). In contrast, Umatac which had the highest mean total hardness, ranged from 108 to 199 mg/l with a mean of 176 mg/l ± 22mg/l (Table 7). Considering the standard deviations, the differences between the rivers is significant but small.

Alkalinity ranged from 61 to 257 mg/l with an overall mean of 147 mg/l for all waters analyses. Pigua station 4 had the lowest river station mean with 143 ± 33 mg/l. The alkalinity increased to a mean of 160 ± 21 mg/l at Pigua station 1. The Geus River also had lower alkalinities with a mean of 147 ± 34 mg/l (Table 11). The Umatac River, which had the greatest ionic concentration of any of the rivers studied, had a mean alkalinity of 197 ± 32 mg/l. Mean alkalinity concentrations in $CaCO_3$ were all greater than the mean total hardness concentrations for all the stations studied, indicating that essentially all hardness was due to carbonates. This can also be observed by noting the low concentrations of other anions measured (chlorides, sulfates, nitrates and phosphates).

Chlorides and Sulfates in Guam River Waters

Chloride concentrations were very low with all river station concentrations below 20 mg/l (Tables 5-11). Sulfates were also very low, generally less than 3 mg/l. Only the Umatac River had a mean sulfate concentration at this figure (3 mg/l). The analytical method for determining sulfate becomes less precise at the lower end of the range. All values were rounded to the nearest unit when below 5 mg/l.

Total Dissolved Solids and Suspended Solids in Guam River Waters

Mean total dissolved solids ranged from 214 at the Pigua to 268 mg/l at the Umatac River (Tables 5-11). Overall range for all stations was 112 mg/l (Geus River on August 26th 1984) to 325 mg/l (Umatac River on August 7, 1984).

Suspended Solids ranged from 0.2 to 41 mg/l at the river stations (Tables 5-11). Mean concentrations ranged from 1.4 at Pigua station 2 to 4.6 mg/l at the Geus River. Discounting the one extremely high value 41 mg/l at the Geus River, the next highest suspended solid concentration at

Table 4. Metal concentrations in shrimp of the Pigua River.

Species	Carapace Length (cm)	Mn (μg/g)	Al (μg/g)	Fe (μg/g)
Macrobrachium lar	3.81	1.3	5.1	3.6
M. lar	3.81	1.7	7.2	2.5
M. lar	1.75	1.7	4.2	3.0
M. lar	2.22	3.0	6.2	3.8
M. lar	1.11	2.4	5.2	2.6
Atyidae Sp.	0.48	6.0	61	23

Table 5. Summary of Pigua River station 1 water analyses. All parameters other than pH (in standard units) temperature (in degrees, Celsius), and previous 48 hour total precipitation (in inches) are expressed as milligrams per liter.

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	26	25.9	0.8	24.8	27.3
Dissolved Oxygen	26	6.4	1.1	3.3	7.8
pH	26	7.32	0.19	6.91	7.60
Total Aluminum	25	0.321	0.324	0.076	1.33
Dissolved Aluminum	26	0.107	0.085	0.001	0.369
Al, Total/Dissolved	23	5.8	9.5	1.0	37
Total Manganese	25	0.107	0.177	0.025	0.918
Dissolved Manganese	26	0.088	0.157	0.007	0.839
Mn, Total/Dissolved	24	1.5	1.0	1.0	5.9
Total Iron	26	0.291	0.387	0.095	1.69
Dissolved Iron	27	0.056	0.04	0.006	0.162
Fe, Total/Dissolved	26	7.4	8.6	1.0	40
Dissolved Calcium	27	34	4	28	45
Total Dissolved Solids	26	220.	33.	132.	275.
Suspended Solids	25	2.3	2.0	0.3	7.0
Volatile Suspended Solids	18	0.3	0.2	0.1	0.9
Nitrate-Nitrogen	23	0.014	0.014	0.002	0.050
Phosphate-Phosphorus	23	0.018	0.014	0.004	0.057
Sulfate	24	2	1	1	6
Alkalinity	25	160	21	110	192
Total Hardness	25	144	19	84	170
Chloride	25	16	2	13	22
Precipitation	25	0.4	0.5	0.0	2.2

Table 6. Summary of Pigua River station 2 water analyses. All parameters other than pH (in standard units) temperature (in degrees, Celsius), and previous 48 hour total precipitation (in inches) are expressed as milligrams per liter.

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	12	26.0	0.8	24.9	27.1
Dissolved Oxygen	11	5.7	1.2	3.9	7.9
pH	11	7.4	0.19	7.12	7.70
Total Aluminum	10	0.377	0.369	0.077	1.15
Dissolved Aluminum	11	0.094	0.137	0.005	0.494
Al: Total/Dissolved	10	7.0	6.7	1.2	24
Total Manganese	10	0.066	0.034	0.037	0.132
Dissolved Manganese	11	0.054	0.035	0.012	0.117
Mn: Total/Dissolved	10	1.6	1.0	1.1	4.2
Total Iron	11	0.257	0.235	0.101	0.921
Dissolved Iron	12	0.049	0.030	0.024	0.125
Fe: Total/Dissolved	11	5.4	4.5	1.3	18.
Dissolved Calcium	12	36	4	30	43
Total Dissolved Solids	11	227	23	190	257
Suspended Solids	10	1.4	1.3	0.2	4.4
Volatile Suspended Solids	6	0.5	0.2	0.3	0.9
Nitrate-Nitrogen	10	0.011	0.013	0.004	0.046
Phosphate-Phosphorus	11	0.028	0.041	0.003	0.143
Sulfate	11	2	1	1	3
Alkalinity	11	165	23	128	192
Total Hardness	11	151	15	134	199
Chloride	11	17	3.4	12	23
Precipitation	11	0.4	0.5	0.0	1.5

Table 7. **Summary of Pigua River station 3 water analyses.** All parameters **other than pH (in standard units)** temperature (in degrees, **Celsius), and previous 48 hour total** precipitation (in inches) **are expressed as milligrams per liter.**

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	12	27.3	1.3	25.8	30.5
Dissolved Oxygen	10	7.0	1.9	5.5	8.7
pH	11	8.01	0.41	7.08	8.55
Total Aluminum	10	0.257	0.174	0.047	0.581
Dissolved Aluminum	11	0.095	0.084	0.006	0.298
Al, Total/Dissolved	10	5.5	5.2	0.6	16.
Total Manganese	10	0.022	0.008	0.011	0.035
Dissolved Manganese	11	0.013	0.004	0.006	0.019
Mn, Total/Dissolved	10	2.0	1.4	1.3	6.1
Total Iron	11	0.189	0.027	0.082	0.482
Dissolved Iron	12	0.038	4.0	0.019	0.113
Fe, Total/Dissolved	11	5.6	4.0	1.9	16
Calcium	12	34	5	28	47
Total Dissolved Solids	11	211	27	168	258
Suspended Solids	10	2.5	1.9	0.8	6.3
Volatile suspended Solids	9	0.4	0.2	0.2	0.8
Nitrate-Nitrogen	10	0.012	0.011	0.002	0.036
Phosphate-Phosphorus	11	0.017	0.016	0.007	0.061
Sulfate	11	2	1	10	3
Alkalinity	11	157	25	109	180
Total Hardness	11	136	16	106	154
Chloride	11	17	4.0	12	23
Precipitation	11	0.4	0.5	0.0	1.5

Table 8. Summary of Pigua River station 4 water analyses. All parameters other than pH (in standard units) temperature (in degrees, Celsius), and previous 48 hours total precipitation (in inches) are expressed as milligrams per liter.

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	27	26.7	1.1	24.9	29.0
Dissolved oxygen	26	8.7	1.2	5.4	11.4
pH	26	7.82	0.35	7.0	8.38
Total Aluminum	25	0.318	0.264	0.077	1.21
Dissolved Aluminum	26	0.106	0.128	0.001	0.608
Al, Total/Dissolved	25	3.7	2.4	1.0	12
Total Manganese	25	0.128	0.164	0.012	0.844
Dissolved Manganese	26	0.100	0.148	0.006	0.774
Mn, Total/Dissolved	25	1.6	0.6	1.0	3.5
Total Iron	26	0.315	0.246	0.087	1.29
Dissolved Iron	27	0.060	0.044	0.008	0.191
Fe, Total/Dissolved	26	7.1	4.6	1.0	20
Dissolved Calcium	27	35	7.5	20	58
Total Dissolved Solids	26	200	40	132	258
Suspended Solids	26	2.4	1.7	0.7	6.4
Volatile Suspended Solids	22	0.5	0.2	0.2	0.9
Nitrate-Nitrogen	23	0.017	0.015	0.002	0.055
Phosphate-Phosphorus	23	0.01	0.012	0.002	0.054
Sulfate	24	3	2	0	8
Alkalinity	25	143	33	95	202
Total Hardness	26	137	29	78	187
Chloride	26	17	4.3	12	27
Precipitation	25	0.4	0.6	0.0	2.2

Table 9. Summary of La Sa Fua River water analyses. All parameters other than pH (in standard units) temperature (in degrees, Celsius), and previous 48 hours total precipitation (in inches) are expressed as milligrams per liter.

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	22	25.4	1.3	23.1	28.0
Dissolved Oxygen	21	8.9	1.0	6.9	11.6
pH	21	7.90	0.27	7.45	8.39
Total Aluminum	22	0.454	0.535	0.048	1.93
Dissolved Aluminum	23	0.205	0.280	0.010	1.19
Al, Total/Dissolved	22	3.2	2.3	1.0	10
Total Manganese	22	0.029	0.021	0.010	0.087
Dissolved Manganese	23	0.008	0.015	0.003	0.068
Mn, Total/Dissolved	22	2.0	1.5	1.0	7.4
Total Iron	23	0.352	0.609	0.010	1.96
Dissolved Iron	24	0.053	0.093	0.004	0.327
Fe, Total/Dissolved	23	12	18	1.1	88
Dissolved Calcium	24	42	7.6	20	55
Total Dissolved Solids	23	231	30	145	283
Suspended Solids	22	2.6	1.9	0.4	6.7
Volatile Suspended Solids	18	0.5	0.3	0.1	0.9
Sulfate	22	2	1	0	3
Alkalinity	22	170	28	86	200
Total Hardness	24	145	25	78	173
Chloride	24	12	2.3	7.4	18
Precipitation	23	0.4	0.6	0.0	2.2

Table 10. Summary of Umatac River water analyses. All parameters other than pH (in standard units) temperature (in degrees, Celsius), and previous 48 hour total precipitation (in inches) are expressed as milligrams per liter.

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	22	26.8	0.9	25.0	28.0
Dissolved Oxygen	21	8.2	1.2	6.4	11
pH	22	7.62	0.22	7.15	8.09
Total Aluminum	22	0.504	1.07	0.076	5.17
Dissolved Aluminum	22	0.125	0.148	0.001	0.554
Al, Total/Dissolved	21	26	95	1.0	441
Total Manganese	22	0.022	0.010	0.002	0.041
Dissolved Manganese	23	0.014	0.006	0.001	0.028
Mn, Total/Dissolved	22	1.6	0.9	1.0	4.9
Total Iron	23	0.501	1.02	0.019	3.55
Dissolved Iron	24	0.065	1.157	0.001	0.665
Fe, Total/Dissolved	22	13	19	1.0	88
Dissolved Calcium	24	53	9	32	68
Total Dissolved Solids	23	268	40	138	325
Suspended Solids	21	3.1	2.9	0.5	13
Volatile Suspended Solids	17	0.4	0.3	0.1	0.9
Sulfate	21	3	2	1	6
Alkalinity	23	197	32	122	257
Total Hardness	24	176	22	108	199
Chloride	22	14	2.6	10	22
Precipitation	22	0.4	0.6	0.0	2.2

Table 11. Summary of Geus River station water analyses. All parameters other than pH (in standard units) temperature (in degrees, Celsius), and previous 48 hours total precipitation (in inches) are expressed as milligrams per liter.

Parameter	Number of Samples Analyzed	Mean	Standard Deviation	Minimum Value	Maximum Value
Temperature	21	25.8	0.8	24.8	27.5
Dissolved Oxygen	21	9.3	1.4	7.7	13.2
pH	22	7.89	0.43	7.00	8.60
Total Aluminum	19	0.958	1.62	0.118	6.12
Dissolved Aluminum	22	0.211	0.204	0.014	0.920
Al, Total/Dissolved	23	4.4	3.8	1.2	15
Total Manganese	22	0.019	0.019	0.005	0.091
Dissolved Manganese	23	0.008	0.014	0.002	0.074
Mn, Total/Dissolved	24	3.8	2.3	1.2	10
Total Iron	22	0.660	1.07	0.032	3.55
Dissolved Iron	24	0.111	0.209	0.002	0.873
Fe, Total/Dissolved	25	11	12	1.8	55
Dissolved Calcium	24	41	7.8	19	51
Total Dissolved Solids	25	240	52	112	300
Suspended Solids	23	4.6	8.2	0.6	41
Volatile Suspended Solids	19	0.4	0.2	0.1	0.8
Sulfate	21	2	1	0	4
Alkalinity	24	147	34	61	184
Total Hardness	24	138	28	65	169
Chloride	24	18	3.6	8.9	28
Precipitation	24	0.4	0.6	0.0	2.2

the Geus was 7.8 mg/l and the median suspended solid at the Geus River was 2.5 mg/l. Volatile suspended solids were generally less than 1 mg/l with mean volatile suspended solids range from 0.3 (Pigua 1) to 0.5 (Pigua 2, Pigua 4, and La Sa Fua River) mg/l. The volatile percentage of total suspended solids ranged from 8.7% at the Geus River to 35.7% at Pigua 2 with an overall mean of 18.1% for all samples combined. This figure can be considered the ambient organic suspended load of small, unpolluted tropical streams of this slope range.

Dissolved Oxygen in Guam River Waters

Oxygen concentrations (measured between 0745 and 1720) in the river waters were generally saturated to supersaturated except in the lower stations of Pigua where river flow was reduced or sometimes barely perceptable. The oxygen saturation concentration for waters at these ionic strengths and temperatures is approximately 8.1 to 8.2 mg/l. Pigua station 4 which was in a exposed sunlit exposed section of the stream recorded a mean DO of 8.7 ± 1.2 mg/l. Algae growth was common in the rock lined pools at this station. The next station sampled downstream (P-3) had a mean DO of 7.4 ± 0.9 mg/l. Pigua 2 recorded a mean 5.7 ± 1.2 mg/l and finally Pigua 1 recorded a 6.4 ± 1.1 mg/l mean DO concentration. The lowest concentration was 3.9 mg/l observed at Pigua station 2. The other three rivers, which are larger, perennial streams, had higher mean oxygen concentrations of 8.2 mg/l (saturation concentrations) or greater.

DISCUSSION

Aluminum

Aluminum concentrations in the four rivers investigated varied widely over time from parts per billion to parts per million for total aluminum and from parts per billion to several hundred parts per billion for dissolved species. This variability is significant because much of the aluminum data obtained prior to the study was obtained from grab samples on one or a few days within a short time span. In evaluating the importance of the data, the meaning of the statistical concepts of mean and median must be understood. If the water source is used continuously for a water supply then a mean aluminum concentration would be most applicable since it will include all averaged water conditions. However, if a water source is used sporatically, for example, only during drought conditions, the median value may be more applicable since it better reflects conditions on any given day than the mean. Furthermore, it is likely that river water during or after rainfall was avoided as a water source when it was heavily silted and rainwater plentiful as a drinking water source.

Mean aluminum concentrations on the rivers for both total and dissolve were higher than most reported data seen previously for Guam. There are few total aluminum analyses from other places to use for comparison and thus for the following discussion we refer to dissolved aluminum unless otherwise stated. The Iwata et al (1978) assays did not report dissolved aluminum in water although they reported, "it is suspected that the very low content of aluminum in water is caused by complete oxidation of the ion to insoluble aluminum in the soil". It appears from the reference that aluminum was measured but not found. They did report that aluminum in Guam's volcanic soil, exceeded world-wide average aluminum content.

Garruto et al. (1984) in their extensive environmental elemental assay of Guam, Kill Peninsula-Japan, and the ALS/PD affected area of New Guinea, determined total aluminum only. Well and tap water in all villages except Talofofo and Umatac and Sinajana (one sample only) were below 0.07 parts per million total aluminum. Three of four samples collected in Talofofo were measurable, between 0.11 and 0.35 parts per million. In Umatac, of the eight sites sampled, six were below detection. The two samples with measurable aluminum were collected from the Madog and La Sa Fua Rivers (2.3 and 2.4 ppm respectively). The higher reported concentrations are outside the maximum range reported in our study for the La Sa Fua (1.9 ppm) but within the range for the Umatac River which is composed both the flow of the Madog and Laelae River (5.2 ppm).

In another study, Morphew (unpub) reported the dissolved species of aluminum as measured by the Eriochrome cyanine R method in both Guam tap waters and rivers (Appendix B). Concentrations in Merizo tap water were 0.04 mg/l for filtered water, 0.1 to 0.13 mg/l for unfiltered tap water. Umatac tap waters were close to these values with 0.06 to 0.09 mg/l for unfiltered tap water and 0.02 to 0.06 for filtered tap water. The Geus, Umatac and Pigua rivers were included in the study, and had unfiltered water aluminum concentrations of 0.01 to 0.03 mg/l aluminum, and 0.00 to 0.01 mg/l for filtered samples. These concentrations tend to be lower than those recorded during this study. These difference may be a result of the difference in analytical method used. Analyses using electrothermal AAS and the Eriochrome Cyanine R method on split samples with GEPA showed that the electrothermal- AAS gave higher concentrations of aluminum.

Other aluminum data made available through the Region 9 office of the Environment Protection Agency (via STORET) show that aluminum concentrations in western U.S. rivers tend to average around 0.020 mg/l except in rivers affected by human activities (Table 12). This data is from 14 rivers and 118 total samples. Southeastern U.S. river aluminum concentrations appear higher with mean dissolved aluminum concentrations of 0.139, 0.317 and 0.079 (N=794) mg/l for Florida, Mississippi and Georgia rivers respectively (Table 13). The mean total aluminum concentrations for river waters in the same states was 1.24, 0.675 and 0.920 mg/l respectively. These means are similar to those of Guam. Thus, the rivers of southern Guam have higher aluminum concentrations than the waters of the western United States but have similar concentrations to rivers in the southeastern United States. This phenomena may relate to similarties in climate which causes extreme weatherings of clay soils in both regions.

Other published data on raw surface water in the United States (Kopp 1970) show that dissolved aluminum ranges from below detection (0.001 mg/l) to 2.76 mg/l with a mean concentration of 0.074 mg/l (Table 14). Aluminum was delectable in only 31% of the collected samples. Drainage Basins in the Southeast had mean aluminum concentrations of 0.117 mg/l. Aluminum concentrations in the Missouri River were of 0.212 mg/l, and those from the West Gulf States averaged 0.332 mg/l. The Ohio River continued a mean of 0.141 mg/l. The remaining twelve drainage basins studied including the

Table 12. Listing of dissolved aluminum concentrations in selected Western U.S. rivers. Data obtained from U.S. EPA, STORET, Region 9.

River	State	N	Mean Dis.Al (mg/ℓ)	S.D. (mg/ℓ)
Colorado	AZ	7	0.016	0.005
Gilia	AZ	3	0.017	0.006
Salt	AZ	8	0.011	0.003
Verde	AZ	6	0.012	0.004
Merced	CA	7	0.032	0.014
Mokelumne	CA	10	0.033	0.023
New	CA	8	0.028	0.034
Russian	CA	8	0.031	0.030
*Sacramento-1	CA	20	483.	40.
Sacramento-2	CA	10	0.398	0.193
Sacramento-3	CA	10	0.163	0.077
Sacramento-4	CA	7	0.041	0.022
San Joaquin	CA	10	0.037	0.034
*Carson	NV	8	0.431	1.16
Walker	NV	8	0.035	0.030

* Sample area affected by mining operations.

Table 13. Concentrations of aluminum from rivers in some southeastern U.S. states and California as comparison. N is the number of samples and S.D. is the standard deviation. Data was obtained from U.S.E.P.A., STORET, Region 9.

State	Mean T.Al (mg/ℓ)	S.D.	N	Mean Dis.Al (mg/ℓ)	S.D. (mg/ℓ)	N
Georgia	0.920	6.17	732	0.079	0.140	794
Florida	1.24	2.24	4719	0.140	0.916	2350
Mississippi	0.675	0.968	78	0.316	0.555	197
California	--	--	--	0.081	±0.123	116

Table 14. Mean concentration of dissolved aluminum, iron, and manganese by U.S. drainage basin in milligrams per liter (Kopp and Kroner, 1970).

Basin	Al	Fe	Mn
Northwest	0.028	0.051	0.004
North Altantic	0.022	0.019	0.003
Southeast	0.117	0.120	0.003
Tennessee River	0.030	0.037	0.004
Ohio River	0.141	0.028	0.232
Lake Erie	0.056	0.035	0.138
Upper Michigan	0.018	0.035	0.010
Western Great Lakes	0.017	0.022	0.002
Missouri River	0.213	0.037	0.014
Lower Mississippi	0.068	0.069	0.009
Colorado River	0.050	0.040	0.012
Western Gulf	0.333	0.173	0.010
Pacific Northwest	0.030	0.032	0.003
California	0.063	0.046	0.003
Great Basin	0.015	0.070	0.008
Alaska	0.011	0.025	0.018

northeastern United States and Alaska had mean dissolved aluminum concentrations of 0.068 mg/l or lower (Table 14).

Raw water supplies are often treated with aluminum (aluminum sulfate) to settle out suspended solids. This treatment process can result in substantial increase in the concentration of dissolved aluminum in the finished water. Barnett et al. (1969) reported a case where aluminum treatment resulted in a five fold increase in aluminum concentrations. In his 1970 study, Kopp (1970) reported that finished water supplies (280 systems) had a mean aluminum concentrations of 0.179 mg/l, substantially greater than the 0.054 mg/l mean for raw water sources.

The data from the present study show that Guam river water is higher in dissolved aluminum than typical United States surface water supply sources when means are compared. If medians are compared instead, to reduce the affects of extreme values, the median is more in line with aluminum concentrations usually encountered in the United States. In order to see if Guam rivers are indeed exceptionally high in aluminum for tropical areas a comparison should be made to nearby Pacific Islands where climatological and soil factors are similar.

For suspended aluminum which can be derived from taking the total minus the dissolved concentration, the mean aluminum concentration in Guam's southern rivers was much lower than the reported mean in the suspended aluminum metal samples from the Kopp and Kroner study (1970). Mean suspended aluminum ranged from 0.212 to 0.747 mg/l (Geus River) for the Guam Rivers suspended metal fraction. This is much lower than 3.86 mg/l mean concentration reported by Kopp and Kroner (1970) for 220 samples from raw water sources from the United States. Guam streams, because they are small, are much quicker to show the effects of daily rainfall patterns and because they generally drain a steeper slope tend to have swifter flows and rockier bottoms. This results in faster turnover of runoff produced silt loads.

Aluminum in water exists in complexes with other anions. Below pH of 4.0, which is not likely to be encountered in surface waters, the Al^{+3} ion predominates (Robertson and Hem, 1969). At neutral pH the aluminum ion polymerizes with hydroxide ions to form microparticles with the structural pattern of Gibbsite. Above neutral pH the predominate form of dissolved aluminum is the anion $Al(OH)_4$. The chemistry is more complicated when silica, fluoride, sulfate or phosphate anion species are as present in significant amounts. When those anions are absent or present in less than ppm concentrations (tenths of ppm for fluoride) the solubility product of aluminum hydroxide (bayerite) gives an estimate of the expected dissolved aluminum concentration to be expected. Fluoride enhances aluminum solubility when present in several ppm concentrations. The flouride concentrations in southern Guam rivers (measured only once) were all less than 0.1 ppm. Therefore, flouride is unlikely to be an important factor in aluminum solubility.

The presence of silica decreases aluminum solubility. Silica has been measured at 5.14 to 19.3 mg/l in the La Sa Fua River and 5.89 to 21.2 mg/l in the Geus River (Zolan, 1981). Since silica shows considerable fluctuation in Guam streams it may be that changes in the concentration of silica plays a significant role in the variability of aluminum concentrations. Rainfall activity which increases the particulate load of streams and serves to dilute spring source waters, is also a major factor (Figure 10a, 10b and 11).

According to the experiments conducted by Robertson and Hem (1969) the solubility of aluminum ranges from 0.054 mg/l at a pH of 7 to 2.14 mg/l at a pH of 8.5, when the sulfate concentration is less than 5 mg/l, and the flouride concentration less than 1.9 mg/l. The solubility of gibbsite aluminum, in contrast to most other metals, increases at increasing pH. The concentration range (0.170-0.678 mg/l) of dissolved aluminum in a concentrated solution with the above conditions, at pH 7.5 to 8.0 was the most characteristic condition in the streams studied. This range does bracket the higher aluminum concentrations observed in the study. That dissolved aluminum was frequently lower than the lower bracket range could be due to silica depression effects or the reduced lack of contact time times with the substrate (a non-concentrated condition).

Manganese

Concentrations of manganese in the rivers studied were low except for the Pigua River which showed exceptionally higher concentrations than the three other rivers studied. Raw surface waters of the United States, 1,577 different waters, have a mean dissolved manganese concentration of 0.058 mg/l (Kropp and Kroner, 1970). The La Sa Fua, Umatac and Geus Rivers had mean manganese concentrations of 0.008, 0.014 and 0.008 mg/l respectively. However, the Pigua River had a mean manganese concentration of 0.064 mg/l which is only slightly above the mean for the United States raw surface water but which is very much higher than in the other Guam rivers surveyed. Total manganese was usually not much higher than the dissolved concentrations, usually from 1.5 to 4 times the dissolved concentration. For aluminum the total concentration was frequently over 5 times the dissolved concentration and in the case of iron the total concentration was frequently 10 times the dissolved fraction.

Suspended manganese concentrations in the United States surface water average 0.105 mg/l (Kropp and Kroner, 1970). This is approximately eight times the 0.014 mg/l level observed in Guam.

Manganese is present in plant tissues in concentrations from 0.1 to 4 ppm and it is highest in dark green leafy portions in plants (up to 8 ppm). In humans manganese ranges from approximately 0.1 ppm in muscle tissue to 1.7 ppm in the liver. It is likely that algae act as major manganese sinks in the path from geologic source to ocean sediments. The data from this study support the idea that manganese is stored in stream bed algae and released during catastrophic events (heat, or drought) or lost in sloughed off algae which is not released until much further down stream or after reaching the ocean.

Iron

Iron concentrations fluctuated even more than aluminum and this was primary due to increased particulate sediment loading during or soon after rainfall events. Mean dissolved iron concentrations ranged from 0.053 to 0.111 with all but one of the rivers (the Geus River) close to 0.05 mg/l. These values are similar to the 0.052 mg/l mean found in the survey of 1,577 United States raw surface waters surveyed by Kopp and Kroner (1970).

Mean suspended iron in the rivers ranged from 0.212 to 0.549 mg/l (Geus River) with an overall mean of 0.374. This is nearly an order of magnitude below the 3.00 mg/l observed in the Kropp and Kroner (1970) study of raw surface waters in the United States.

Calcium

Calcium concentrations in the rivers studied were similar to two previous surveys of the southern Guam rivers. A USGS survey in 1952 (Ward et al, 1965) found the Umatac River to have 48 mg/l calcium. No other southern Guam River was surveyed. Zolan (1981) found average calcium concentration of 37 mg/l and 31 mg/l for the La Sa Fua and Geus Rivers respectively (8 samples, each river, over a one year period within 300m of where samples were collected for this study). In 1984-1985 the mean of these two rivers was 42 mg/l. Total hardness also was somewhat higher in the later study with mean concentrations of 145 and 138 compared to means of 127 and 104 mg/l. The earlier study consisted of only 8 total samples collected over a one year period with two samples collected per quarter. Thus, it does not appear from the past studies or the data collected by this survey that Guam southern rivers are low in calcium. The spring sources lay in limestone in almost all instances (the exception being Pigua Spring) and low calcium concentrations would not be expected. Overall water hardness is borderline hardwater (150 mg/l), and this together with a river pH usually in excess of 7.5 means that most heavy metals will tend to be complexed, precipitated or adsorbed. There is no evidence from the data collected that Guam's river waters are low in calcium. Only one source, the Pigua Spring which currently supplies only part of Umatac Village is low in calcium (less than 10 mg/l).

CONCLUSIONS

Mean dissolved aluminum concentrations in water from the La Sa Fua, Umatac, Pigua, and Geus Rivers of southern Guam are higher than the overall reported mean concentration for dissolved aluminum in rivers of the continental United States. Although the individual rivers contained 27 to 285% higher mean concentrations of dissolved aluminum during the 12 months study the median values were more in keeping with mean aluminum concentrations in the United States of 0.07 mg/l.

Concentrations of calcium in these same rivers were consistently high, and characteristic of borderline hard waters. Mean calcium concentrations ranged from 34 to 53 mg/l.

The southern Guam rivers studied had much lower dissolved and suspended manganese concentrations than the reported means of continental United States rivers. Total manganese was generally less than 0.020 mg/l excepting in the Pigua River where the mean dissolved manganese concentration was 0.064 mg/l.

A small fraction of the variability in metal concentrations was shown to be dependent upon rainfall totals during the 48 hours preceeding sampling. Remaining variability is also believed to be related to sampling times with respect to rainfall events. Because the southern Guam rivers are small (most would consider them streams) and steeply sloped, the effects of rainfall runoff are quickly manifested in the river's water quality.

Algae attached to stream beds (Spirogyra spp.) sequester manganese which is required in algal enzyme reactions and is a component of lamellae in chloroplasts. Noticeable fluctuations in manganese concentrations occurred during periods of drought, (decreased dissolved manganese) and during periods when algae was dying or sloughing off (increased dissolved manganese).

The WERI study findings of higher than U.S. average aluminum concentrations in Guam's southern rivers does not mean the waterborn aluminum constitutes a threat to human health or plays a role in the etiology of ALS/PD. Surface waters from tropical or warm humid areas appear to have higher aluminum concentrations than temperate waters (Tables 12-14). A comparison study of aluminum in surface waters of nearby islands whose inhabitants do not experience ALS/PD would be beneficial in lending perspective to the Guam study.

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APPENDIX A
Biweekly water quality data collected 6/17/85 - 7/27/85 by station

Table A-1. Water analyses results from Pigua River Station 1. Concentrations are in milligrams per liter (mg/l). Letters D and T denote dissolved and total respectively. Precipitation is in inches recorded during the 48 hour period prior to the sampling date.

DATE	TIME	TEMP.	DO_2	pH	T.Al	D.Al	Al.T/D	T.Mn	D.Mn	MnT/D	T.Fe	D.Fe
6/17/84	1300	26.0	6.0	7.10	1.33	0.036	6.9	0.041	0.007	5.9	1.69	0.042
7/9/84	1100	27.0	5.0	7.46	0.083	0.081	1.0	0.068	0.069	1.0	0.108	0.045
7/22/84	1240	27.0	5.4	7.45	0.116	0.188	.	0.110	0.084	1.3	0.154	0.115
8/7/84	1110	27.0	6.8	7.18	0.185	0.043	4.3	0.026	0.030	.	0.324	0.063
8/21/84	1225	27.2	7.0	7.31	0.142	0.124	4.2	0.007	0.035	1.9	0.114	0.113
8/26/84	1430	26.2	7.8	7.20	0.546	0.105	5.2	0.029	0.030	1.0	0.262	0.031
9/4/84	1245	27.3	7.2	7.05	0.815	0.025	33.9	0.071	0.044	1.8	0.397	0.019
9/18/84	1120	.	.	7.50	0.082	0.080	1.1	0.050	0.045	1.1	0.128	0.026
10/3/84	1215	27.1	6.9	7.54	0.114	0.022	5.2	0.053	0.048	1.2	0.095	0.025
10/16/84	1030	25.1	6.8	7.00	0.163	0.280	1.0	0.048	0.040	1.2	0.149	0.162
11/1/84	1200	25.7	6.7	7.05	0.377	0.066	5.7	0.045	0.039	1.1	0.224	0.013
11/20/85	1145	25.4	7.6	7.41	0.173	0.048	5.2	0.044	0.040	1.1	0.138	0.016
12/10/84	1030	25.5	7.2	7.41	0.081	0.001	8.1	0.047	0.040	1.2	0.123	0.027
12/20/84	0930	24.9	7.0	7.40	0.160	0.063	2.5	0.058	0.048	1.2	0.160	0.046
1/3/85	1120	25.4	6.1	7.03	0.214	0.044	4.9	0.056	0.049	1.1	0.140	0.049
1/17/85	1100	25.5	7.2	7.44	0.145	0.052	2.8	0.041	0.036	1.1	0.103	0.006
1/31/85	1140	26.0	6.4	7.33	0.152	0.112	1.4	0.056	0.050	1.1	0.156	0.049
2/13/85	1015	25.1	5.9	7.25	0.157	0.083	1.4	0.103	0.096	1.1	0.105	0.038
3/2/85	1015	25.0	5.2	7.31	0.321	0.164	1.9	0.106	0.102	1.0	0.165	0.125
3/18/85	1300	25.5	6.0	7.49	0.247	0.178	2.0	0.095	0.088	1.1	0.152	0.046
4/1/85	1120	25.9	5.0	7.54	.	.	.	.	.	.	0.245	0.102
4/17/85	1120	26.0	3.3	6.91	0.429	0.367	1.2	0.0918	0.839	1.1	0.334	0.042
4/30/85	1150	25.5	4.6	.	0.076	0.020	3.8	0.0918	0.180	1.1	0.126	0.014
5/17/85	1045	24.8	7.5	7.60	0.776	0.123	6.3	0.253	0.078	3.2	1.43	0.100
5/30/85	1045	26.3	7.2	7.40	.	0.184	.	.	0.093	.	.	0.066
6/13/85	1515	25.2	6.8	7.40	0.160	0.123	1.3	0.079	0.062	1.3	0.980	0.026
6/27/85	.	26.4	7.5	7.45	0.972	0.161	6.0	0.025	0.017	1.5	0.436	0.122

Table A-1. continued.

Date	FeT/D	Ca	TDS	SS	VSS	NO_3-N	PO_4-P	SO_4	Alk	Hrd	Cl	PPT
6/17/84	40.3	37	.	.	.	0.016	0.019	.	.	.	.	.
7/9/84	2.4	33	270	1.1	.	.	.	.	.	.	.	.
7/22/84	1.3	34	182	.	.	0.024	0.009	2	161	158	21	0.6
8/7/84	5.2	33	235	1.6	.	.	.	3	152	136	14	0.8
8/21/84	1.1	42	132	3.2	0.3	0.037	0.031	2	150	136	14	0.7
8/26/84	8.4	32	200	1.6	0.8	0.002	0.011	2	136	124	14	1.5
9/4/84	19.5	28	180	5.6	0.2	0.007	0.025	2	155	139	15	0.1
9/18/84	5.0	45	226	5.8	0.9	0.009	0.010	3	158	146	13	0.1
10/3/84	3.9	39	200	1.8	.	0.007	0.010	2	164	146	16	1.0
10/16/84	1.0	31	222	4.6	.	0.003	0.050	2	134	122	13	0.6
11/1/84	18.3	30	208	4.0	0.7	0.050	0.057	2	134	122	13	0.2
11/20/84	9.0	31	275	1.1	0.2	0.045	.	3	137	133	14	0.0
12/10/84	4.6	36	202	1.1	0.3	.	0.037	2	160	139	14	0.0
12/20/84	3.5	35	222	0.8	0.4	0.003	0.020	1	162	154	14	0.0
1/3/85	2.8	35	220	0.8	0.4	0.010	0.018	2	164	152	15	0.3
1/17/84	16.0	42	220	0.9	0.1	0.004	0.018	6	157	148	16	0.2
1/31/85	3.2	34	265	1.0	0.3	0.008	0.020	3	179	162	15	0.0
2/13/85	2.8	35	238	0.5	0.2	0.003	0.019	3	180	170	17	0.0
3/2/85	1.3	34	228	0.4	.	0.011	0.005	0	192	162	15	0.0
3/18/85	3.3	33	218	1.0	0.1	0.008	0.005	4	167	156	22	0.1
4/1/85	2.4	32	248	5.8	0.3	0.014	0.006	1	185	162	20	0.1
4/17/85	7.9	33	242	2.6	0.3	0.021	0.010	.	189	163	14	0.0
4/30/85	9.0	28	252	1.7	0.1	0.028	0.004	1	180	152	21	0.0
5/17/85	14.3	28	192	7.0	0.2	0.007	0.013	4	110	84	18	2.2
5/30/85	.	32	233	0.3	.	0.003	0.005	3	178	147	19	0.1
6/13/85	3.7	39	225	1.2	0.1	0.006	0.004	2	190	159	18	0.1
6/27/85	3.6	31	116	1.4	.	.	.	4	130	108	14	1.5

Table A-2. Water Analyses results from Pigua River Station 2. Concentrations are in milligrams per liter (mg/l). The letters D and T denote dissolved and total respectively. Precipitation is in inches recorded during the 48 hour period prior to the sampling date.

DATE	TIME	TEMP.	pH	D.Al	T.Al	Al.T/D	D.Fe	T.Fe	FeT/D	D.Mn	T.Mn	MnT/D
6/17/84	1400	26.0	7.70	0.090	0.160	8.6	0.050	0.921	18.4	0.012	0.051	4.2
7/22/84	1320	27.1	7.59	0.043	0.972	3.3	0.024	0.101	4.2	0.087	0.102	1.2
8/26/84	1530	26.2	7.30	0.094	0.771	11.3	0.024	0.287	5.7	0.023	0.037	1.4
9/18/84	1200	27.0	7.55	0.059	0.146	2.9	0.025	0.150	6.0	0.042	0.049	1.2
10/16/84	1100	26.0	7.20	0.109	1.15	4.9	0.056	0.219	3.8	0.022	0.043	1.9
12/10/84	1125	25.5	7.57	0.019	0.172	6.8	0.028	0.112	4.0	0.033	0.037	1.1
1/3/85	1305	25.0	7.12	0.005	0.513	24.1	0.035	0.124	3.5	0.044	0.052	1.2
1/31/85	1225	26.0	7.46	0.043	0.129	2.0	0.065	0.178	2.8	0.042	0.046	1.1
3/2/85	1120	24.9	7.29	0.494	0.118	1.2	0.125	0.165	1.3	0.100	0.107	1.1
4/1/85	1230	26.9	7.50	.	0.084	.	0.087	0.387	4.5	.	.	.
4/30/85	1225	25.2	.	0.015	0.613	5.1	0.033	0.187	5.7	0.117	0.132	1.1
5/30/85	1020	26.7	7.65	0.063	.	.	0.032	.	.	0.072	.	.

DATE	Ca	HARD	TDS	SS	VSS	DO_2	ALK	Cl	So_4	NO_3-N	Po_4-P	PPT
6/17/84	38	.	.	.	.	5.9	.	.	.	0.017	0.143	.
7/22/84	36	158	198	.	.	5.0	162	23	3	.	.	0.6
8/26/84	33	123	190	0.4	.	7.9	128	14	2	0.004	0.014	1.5
9/18/84	38	139	202	4.4	0.9	.	148	13	2	0.008	0.011	0.1
10/16/84	30	134	215	2.8	0.5	6.4	142	16	3	0.005	0.056	1.3
12/10/84	36	145	230	1.4	0.6	7.2	145	15	2	.	0.020	0.0
1/3/85	43	145	225	0.2	.	5.9	163	15	2	0.008	0.017	0.3
1/31/85	37	168	238	0.5	.	5.0	177	15	3	0.007	0.021	0.0
3/2/85	34	168	255	1.0	0.3	3.9	192	20	1	0.008	0.005	0.0
4/1/85	36	168	252	1.5	0.5	5.2	191	21	1	0.046	0.010	0.1
4/30/85	31	156	258	1.5	0.4	4.6	190	21	1	0.005	0.003	0.0
5/30/85	38	159	238	0.5	.	6.3	184	19	3	0.005	0.005	0.1

Table A-3. Water analyses results from Pigua River Station 3. Concentrations are in milligrams per liter (mg/l). The letters D and T denote dissolved and total respectively. Precipitation is in iches recorded during the 48 hour period prior to the sampling date.

DATE	TIME	TEMP	pH	D. Al	T. Al	AlT/D	D. Fe	T. Fe	FeT/D	D. Mn	T. Mn	MnT/D
6/17/84	1515	27.8	8.20	0.035	0.321	9.2	0.031	0.482	15.5	0.006	0.035	6.1
7/22/84	1400	30.5	8.20	0.082	0.047	0.6	0.019	0.089	4.2	0.012	0.016	1.3
8/26/84	1600	26.0	7.08	0.056	0.581	10.4	0.028	0.310	10.3	0.007	0.011	1.6
9/18/84	1240	27.0	7.45	0.086	0.123	5.0	0.022	0.096	4.7	0.012	0.030	1.5
10/16/84	1125	27.0	7.45	0.089	0.446	5.0	0.051	0.217	4.2	0.019	0.030	1.6
12/10/84	1150	27.2	8.55	0.008	0.124	15.9	0.022	0.118	5.4	0.014	0.021	1.5
1/3/85	1455	27.0	8.09	0.172	0.266	1.6	0.030	0.120	4.0	0.015	0.028	1.9
1/31/85	1330	28.0	8.30	0.143	0.262	1.8	0.113	0.301	2.7	0.013	0.020	1.5
3/2/85	1210	25.8	8.00	0.298	0.350	1.2	0.044	0.082	1.9	0.012	0.016	1.3
4/1/85	1330	27.5	8.21	.	.	.	0.060	0.147	2.4	.	.	.
4/30/85	1320	26.0	.	0.006	0.055	7.8	0.020	0.116	5.8	0.014	0.029	2.1
5/30/85	1145	28.0	8.10	0.072	.	.	0.021	.	.	0.017	.	.

DATE	Ca	HARD	TDS	SS	VSS	DO_2	ALK	Cl	So_4	NO_3-N	Po_4-P	PPT
6/17/84	47	.	.	.	.	6.2	.	.	.	0.015	0.026	.
7/22/84	35	144	172	.	.	5.5	150	23	3	0.027	.	0.6
8/26/84	33	106	184	3.6	0.6	8.2	109	13	3	0.002	0.014	1.5
9/18/84	28	118	168	1.9	0.8	.	178	12	3	0.009	0.011	0.1
10/16/84	30	131	215	6.3	.	7.1	122	13	3	0.002	0.016	1.3
12/10/84	35	119	208	2.0	0.2	8.0	123	12	3	.	0.018	0.0
1/3/85	35	133	230	1.2	0.5	7.1	143	15	2	0.005	0.023	0.3
1/31/85	32	142	218	5.3	0.4	7.4	154	15	3	0.004	0.019	0.0
3/2/85	34	154	230	1.2	0.6	8.2	177	20	0	0.036	0.002	0.0
4/1/85	34	149	225	0.8	0.3	.	172	20	1	0.012	0.005	0.1
4/30/85	33	150	258	1.6	0.3	8.0	180	21	1	.	0.008	0.0
5/30/85	34	149	218	1.1	0.2	8.2	162	20	3	0.010	0.003	0.1

Table A-4. Water analyses results from Pigua River Station 4. Concentrations are in milligrams per liter (mg/l). The letters D and T denote dissolved and total respectively. Precipitation is in inches recorded during the 48 hour period prior to the sampling date.

DATE	TIME	TEMP	pH	D. Al	T. Al	AlT/D	D. Fe	T. Fe	FeT/D	D. Mn	T. Mn	MnT/D
6/17/84	1600	27.5	7.90	0.024	0.158	3.5	0.037	0.507	14.0	0.037	0.130	3.5
7/9/84	1130	28.0	7.95	0.018	0.077	4.2	0.072	0.245	3.4	0.049	0.078	1.6
7/22/84	1500	28.5	8.00	0.124	0.264	2.1	0.092	0.228	2.5	0.069	0.093	1.3
8/7/84	1020	26.5	7.43	0.032	0.138	4.3	0.126	0.306	2.4	0.018	0.014	1.0
8/26/84	1220	25.8	7.00	0.115	0.467	4.1	0.039	0.348	8.8	0.010	0.019	2.9
9/4/85	1325	27.0	7.34	0.048	0.196	3.9	0.034	0.196	5.7	0.021	0.038	1.8
9/18/84	1320	27.0	8.00	0.022	0.116	5.3	0.028	0.143	4.8	0.029	0.043	1.3
10/3/84	1320	28.2	8.10	0.098	0.082	1.0	0.113	0.087	1.0	0.048	0.036	1.0
10/16/84	1215	26.0	7.35	0.089	0.446	4.0	0.088	0.211	7.6	0.045	0.069	1.6
11/1/84	1730	27.2	7.70	0.043	0.117	2.9	0.016	0.093	5.8	0.034	0.052	1.9
11/20/84	1040	25.6	7.78	0.065	0.235	3.6	0.020	0.162	8.0	0.036	0.078	0.1
12/10/84	1255	26.2	7.89	0.038	0.157	4.1	0.030	0.270	9.0	0.046	0.059	1.3
12/20/84	1036	24.9	8.10	0.001	0.259	2.5	0.047	0.352	7.5	0.080	0.120	1.5
1/3/85	1630	25.1	8.00	0.015	0.186	12.4	0.045	0.255	5.7	0.100	0.113	1.1
1/17/85	1300	26.0	8.18	0.115	0.308	2.7	0.008	0.155	20.3	0.089	0.097	1.1
1/31/85	1500	27.0	8.10	0.097	0.126	1.3	0.034	0.280	8.2	0.117	0.127	1.1
2/13/85	1100	25.2	8.05	0.139	0.216	1.6	0.021	0.228	10.8	0.167	0.180	1.1
3/2/85	1330	27.0	7.70	0.052	0.142	2.7	0.081	0.229	2.8	0.179	0.262	1.5
3/18/85	1330	26.5	8.38	0.394	0.591	1.5	0.092	0.715	7.8	0.177	0.198	1.1
4/1/85	1500	29.0	8.20	.	.	.	0.060	0.147	2.4	.	.	.
4/17/85	1220	28.0	7.78	0.608	0.722	1.2	0.021	0.192	9.1	0.774	0.844	1.1
4/30/85	1400	28.0	.	0.098	0.458	4.7	0.028	0.412	14.7	0.190	0.247	1.3
5/17/85	1150	25.5	7.90	0.014	0.681	6.5	0.129	1.29	10.0	0.074	0.139	1.9
5/30/85	1255	28.0	8.00	0.040	.	.	0.020	.	.	0.082	.	.
6/13/85	1610	26.1	7.90	0.109	0.130	1.2	0.191	0.222	1.2	0.108	0.127	1.2
6/27/85	0830	26.0	7.50	0.165	1.21	7.3	0.104	0.501	2.3	0.012	0.027	1.3

Table A-4. Continued.

DATE	Ca	HARD	TDS	SS	VSS	DO_2	ALK	Cl	So_4	NO_3-N	Po_4-P	PPT
6/17/84	58	.	.	.	.	7.4	.	.	.	0.015	0.026	.
7/9/84	36	154	132	1.4	.	5.4	.	26	.	.	.	.
7/22/84	38	145	210	1.4	.	6.6	157	25	3	0.022	0.003	0.6
8/7/84	31	117	132	2.4	.	7.6	123	17	1	.	.	0.8
8/26/84	33	102	152	1.8	0.5	8.9	108	13	3	0.003	0.014	1.5
9/4/84	20	102	184	6.4	0.4	8.2	122	14	3	0.006	0.17	0.1
9/18/84	30	120	190	1.7	0.8	.	125	12	3	0.022	0.010	0.1
10/3/84	30	117	175	6.0	0.8	7.8	127	12	2	0.030	0.011	0.0
10/16/84	32	126	185	6.1	0.9	8.2	125	13	3	0.003	0.054	1.3
11/1/84	29	120	182	2.1	0.7	7.8	108	14	3	0.055	0.037	0.6
11/20/84	29	112	200	1.5	0.3	8.2	106	13	4	0.050	.	0.2
12/10/84	31	126	192	1.1	0.6	8.7	120	13	3	.	0.018	0.0
12/20/84	31	132	198	0.9	0.8	9.0	139	14	2	0.002	0.017	0.0
1/3/85	37	141	192	1.1	0.06	8.4	148	15	2	0.006	0.019	0.3
1/17/85	36	146	222	1.7	0.5	9.4	138	17	8	0.008	0.017	0.2
1/31/85	36	158	223	0.7	0.6	9.1	161	15	4	0.011	0.019	0.0
2/13/85	38	164	240	1.5	0.6	9.8	168	16	3	0.004	0.017	0.0
3/2/85	39	178	255	2.4	0.5	10.0	184	20	1	0.010	0.002	0.0
3/18/85	38	172	225	0.9	0.6	9.3	171	27	5	0.012	0.017	0.1
4/1/85	46	176	255	2.9	0.3	9.6	192	21	1	0.009	0.004	0.1
4/30/85	38	170	255	2.7	0.2	9.8	202	18	.	0.009	0.011	0.1
5/17/85	26	101	152	6.0	0.2	11.4	196	20	1	0.033	0.006	0.0
5/30/85	37	153	245	1.2	0.2	9.0	96	20	5	0.024	0.010	2.2
6/13/85	42	157	242	1.4	0.4	9.8	169	20	3	0.033	0.003	0.1
6/27/85	23	78	140	2.6	.	8.7	95	13	4	.	.	1.5

Table A-5. Water analyses results from the La Sa Fua River. Concentrations are in milligrams per liter (mg/l). The letters D and T denote dissolved and total respectively. Precipitation is in inches recorded during the 48 hour period to the sampling date.

DATE	TIME	TEMP	pH	D. Al	T. Al	AlT/D	D. Fe	T. Fe	FeT/D	D. Mn	T. Mn	MnT/D
7/9/84	.	.	.	0.037	0.088	2.4	0.010	0.116	11.6	0.021	0.032	1.5
7/22/84	.	.	.	0.497	1.93	3.9	0.270	1.95	7.3	0.026	0.087	3.4
8/7/84	1225	27.0	7.53	0.016	0.164	10.0	0.052	0.213	4.1	0.022	0.016	1.0
8/21/84	1140	26.2	7.70	0.039	0.113	2.9	0.005	0.109	21.4	0.014	0.023	1.6
9/4/84	1130	26.9	7.80	0.039	0.315	8.2	0.009	0.167	18.6	0.010	0.020	2.0
9/18/84	1030	26.0	8.05	0.031	0.136	4.4	0.009	0.147	17.1	0.013	0.022	1.7
10/3/84	1040	26.2	8.15	0.072	0.048	1.0	0.021	0.024	1.1	0.010	0.010	1.0
10/16/84	0910	25.2	7.79	0.718	1.52	2.2	0.327	1.96	5.9	0.011	0.027	2.4
11/1/84	1000	25.5	7.90	0.339	0.778	2.3	0.130	0.452	3.5	0.013	0.022	1.7
11/20/84	1300	27.0	8.05	0.084	0.247	3.9	0.004	0.097	24.5	0.010	0.014	1.4
12/10/84	0900	24.7	7.95	0.073	0.240	3.3	0.005	0.194	88.3	0.010	0.014	1.4
12/20/84	0755	23.1	7.60	0.032	0.125	3.9	0.008	0.079	9.9	0.007	0.010	1.3
1/3/85	1010	24.2	7.65	0.079	0.143	1.8	0.006	0.010	1.7	0.012	0.015	1.3
1/31/85	0915	24.0	8.10	0.187	0.237	1.3	0.013	0.072	5.5	0.060	0.063	1.1
2/13/85	0900	23.5	7.60	0.267	0.453	1.7	0.021	0.103	4.9	0.068	0.077	1.1
3/2/85	1045	24.5	7.49	0.170	0.238	1.4	0.009	0.033	3.5	0.013	0.018	1.4
3/18/85	1200	25.2	8.39	0.074	0.108	1.4	0.037	0.133	3.6	0.013	0.019	1.4
4/1/85	1000	25.0	8.10	.	.	.	0.033	0.109	3.3	.	.	.
4/17/85	1020	25.1	8.19	1.188	1.39	1.2	0.008	0.032	4.1	0.016	0.033	1.4
4/30/85	1500	28.0	.	0.010	0.060	6.0	0.013	0.261	20.1	0.003	0.021	7.4
5/17/85	0945	24.1	7.45	0.333	1.04	3.1	0.252	1.68	6.7	0.010	0.049	4.9
5/30/85	1400	28.0	8.25	0.015	.	.	0.007	.	.	0.013	.	.
6/13/85	1300	25.2	7.98	0.333	0.423	1.3	0.012	0.075	6.2	0.018	0.029	1.6
6/27/85	.	25.5	8.10	0.073	0.193	2.6	0.016	0.064	4.0	0.018	0.023	1.3

Table A-5. Continued.

DATE	Ca	HARD	TDS	SS	VSS	DO_2	ALK	Cl	So_4	NO_3-N	Po_4-P	PPT
7/9/84	44	78	.	.	.	.	.	10	.	.	.	.
7/22/84	30	117	145	.	.	.	127	13	0	.	.	0.6
8/7/84	49	173	283	3.6	.	6.9	193	15	2	.	.	0.8
8/21/84	55	172	244	2.2	0.8	7.7	181	11	2	.	.	0.7
9/4/84	31	165	248	3.2	0.3	8.4	190	13	2	.	.	0.1
9/18/84	50	162	260	5.7	0.9	.	187	10	2	.	.	0.1
10/3/84	34	169	226	4.8	.	8.2	197	11	2	.	.	0.1
10/16/84	32	117	213	6.7	.	8.2	124	7	0	.	.	1.3
11/1/84	39	131	243	3.5	0.1	8.2	136	9	1	.	.	0.6
11/20/84	46	154	230	0.6	0.3	8.6	168	11	1	.	.	0.2
12/10/84	43	152	233	1.0	0.6	8.3	173	16	1	.	.	0.0
12/20/84	44	154	238	0.9	0.2	9.0	.	11	1	.	.	0.0
1/3/85	45	138	215	1.3	0.6	8.9	172	11	1	.	.	0.3
1/31/85	44	166	243	1.1	0.6	9.4	182	10	2	.	.	0.0
2/13/85	43	159	231	1.8	0.8	9.2	174	11	2	.	.	0.0
3/2/85	43	146	210	1.5	0.6	9.7	177	13	1	.	.	0.1
3/18/85	46	152	225	1.4	0.4	9.2	175	14	2	.	.	0.1
4/1/85	43	149	238	2.1	0.8	9.7	177	13	1	.	.	0.1
4/17/85	41	145	245	1.9	0.2	10.1	176	11	.	.	.	0.1
4/30/85	38	128	238	3.2	0.4	11.6	167	11	1	.	.	0.0
5/17/85	20	81	158	6.7	0.2	9.1	86	13	3	.	.	2.2
5/30/85	44	151	244	1.1	0.2	9.5	188	18	2	.	.	0.1
6/13/85	49	161	268	2.2	0.1	8.9	200	12	2	.	.	0.1
6/27/85	46	159	238	0.4	.	8.2	189	12	2	.	.	1.5

Table A-6. Water analyses results from the Umatac River. Concentrations are in milligrams per liter (mg/l). The letters D and T denote dissolved and total respectively. Precipitation is in inches recorded during the 48 hour period prior to the sampling date.

DATE	TIME	TEMP	pH	D. Al	T. Al	AlT/D	D. Fe	T. Fe	FeI/D	D. Mn	T. Mn	MnI/D
7/9/84	.	.	.	0.060	0.119	2.0	0.016	0.121	7.6	0.005	0.010	1.6
7/22/84	.	.	.	0.254	0.742	2.9	0.304	1.09	3.6	0.009	0.041	4.9
8/7/84	1150	28.0	7.26	.	0.108	.	0.036	0.224	6.3	0.028	0.027	1.0
8/21/84	1205	27.2	7.31	0.012	0.414	33.7	0.005	0.109	20.0	0.022	0.029	1.3
9/4/84	1212	27.9	7.15	0.417	5.17	12.4	0.665	3.55	5.3	0.009	0.019	2.2
9/18/84	1045	26.9	7.50	0.011	0.076	6.9	0.004	0.124	28.3	0.018	0.025	1.4
10/3/84	1130	27.8	7.80	0.011	0.098	8.9	0.074	0.020	1.0	0.016	0.014	1.0
10/16/84	0950	25.8	7.50	0.090	0.269	3.0	0.226	3.46	15.3	0.014	0.019	1.3
11/1/84	1050	28.0	7.70	0.055	0.267	4.9	0.024	0.137	5.7	0.020	0.030	1.5
11/20/84	1210	28.0	7.67	0.066	0.242	3.7	0.000	0.111	.	0.024	0.027	1.1
12/10/84	0945	26.3	7.70	0.001	0.265	441.0	0.002	0.194	88.3	0.020	0.025	1.3
12/20/84	0805	25.0	7.40	0.052	0.160	3.1	0.036	0.113	3.1	0.021	0.038	1.8
1/3/85	1045	26.0	7.51	0.064	0.266	4.1	0.007	0.079	10.8	0.018	0.022	1.2
1/17/85	1020	26.0	7.62	0.129	0.193	1.5	0.017	0.044	2.6	0.013	0.014	1.1
1/31/85	1000	26.0	7.80	0.089	0.090	1.0	0.006	0.029	4.8	0.011	0.012	1.1
2/13/85	0940	25.9	7.70	0.035	0.117	3.4	0.007	0.038	5.1	0.013	0.015	1.1
3/2/85	1000	26.0	7.60	0.145	0.177	1.2	0.004	0.026	6.4	0.010	0.011	1.1
3/18/85	1225	27.5	7.49	0.305	0.402	1.3	0.022	0.096	4.5	0.015	0.017	1.1
4/1/85	1030	27.5	8.09	.	.	.	0.025	0.080	3.2	.	.	.
4/17/85	1050	27.2	7.75	0.554	0.581	1.0	0.011	0.128	11.5	0.010	0.014	1.4
5/17/85	1015	25.8	7.70	0.300	1.11	3.7	0.057	1.67	29.4	0.013	0.040	3.1
5/30/85	1325	28.0	8.00	0.014	.	.	0.002	.	.	0.010	.	.
6/13/85	1420	27.0	7.65	0.054	0.088	1.6	0.003	0.019	6.9	0.013	0.024	1.8
6/27/85	.	27.0	7.80	0.042	0.125	3.0	0.005	0.056	11.2	0.001	0.002	1.5

Table A-6. Continued.

DATE	Ca	HARD	TDS	SS	VSS	DO_2	ALK	Cl	So_4	PPT
7/9/84	46	154	.	.	.	.	.	.	.	.
7/22/84	40	139	137	.	.	.	157	.	.	.
8/7/84	69	192	325	.	.	6.4	214	18	6	0.7
8/21/84	63	195	304	4.2	0.5	7.0	205	14	4	0.7
9/4/84	40	181	292	13.0	0.2	7.4	200	11	4	0.0
9/18/84	58	195	286	5.0	0.7	.	210	12	3	0.1
10/3/84	60	153	275	6.0	.	7.7	217	13	3	0.0
10/16/84	49	159	288	3.3	.	8.0	117	10	1	1.2
11/1/84	45	146	245	1.4	0.6	7.5	143	16	1	0.6
11/20/84	58	186	282	4.1	0.3	6.6	194	13	2	0.1
12/10/84	58	186	282	4.1	0.3	7.4	257	12	2	0.0
12/20/84	61	199	285	2.9	0.9	7.6	122	13	2	0.0
1/3/85	60	180	290	2.7	0.4	8.8	210	13	2	0.3
1/17/85	40	177	250	1.1	0.2	7.9	190	14	5	0.2
1/31/85	55	195	307	4.3	0.8	8.4	212	14	4	0.0
2/13/85	53	186	285	0.5	0.2	10.4	206	14	4	0.0
3/2/85	57	190	288	0.5	.	8.1	222	16	6	0.1
3/18/85	56	184	253	1.0	0.1	7.7	203	18	5	0.1
4/1/85	51	178	263	1.5	0.3	9.7	212	16	4	0.1
4/17/85	53	188	270	1.1	0.2	10.4	215	14	.	0.1
5/17/85	32	108	180	6.3	0.1	8.0	124	15	2	2.0
5/30/85	55	173	273	1.3	0.3	11.0	212	22	4	0.0
6/13/85	60	189	268	2.1	0.8	8.4	220	14	4	0.1
6/27/85	58	187	254	1.0	.	7.4	210	14	3	1.5

Table A-7. Water analyses results from the Geus River. Concentrations are in milligrams per liter (mg/l). The letters D and T denote dissolved and total respectively. Precipitation is in inches recorded during the 48 hour period prior to the sampling date.

DATE	TIME	TEMP	pH	D. Al	T. Al	AlT/D	D. Fe	T. Fe	FeT/D	D. Mn	T. Mn	MnT/D
7/9/84	.	.	.	0.274	0.558	2.2	0.155	0.355	2.3	0.074	0.016	.
7/22/84	.	.	.	0.508	2.75	5.4	0.873	2.89	3.3	0.010	0.049	4.9
8/7/84	0936	26.0	7.15	0.120	0.585	4.9	0.141	0.657	4.7	0.004	0.019	4.0
8/26/84	1800	26.0	7.00	0.085	0.669	7.8	0.039	0.408	10.1	0.005	0.012	1.9
9/4/84	1405	27.0	7.47	0.417	5.17	12.2	0.665	3.55	5.3	0.009	0.019	2.2
9/18/84	1410	.	8.60	0.053	0.265	5.0	0.004	0.125	32.1	0.004	0.015	3.2
10/3/84	1415	27.5	8.00	0.081	0.118	1.5	0.012	0.072	6.0	0.006	0.007	1.2
10/16/84	1245	.	7.10	0.920	6.13	6.7	0.226	3.46	16.3	0.009	0.091	10.2
11/1/84	1130	26.0	7.80	0.108	0.275	2.6	0.130	0.452	3.3	0.008	0.014	1.8
11/20/84	1010	25.1	7.78	0.070	0.325	4.6	0.002	0.137	55.1	0.003	0.009	3.1
12/10/84	1355	25.4	8.10	0.123	0.330	2.7	0.008	0.128	16.4	0.003	0.009	2.9
12/20/84	1107	24.8	8.10	0.147	0.172	1.2	0.039	0.155	4.0	0.004	0.010	2.4
1/3/85	1705	25.0	7.90	0.243	0.339	1.4	0.011	0.032	2.9	0.002	0.005	2.6
1/17/85	1400	25.5	8.08	0.015	0.147	9.8	0.033	0.133	4.0	0.005	0.008	1.7
1/31/85	1050	25.0	8.00	0.092	0.243	2.6	0.010	0.191	19.9	0.002	0.005	4.5
2/13/85	1135	25.8	8.18	0.203	0.279	1.4	0.009	0.072	7.8	0.003	0.006	2.0
3/2/85	1320	25.5	8.41	0.478	0.388	1.2	0.063	0.144	1.8	0.002	0.005	3.3
3/18/85	1450	25.8	8.30	0.178	0.225	1.3	0.052	0.344	6.6	0.005	0.012	2.6
4/1/85	1630	27.0	8.32	.	.	.	0.093	0.315	3.4	.	.	.
4/17/85	1300	27.0	8.10	.	.	.	0.015	0.097	6.6	0.007	0.037	5.2
4/30/85	1120	25.2	.	0.014	0.209	14.9	0.013	0.261	20.1	0.003	0.021	7.4
5/17/85	1220	25.0	8.10	0.294	0.991	3.4	0.121	1.51	12.5	0.004	0.033	8.2
5/30/85	1000	26.0	8.00	0.032	.	.	0.006	.	.	0.001	.	.
6/13/85	1650	25.1	7.70	0.294	0.378	1.3	0.019	0.100	5.3	0.004	0.016	4.2
6/27/85	0745	25.6	7.40	0.187	0.461	2.5	0.039	0.274	7.0	0.004	0.012	3.3

Table A-7. Continued.

DATE	Ca	HARD	TDS	SS	VSS	DO_2	ALK	Cl	So_4	PPT
7/9/84	35	.	.	.	.	.	.	.	.	.
7/22/84	24	97	190	.	.	.	98	18	0	0.6
8/7/84	35	118	288	2.6	.	7.7	127	18	0	0.7
8/26/84	37	118	112	.	0.1	9.0	103	17	1	0.5
9/4/84	18	87	172	41.4	0.2	8.5	94	13	.	0.1
9/18/84	46	154	230	4.5	0.7	.	159	15	1	0.1
10/3/84	51	162	260	4.9	.	7.9	173	17	2	0.0
10/16/84	27	96	205	6.7	.	.	98	9	0	1.3
11/1/84	25	146	245	1.4	0.5	8.6	144	15	2	0.1
11/20/84	39	122	228	1.8	0.3	8.4	122	15	2	0.1
12/10/84	45	143	258	2.5	0.4	9.3	157	16	1	0.0
12/20/84	49	169	293	1.1	0.2	8.2	173	18	1	0.0
1/3/85	46	152	265	0.9	0.3	8.4	168	17	1	0.3
1/17/85	45	162	240	1.9	0.3	9.6	155	18	4	0.2
1/31/85	47	161	292	4.2	0.6	8.7	184	17	3	0.0
2/13/85	46	163	263	0.6	0.3	10.8	174	20	3	0.0
3/2/85	43	150	283	1.7	0.4	13.2	175	21	2	0.1
3/18/85	42	152	270	2.4	0.7	10.1	168	22	4	0.1
4/1/85	46	156	265	2.8	0.5	9.1	175	21	3	0.1
4/17/85	45	151	300	3.0	0.2	11.1	174	19	.	0.1
4/30/85	39	144	270	3.7	0.2	12.1	171	20	1	0.0
5/17/85	46	65	125	7.8	0.2	9.1	61	20	.	2.2
5/30/85	44	155	.	2.6	0.1	8.5	164	28	2	0.1
6/13/85	46	157	278	1.7	0.8	8.7	174	19	2	0.1
6/27/85	41	130	202	1.0	.	8.1	141	17	2	1.5

Appendix B. Aluminum in surface waters of Guam.

One time measurements of filterable and non-filterable (0.45 µm membrane filter) aluminum in surface waters of Guam. Sampling and analyses by the Guam Environmental Protection Agency under the supervision of Kenneth L. Morphew. Samples were collected during 1984 and analyzed by the eriochrome cyanine R method as presented in the 15th edition of Standard Methods (APHA, AWWA, APHA, 1980). Concentrations are in mg/l, waters.

DATA:

RIVERS	UNFILTERED	FILTERED
Maloloj	0.01	<0.01
Agana River	0.40	0.02
Namo River	<0.10	<0.01
Salinas River	0.40	0.02
Gautili River	0.08	0.03
Asan River	4.10	0.17
Masso River	2.00	0.08
Acorp River	<0.01	<0.01
Fonte River	0.75	0.03
Sasa River	<0.01	<0.01
Langga River	<0.01	<0.01
Fimile River	<0.01	<0.01
Aguada River	0.01	<0.01
Tatqua River	0.01	<0.01
Pagachao River	<0.01	<0.01
Matque River	<0.01	<0.01
Aceoys S.W.	0.02	0.01
Fonte F.W.	1.49	0.17
Masso F.W.	0.32	0.08
Gautali S.W.	0.06	0.03
Agana F.W.	0.01	0.01
Asan F.W.	0.03	0.01
Namo F.W.	0.11	0.03
Salinas F.W.	0.13	0.04
Umatac F.W.	0.01	0.01
Finile (Agat) S.W.	<0.01	<0.01
Talafofo Up Falls	0.01	0.01
Tatgua River	<0.01	<0.01
Langga	0.01	0.01
Aguada	0.01	0.01
Togcha F.W.	<0.01	<0.01
Ylig F.W.	<0.01	<0.01
Geus S.W.	0.01	<0.01
Rago F.W.	0.01	<0.01
Merizo Sumay	0.01	0.01
Merizo Bile	0.01	0.01
Merizo Liyog	0.01	0.01
Merizo Pigua	0.03	<0.01
Merizo Suyafe	0.01	0.01

Appendix B. Continued.

Merizo Maereno	0.08	<0.01
Merizo F.W.	0.04	<0.02
Pauliluc Inj.	0.02	0.01
Payfe Merizo	0.04	0.01
Agua Merizo	0.06	0.04
Fayan Inj.	0.01	0.01
Bile Merizo	0.04	0.03
Paulilua	0.01	<0.01
Liyog	0.01	<0.01
Agana Springs	0.40	0.02
Average	0.221	0.019

Appendix C. WERI-U.S.D.A. Soil Conservation Service Soil Sampling, June 1985.

Soils from the vicinities of the water sampling sites were collected with the assistance of Fred Young, Soil scientist of the U.S.D.A. Soil Conservation Service. The following descriptions are field collection notes:

I. Location: Geus River.
Vegetation: Forest.
Slope/site characteristics: about 80% slope; short slopes, broken by rock outcrop, narrow benches. Colluvial. 10 meters from river.

Soil type: Agfayan clay (deeper than typical)
Profile notes: 0-20 cm; black clay
20-45 cm; very dark greyish brown clay
45 cm; pale yellow weathered tuffaceous sandstone
occasional gravel, cobbles and stones on soil surface

Sampling Depth: 0-45 cm; fragment of sandstone.

II. Location: Upper Pigua River (#1)
Vegetation: Sparse savannah. Degraded.
Slope/site characteristics: 20% slope; about 1/3 of immediate are is rock outcrop. 50 meters from river.

Soil type: Agfayan clay (shallow end of range)
Profile notes: 0-10 cm; black clay.
10 cm; dark, weathered tuffaceous sandstone.

Sampling Depth: 0-10cm.

III. Location: Lower Pigua River (#2).
Vegetation: Banana plantation - clean cultivated.
Slope/site characteristics: Level. Narrow stream floodplain; river is 10 m away, incised 2 meters. Seasonal water table, probably below 50 cm in rainy season. Flooding common.

Soil type: Inarajan clay (drainage better than typical).
Profile notes: Very deep, dark clay. Buried surface horizon at 65 cm. Gleyed (reduced) colors below 80 cm.

Sampling Depth: 45-85 cm.

IV. Location: Umatac (#1); north slope above valley.
Vegetation: Sparse, degraded savannah.
Slope/site characteristics: About 60% slope; over half of slope is rock outcrop, with pockets of soil. Actively eroding. About 200 meters from river.

Appendix C. Continued.

Soil type: Agfayan clay.
Profile notes: 0-20 cm; dark brown gravelly clay. Much gravel and cobbles on the surface.

Sampling Depth: 0-20 cm.

V. & VI. Location: La Sa Fua (#1 and #2).
Vegetation: Old coconut plantation.
Slope/site characteristics: 60% slope; ridgeline, sampled just below slope shoulder. Approximately 200 meters from river.

Soil type: Akina (estimate higher in bases than typical), darker colors than typical. Akina - Agfayan intergrade.
Profile notes: 0-65 cm; dark clay, very sticky.
65+ ; soft tuffaceous saprolite, crushes easily to clay.

Sampling Depth: #1: 20-65 cm
#2: 75-110 cm

VII & VIII. Location: Umatac #2 and #3; near water tank, south of Umatac valley.
Vegetation: Savannah; 100% cover.
Slope/site characteristics: About 3% slope, 5 meters back from slump headwall (edge of valley sideslope). Approximately 200 meters from river.

Soil type: Atate.
Profile notes: Thin dark surface (clay).
Upper subsoil; reddish brown clay, well structured.
Lower subsoil; dark red clay, well structured.

Sampling Depth: #2: 25-80 cm
#3: 115-150 cm

The collected soils were analyzed (excepting pH) after they were oven dryed at 100°C and milled in a porcelain ball mill for three hours.

The pH of the soil was measured according to the glass electrode-pH meter method or presented by Peech (1965). Carbonate content of the soils was determined by the gravimetric method employing 3N HCL as presented by Allison and Moodie (1968). Total exchangeable bases was determined by ammonium acetate leaching (Chapman, 1965), and exchangeable acidity by barium chloride-triethanolamine leaching (Peech, 1965), Cation exchange capacity was derived by summing the exchangeable bares and exchangeable acidity.

A test for exchangeable aluminum ran into difficulties because the KCl extractant produced background interference and reduced sensitivity with the atomic absorption graphite furnace method for determining aluminum concentrations. The aluminum extracts were then analyzed with the eriochrome cyanine r colorometric method. However, the results were called into question by a soil scientist reviewer. Those results are not presented in the table but are available to interested parties who wish to repeat the analyses themselves. The collected soils are also available to any investigator who wishes to repeat these analyses.

Table C-1. Analyses of typical soils collected in proximity to river water sampling stations.

Stations	Soil Type	pH Water	Cation Exchange Capacity (meq/100gm)	Exchangeable Bases (meq/100gm)	Exchangeable Acidity (meq/100gm)	Carbonate (meq/100gm)	Exchangeable Nitrate (meq/100gm)
Pigua 1	Agfajan	6.43	55.5	32.8	22.6	0.01	0.002
Pigua 2	Inarajan	6.68	35.5	17.4	18.2	0.00	0.006
La Sa Fua 1	Akina	5.93	36.0	15.9	20.2	0.00	0.005
La Sa Fua 2	Akina	6.49	41.7	23.8	18.0	0.00	0.014
Umatac 1	Agfajan	6.82	52.4	33.2	19.2	0.00	0.004
Umatac 2	Atate	6.19	22.3	3.86	18.5	0.00	0.003
Umatac 3	Atate	6.04	13.5	1.84	13.3	0.02*	0.003
Geus	Agfajan	7.01	34.0	22.3	17.5	0.06	0.014

* Test repeated with same result however believe, there is another factor involved (loss of absorbed water as vapor?) in the positive result in this sample.

Appendix C. Literature Cited.

Allison, L.E. and C.D. Moodie. 1965. Carbonate - In Methods of Soil Analysis, Part 2. (C.A. Black ed). American Society of Agronomy. p. 1384-1385.

Chapman, H.D. 1965. Catin-exchange capcity. In Methods of Soil Analysis, Part 2. (C.A. Black ed). American Society of Agronomy. p. 1384-1385.

Chapman, H.D. 1965. Exhangeable bases. In Methods of Soil Analysis, Part 2. (C.A. Black ed). American Society of Agronomy. p. 903-904.

Peech, M. 1965. Exchangeable acidity. In Methods of Soil Analysis, Part 2. (C.A. Black ed). American Society of Agronomy. p. 905-913.

Peech, M. 1965. Hydrogen-ion activity. In Methods of Soil Analysis, Part 2. (C.A. Black ed). American Society of Agronomy. p. 914-925.

Appendix D. Perkin-Elmer HGA 2200 programs for trace metal analyses of digested, undigested water samples.

HGA APPLICATIONS DATA SHEET

Element: Aluminum Matrix. 1.5% HNO_3 in dist. HOH for STD's, sample dilution
for total or dissolved metal

HGA-500 Program Location: AA notebook #5

Instrumental Parameters

Inst. Model : 560

Wavelength : 309.5

Spectral Bandwidth: 0.7 nm alt

Light Source : hollow cathode

Current/Watts : 25 mA

Background Correction? yes

Readout Parameters

Absorbance/Conc: 500 ug/l = 0.103 Ab (av

☐ Peak Height; time normal setting

☐ Peak Area; time normal absorbanc in calculations

☒ Recorder: 10 mv scale, hitachi model 56, 10 mm/min

HGA Parameters

HGA Model : 220

Graphite Tube : Pyro

Sample Aliquot: 20 ml

Sample Introduction

Manual: xxxx

Automated: no

Replicates: min- 2

Purge Gas : Argon

Alternate Gas : n/a

Keyboard Entries

Step	1	2	3	4	5	6	7	8
Temp °C	100°	1250°	2700°					
Ramp (s)	20s	10s	---					
Hold (s)	30s	20s	8s					
Read	raw absorbances							
Rec.	10 mv scale							
Baseline	.000	- .002 absorbance						
Int.Flow ml/min	55							
Int.Alt. ml/min	--							
Ext.Alt. ml/min	--							

HGA APPLICATIONS DATA SHEET

Element: Iron

Matrix: 1.5% HNO_3 in dist. HOH for STD's, sample dilutions

HGA-500 Program Location: AA notebooks #5

Instrumental Parameters

Inst. Model : 560

Wavelength : 248.3 nm

Spectral Bandwidth: 0.2 nm

Light Source : hollow cathode

Current/Watts : 30 mA

Background Correction? yes

Readout Parameters

Absorbance/Conc: 40 ug/l = 0.173 abs.

☐ Peak Height; time normal setting

☐ Peak Area; time absorbance used in calculations

☒ Recorder: 10 mu scale, Hitachi model 56, 10mm/min

HGA Parameters

HGA Model : 2200

Graphite Tube : pyro

Sample Aliquot: 20 ml

Sample Introduction

Manual: xxxx

Automated:

Replicates: 2 - min

Purge Gas : argon

Alternate Gas : n/a

Keyboard Entries

Step	1	2	3	4	5	6	7	8	9
Temp °C	100°	1200°	2400°						
Ramp (s)	20s	10s	---						
Hold (s)	30s	20s	8s						
Read	raw absorbances								
Rec.	10 mv scale								
Baseline	.000 - .002 absorbance								
Int.Flow ml/min	55								
Int.Alt. ml/min									
Ext.Alt. ml/min									

HGA APPLICATIONS DATA SHEET

Element: Manganese Matrix. 1.5% HNO_3 in dist. water for standards sample dilutions, make up volumes

HGA-500 Program Location: AA notebook #5

Instrumental Parameters

Inst. Model : 560

Wavelength : 279.5 nm

Spectral Bandwidth: 0.2 nm

Light Source : hollow cathode

Current/Watts : 20 mA

Background Correction? yes

Readout Parameters

Absorbance/Conc: 10 ug/l = 0.172 absorbance

☐ Peak Height; time normal setting

☐ Peak Area; time absorbances used in calculations

☒ Recorder; 10 mv scale, Hitachi model 56, 10 mm/min

HGA Parameters

HGA Model : 2200

Graphite Tube : pyro

Sample Aliquot: 20 ul

Sample Introduction

Manual: xxx

Automated:

Replicates: 2 - min

Purge Gas : argon

Alternate Gas : n/a

Keyboard Entries

Step	1	2	3	4	5	6	7	8	9
Temp °C	100°	1000°	2600°						
Ramp (s)	20s	10s	---						
Hold (s)	30s	20s	8s						
Read	raw absorbances								
Rec.	10 mv								
Baseline	0.000 - 0.002								
Int.Flow ml/min	55								
Int.Alt. ml/min	---								
Ext.Alt. ml/min	---								