DIATOM ASSEMBLAGES AS INDICATORS OF WATER QUALITY IN FRESHWATER HABITATS OF GUAM

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Technical Report No. 29

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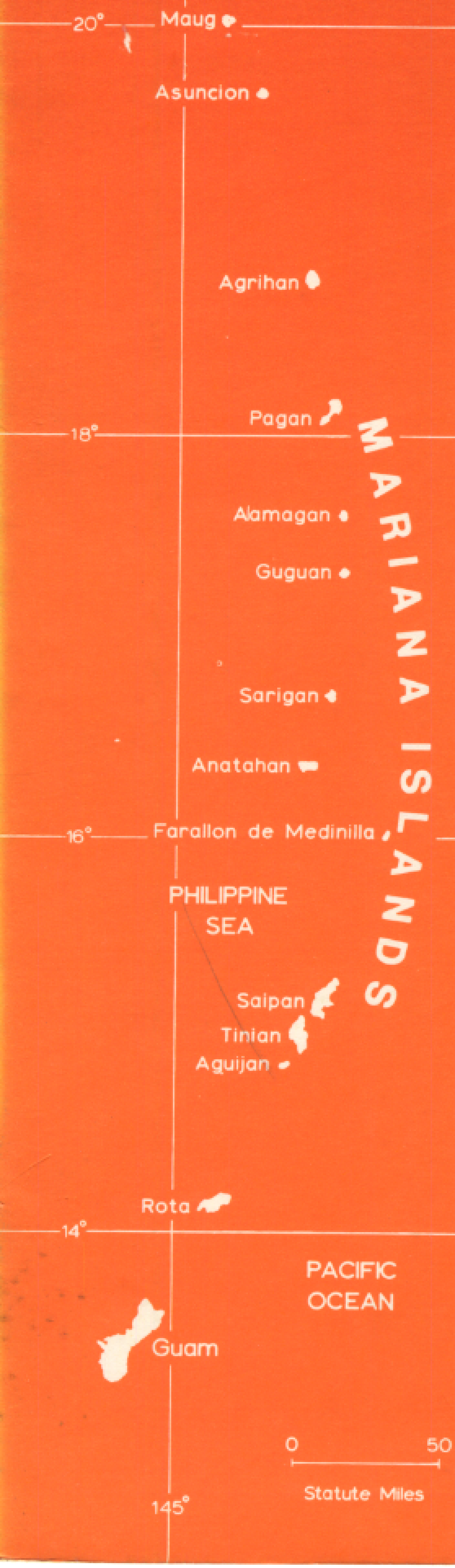

DEPARTMENT OF THE INTERIOR • OFFICE OF WATER RESEARCH AND TECHNOLOGY

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Project Completion Report

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Principal Investigators: J. A. Marsh, Jr. and W. J. Zolan

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ABSTRACT

Glass slides were immersed quaterly in five bodies of freshwater (polluted and unpolluted) for 10 to 14 days to collect periphytic diatoms. Concurrent with the periphyton collection period, water samples were collected on three separate days and analyzed for 22 water quality parameters. Natural surfaces (plants, rocks and sediments) were also collected and the inhabitant diatom assemblages analyzed to compare with the glass slide collections. Diatom collections were analyzed by randomly selecting an area on an exposure slide (or prepared cover slip) and counting at least 750 diatom frustules, identifying individuals to species. This data was used to calculate species diversity indices (Shannon-Wiener function and Simpson's index), a sample similarity index, and to determine if diatom assemblages occur according to water quality or habitat type.

Results revealed that bodies of water derived from or containing urban runoff can be expected to have diatom assemblages dominated by Nitzschia palea and have low species diversity. This response is particularly evident where nutrient (NO_3-N and PO_4-P) enrichment occurs. In extreme cases the diatoms (primarily Navicula palea) are replaced by blue-green algae (a mixture of Oscillatoria, Spirulina, and Anabaena spp.).

In ponded habitats where the concentrations of mineralized nutrients were excessively low (<.020 mg/ℓ), Gomphonema parvulum dominated the diatom assemblage. Diatom coverage of the slides at this site was the lowest observed. In unpolluted small rivers (average flow ≤1.0 mgd), diatom assemblages were more diverse and were dominated by Gomphonema clevei. The high degree of sample similarity between river stations over time indicate that distinct diatom assemblages exist according to water quality and habitat type.

Comparisons of diatom assemblages occurring on natural substrata with those collected on glass slides showed reduced species numbers (over 33%) and species diversity occurring on the glass slide samples. However, this may have resulted in part or in total from the fact that there was no time limitation for diatom colonization of the natural surfaces. However, the glass slides did collect diatoms from all the habitats; epiphytic, epipelic and epilithic since the dominant species in the natural substrata collections were also found on the slides.

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INTRODUCTION

Periphytic diatoms are useful indicators of pollution stress in natural systems because they demonstrate biological change in a time period intermediate between grab water samples and gross changes in higher organism (e.g., aquatic plants and invertebrates) communities. Because they represent a continuous sample over a period of days or weeks, periphytic diatom monitoring can indicate the occurrence of subtle though biologically important changes in water chemistry which may not be noticed in periodic or infrequent grab water sampling programs. In conjunction with water quality analysis, biomonitoring of a natural body of water can provide an indication of which water parameters or pollutants are most detrimental in affecting biological systems.

The use of diatoms as indicators of water quality in freshwaters has been extensively studied (see Patrick, 1977 for a detailed review). The investigations by Butcher (1947), Wantanabe (1962), and Fjeringstad (1964) have classified diatoms or diatom communities (and other aquatic life) according to the physio-chemical environments in which they flourish. Lowe (1974) has produced a compilation of ecological requirements and tolerances for common freshwater diatoms.

Because many diatom species (and those of other organisms) are found to inhabit a wide range of environmental conditions, another approach in biomonitoring has been to observe how the total assemblage of diatom species reacts to changes in water quality. The changes analyzed include changes in total species, species diversity (a measure of total species and the distribution of individuals among species) and productivity (as increases in density of cells, mass, or chlorophyll). Patrick et al. (1954) pioneered the use of changes in diatom assemblages as indicators of pollution in aquatic habitats. They determined that the distribution of individuals among species (grouped into harmonic intervals) can be described as a truncated log normal curve (Preston, 1948). Habitats under pollution stress result in a flattening of the truncated log normal distribution in contrast to those habitats free of pollution. Their method, however, requires substantial numbers of species (at least 30 per sample, with better results for communities with over 50 species). It also requires large counts of individuals (from 2,000 to 8,000), which are very time-consuming to obtain. Other methods utilize species diversity indices (see Peet, 1974, and Hurlbert, 1971, for a review of their usefulness) which measure, with one number, changes in total species and the distribution of individuals among species. Popular species diversity indices include the Simpson Index as presented by Pielou (1969) and the Shannon-Wiener function (Shannon-Weaver, 1949) as used by Margalef (1957) or Patten (1962). Because no two diversity indices measure changes in total species and the distribution of individuals equally, two or more indices are usually employed and their reported bias stated (Peet, 1974). Recent uses of species diversity indices in periphytic diatom communities include Amspoker (1977), Archibald (1972), Montgomery et al. (1977) and Sullivan (1977). The methodology of periphyton productivity measurements has been standardized by Weber (1973) and the American Public Health Association (1981), and is commonly used to monitor biological reactions to changed conditions (Marcus, 1980).

Past work using periphytic diatom assemblages in biomonitoring has occurred chiefly in temperate climates. Tropical investigations are just beginning. Most tropical studies to date have been concerned with obtaining baseline data on natural unaffected diatom assemblages (Montgomery et al., 1977; Ricard, 1977; Zolan, 1980). On Guam, two biomonitoring programs are currently being operated; one by the U.S. Geological Survey (USGS) and the other by the Guam Environmental Protection Agency (GEPA). The focus of the USGS program is the Pago River where periphyton samples are currently collected quarterly and sent off-island for analyses (both biomass and organism community structure measurements). The GEPA survey emphasizes the marine habitat and utilizes coral, macroalgae and other macro-sized organisms for monitoring purposes.

This present diatom survey of various Guam freshwater sites, including those known to be polluted, identifies which diatoms are the predominant species in the periphyton according to habitat and water quality. By comparison to previous investigations, those diatom species which can be used as biological indicators of increased pollution concentrations, are identified. The study also provides ranges of common species diversity indices for the periphyton assemblages and determines their usefulness in perphytic diatom biomonitoring of these waters.

METHODS AND MATERIALS

Study Sites

Five freshwater sites (Figure 1) were chosen for study. Two study sites were selected in small unpolluted southern Guam rivers upstream from any urban or rural land use (Figures 2,3, and 4). One of these sites was located in the La Sa Fua River (average flow approximately 1 mgd) approximately 150 m west of the Route 2 bridge. The La Sa Fua drains into Fouha Bay. The other river site was in the Geus River (average flow approximately 0.6 mgd) about 300 m upstream from the water dam from which the Public Utility Agency of Guam (PUAG) pumps water to Merizo Village. During the course of the study, both rivers were used to supply freshwater to nearby villages. Chlorination was the only treatment the water received prior to pumpage into the distribution system. Kami et al. (1974) conducted a biological study of the Geus River basin which presents a detailed description and photos of that area. The remaining three study sites were selected in northern Guam, where urbanization influences runoff water quality. The sites selected were Perez Acres ponding basin, Chalan Passajeros (Airport Road) storm drainage basin, and the storm drainage ditch off Sereno Avenue adjacent to Mark's L.P.G. outlet (Figure 5). A previous study (Zolan et al. 1978) had shown that the water quality of these sites differed with respect to nutrient concentrations.

Perez acres ponding basin usually has low concentrations of nitrogen and phosphorus and a low BOD (Zolan et al. 1978). It possesses a large standing crop of *Hydrilla verticillata* (Fig. 6) which may be responsible for rapid uptake of the runoff inorganic nutrient load. The waters in the pond are non-flowing except when they rise to the cement spillway during extremely high rainfall periods.

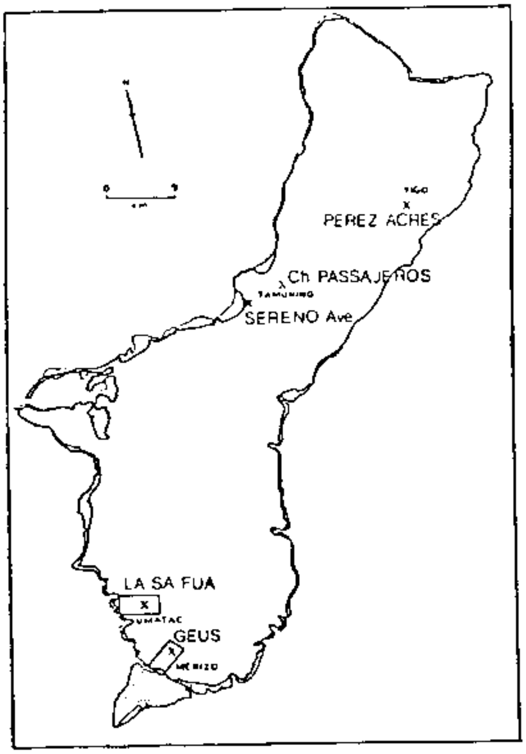

Figure 1. Diatom study sites. The boxed areas at La Sa Fua and Geus are the river drainage areas shown in Fig. 4.

Figure 2. Sampling pool at the La Sa Fua River. The upper portion of the photo shows savannah terrain.

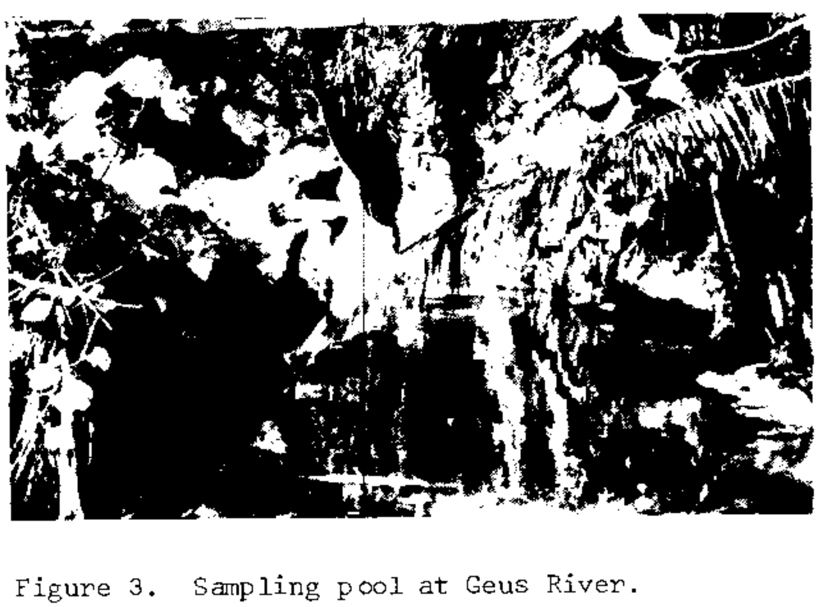

Figure 3. Sampling pool at Geus River.

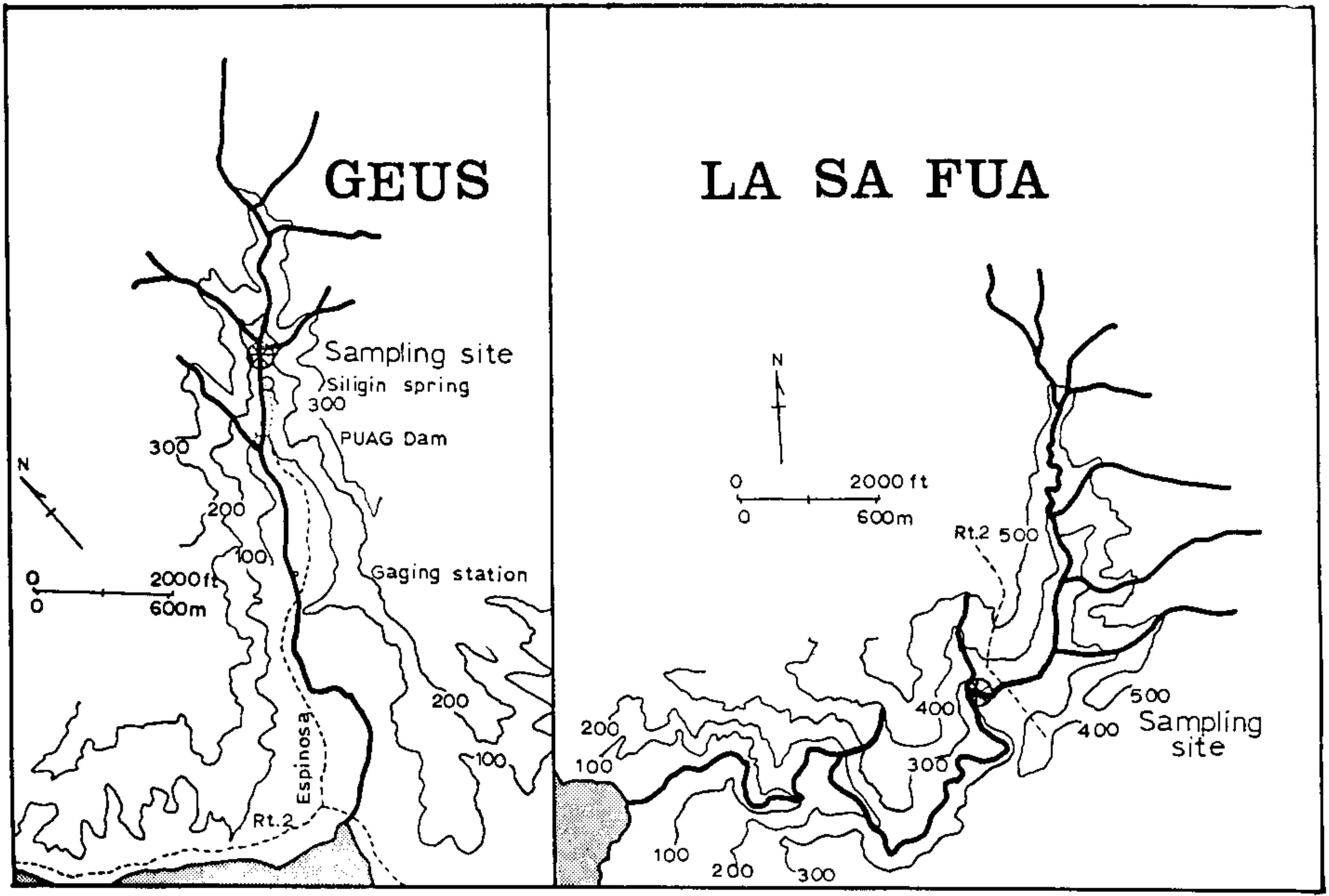

Figure 4. Sampling locations on the Geus and La Sa Fua Rivers. Shaded areas are ocean waters. Maps adapted from Austin, Smith and Associates (1968).

Figure 5. Sereno Avenue storm drainage ditch. A dense growth of *Panicum maximum* covers the sides along the entire length of the ditch.

Figure 6. *Hydrilla verticillata* at the Perez Acres ponding basin. The plant coverage of water surface is complete except along the edge of the pond.

The drainage basin off Chalan Passajeros, west of Mendiola Hotel, collects waters from parking areas at the Guam International Airport and from airport runway-apron areas. Airplane washing, with detergents containing phosphates, produces a high phosphate concentration in the runoff collection basin. The basin waters have intermittant flow depending upon rainfall and washing operations.

The storm drainage ditch at Sereno Avenue (Figure 5) collects storm runoff from Marine Drive and the Camp Watkins Road intersection and from points north along Marine Drive to Chalan Passajeros. Waters in the ditch flow constantly and usually contain high nitrate-nitrogen concentrations (Zolan et al. 1978) due to groundwater flow out of the storm culvert. This groundwater originates from the public water distribution system either from water-line usage or leakage. Also, perhaps more importantly, a groundwater springs area exists in the ditch at the 90° turn to the west midway between the storm culvert and the outlet at the shoreline. The diatom collection site was located approximately 40 m east or upstream from the springs location. Directly opposite the diatom collector location a small pipe (six-inch diameter) periodically discharges what smells like raw sewage into the ditch. The source of the pipe discharge was not investigated but it probably comes from business(es) or houses on the west side of Sereno Avenue south of the culvert. Normally, because of the dense grass (*Panicum maximum*) lining the drainage ditch, this pipe is not visible.

Sampling Methodology

Sample collectors consisted of stainless steel glass slide holders which were filled with four glass slides each. The collectors were fixed to the bottom substrate by either tying them to aged cement blocks or wiring (stainless steel) them to stainless steel poles hammered into the substrate. The poles were used at all sites except Chalan Passajeros, where the basin is cement-lined.

Collectors were placed in pools in the southern river study sites to minimize differences in current velocity on diatom colonization of the slide surfaces. Shading effects were minimized by placing all collectors in the open, with clear overhead. However, because the river basins were steeply sloped, these study sites probably received less direct sunlight than the northern sample sites.

The collectors were positioned from .1 to .5m deep at all stations and oriented north to south for maximum sun exposure. Depth varied with rainfall activity. With the exception of the Perez Acres ponding basin, differences in depths were less than .3m. Collectors were put in place quarterly (every three months) from October 1978 to July 1979. Slides were allowed a minimum of 10 days and a maximum of 14 days of exposure for colonization. All exposure times were equal for a particular quarterly sample. Previous experience (Zolan, 1980) and literature (Patrick et al. 1954) indicated an exposure period of 10 to 14 days to be sufficient for diatom colonization.

Upon collection, half of the slide surfaces were scraped into a bottle containing two percent neutralized formalin. The slides were then air dried.

At the laboratory, the slides were placed in concentrated sulfuric acid for 45 minutes, then placed in a concentrated solution of potassium dichromate for one hour. This process removes the organic material from diatom frustules, a necessity for their identification. Schmidt et al. (1874-1959), Patrick and Reimer (1966; 1975), Collins and Kalinsky (1977), Lange-Bertalot and Simonsen (1978), Boyer (1926; 1927) and Van Landingham (1967-1978) were the principal taxonomic references used in identification of species. Sample counts were made by randomly selecting preset coordinates of a slide surface and counting down the slide surface through 10 fields of view (600X magnification). When identification of diatoms required a higher power, 1000X or a 1500X power with oil immersion was used. Photographs were taken at 1000X power and oil immersion. Counting continued in this fashion until 750 individual diatoms were identified and counted. The number 750 was selected on the basis of preliminary counts which indicated that all or a great majority of species were observed within this limit. Count totals in the literature vary from 250 to 8,000 (APWA, 1980; Patrick et al., 1954). Diatom counts were used to calculate species diversity indices for each sample analyzed.

Two species diversity indices, the Simpson Index (S) as presented by Pielou (1975) and the Shannon-Wiener function (H) as presented by Cox (1972), were determined for each sample:

$$S = 1/\Sigma \quad Pi, \tag{1}$$

and

$$H = 3.3219 \ (\log N \frac{1}{N} \Sigma ni \log_{10} ni) \tag{2}$$

where Pi is the proportion of the ith species; N is the number of all individuals counted; ni is the number of individuals in the ith species; and 3.3219 is the conversion factor from $\log_{10}$ to $\log_2$.

Additionally, to compare selected pairs of samples for relative similarity of diatom assemblages, the similarity index (Stander, 1970) presented by McIntire and Moore (1977) was employed:

$$SIMIab = \frac{\sum_{i=1}^{S} Pa_i \cdot Pb_i}{\sqrt{\sum_{i=1}^{S} P^2 a_i} \cdot \sqrt{\sum_{i=1}^{S} P^2 b_i}} \tag{3}$$

Where Pai and Pbi are the proportions of the ith species in the a sample and b samples respectively.

Water quality was determined during the course of the diatom collection period. The parameters and frequency of testing conducted during each diatom collection period are presented in Table 1. Water samples were collected by hand in linear polyethylene bottles and transported back to the lab on ice for analysis. All samples were collected between 0830 and 1615 hours.

Table 1. Water quality analyzed during the study and the testing frequency per sampling period.

Parameters	Frequency Per Sampling Period (10-14 days)	Methods	Source of Method
pH	3	Glass electrode	APHA (1975)
Temperature	3	Mercury thermometer	APHA (1975)
Turbidity	3	Nephelometer	APHA (1975)
Suspended Solids	3	GF/C filtration drying at 105°C (TNFR)	APHA (1975)
Specific Conductance	3	Wheatstone bridge	APHA (1975)
Dissolved Oxygen	3	Iodometric-azide modification	APHA (1975)
Chloride	2	Mercuric nitrate titration	APHA (1975)
Total Hardness	2	EDTA tritration	APHA (1975)
Calcium Hardness	2	EDTA titration	APHA (1975)
BOD_5	2	5-day incubation at 20°C	APHA (1975)
Total Kjeldahl Nitrogen (TKN)	2	Macrodigestion-distillation with nesslerization	APHA (1975)
Nitrate+Nitrite Nitrogen	2	Cadmium reduction	APHA (1975)
Total Phosphorus (TP)	2	Persulfate digestion/	
Orthophosphorus (PO_4-P)	2	ascorbic acid reduction	APHA (1975)
Silica-Silicon	2	Molybdosilicate	Strickland and Parsons (1972)
Chlorophyll a	2	Acetone extraction/with spectrophotometric finish	Strickland and Parsons (1972)
Total Carotenoids	2	" "	Strickland and Parsons (1972)
Total Bacteria	1	Membrane filter	Millepore Corp. (1974)
Fecal Coliform	1	Membrane filter	Millepore Corp. (1974)
Oil and Grease	1	Partition-gravimetric	APHA (1975)
Total Alkalinity	1	Potentiometric titraction	APHA (1975)
Manganese	1	Persulfate-spectrophotometric	APHA (1975)

On the last day of each diatom sample period, natural substrates were collected from the vicinity of the collector. Three types of substrates were collected: aquatic plant material (usually in the rivers, Panicum maximum or Hydrilla verticillata in the northern collection sites), sediments (which varied from clays to sands in particle size), and hard rocks. Materials collected from the substrates were cleaned with concentrated sulfuric acid and potassium dichromate solution as were the slides. Plant material was digested intact; rocks were scraped with a metal spatula and the scrapings digested. Sediments were transported back to the lab and poured into petri dishes, and one layer of lens paper was placed over the sediments, resting on the sediment surface. The lens paper was removed the next day and digested. Diatoms in the sediments migrate into the tissue paper diurnally (Eaton and Moss, 1966). Due to time limitations, complete analyses of all natural substrate samples were not completed. However, sufficient samples were analyzed for determining the major specific habitats of important diatoms (i.e., epiphytic, epilithic) found on the glass slides.

The diatom material was then cleaned by centrifuging (3000 rpm for 10 min.) to separate diatoms from the solution. The cleaning solution was then removed by pipet and distilled water was added. This process was repeated until the rinse water was free of dichromate. An amount of diatom suspension was then added to a cover slip and evaporated. The slips with diatoms were then mounted onto cleaned glass slides with hyrax mounting media (Hanna, 1930). The slips were then processed like the field slides by randomly selecting a starting point and counting downwards until 750 individuals were counted. Repeated slips were counted if diatom densities were low. The count data were then analyzed in the same fashion as the field slides, calculating species diversity indices (S and H) and using the SIMI index to compare samples.

RESULTS

Water Quality of Study Sites

Water quality at the five study sites was as anticipated with the two rivers showing similar water quality characteristics (Table 2; see Appendix A, tables A-1, A-2, A-3, and A-4 for analyses results for each sampling period) and the three northern sites showing variable water quality due to the different source waters. Rainfall had a vary noticeable effect on both dissolved and particulate water constituents. Rainfall was plotted for 48 hours previous to the sampling date and compared to the water analyses. Certain dissolved constituents; chloride, specific conductance (a measure of total dissolved ionic species), silica-silicon, hardness, and calcium hardness showed concentration effects due to rainfall activity. Other dissolved constituents did not show a strong relationship to rainfall. These included the nutrients (NO_2 plus NO_3-N, TKN, TP and PO_4-P), dissolved oxygen, and BOD. It may be that these latter parameters are more likely to be carried out in the initial runoff waters immediately after rainfall activity begins. Data supporting this "first flush" theory have been presented by Buckingham et al. (1970), McElroy III et al. (1976) and Thompson et al. (1974). The first flush effect was also observed in the Perez Acres ponding basin in the earlier Guam urban runoff study (Zolan et al., 1978). After the initial runoff waters pass through the watershed, additional runoff may contain ambient or lower concentrations of dissolved and suspended materials.

Table 2. Range, mean, standard deviation, and number of samples collected for each water quality parameter analyzed during the study.

	Perez Acres				Chalan Passejeros				Sereno Avenue			
	Range	Mean	Standard Deviation	Number	Range	Mean	Standard Deviation	Number	Range	Mean	Standard Deviation	Number
Temperature °C	25.3-30.6	28.9	1.6	12	25.1-34.6	30.4	2.4	12	27.0-31.5	2.90	1.2	12
Turbidity (NTU)	1.0-4.9	2.6	1.1	15	3.9-120	30	32	15	1.2-23	7.0	7.2	15
Suspended Solids (mg/ℓ)	1.2-11	3.2	2.4	15	4.5-96	29	26	15	0.5-30	6.2	7.5	15
Specific Conductance (μmhos/cm)	61.2-330	170	84	15	100-470	260	84	15	860-2890	1340	470	16
pH	7.2-9.6	8.5	0.7	12	6.9-8.6	7.6	0.5	12	6.6-7.4	7.0	0.2	12
Dissolved Oxygen (mg/ℓ)	0.9-17.2	7.6	4.2	11	0.2-7.6	3.6	2.9	12	0.6-6.4	3.8	2.1	17
Chloride (mg/ℓ)	4.4-2.5	10	7.0	8	5.9-40	19	14	8	113-379	223	83	8
Total Hardness (mg/ℓ $CaCo_3$)	26-49	38	9.4	8	34-105	65	26	8	112-369	273	85	8
Calcium Hardness (mg/ℓ $CaCo_3$)	23-49	38	10	7	32-76	53	18	8	112-274	219	63	8
BOD_5 (mg/ℓ)	1.3-4.5	2.9	1.1	8	20-168	58	48	8	0.6-27	6.1	8.5	8
TKN (mg/ℓ)	0.15-0.68	0.29	0.19	8	0.26-0.80	0.50	0.18	8	0.19-0.73	0.37	0.21	8
Nitrite + Nitrate Nitrogen	0.001-0.070	0.016	0.022	9	0.001-0.081	0.032	0.032	9	0.044-1.30	0.696	.430	9
Total Phosphorus (mg/ℓ)	0.033-0.051	0.045	0.005	8	0.991-10.8	4.69	3.67	8	.041-.328	.156	.115	6
Orthophosphate-phosphorus (mg/ℓ)	.001-.022	.011	.009	8	.467-9.87	3.51	3.55	8	.012-.330	.104	.102	8
Silica-Silicon (mg/ℓ)	.061-.980	.456	.305	8	.464-1.60	1.31	1.02	8	.539-1.32	.855	.261	3
Chlorophyll a(mg/m^3)	0.53-19.2	6.06	6.48	8	<0.01-108	18.0	36.9	8	0.87-6.50	2.60	2.20	8
Carotenoids (mg/m^3)	0.14-7.97	3.64	2.98	7	<0.01-65.8	12.4	24.1	7	0.05-3.81	1.15	1.28	7
Oil and Grease (mg/ℓ)	1.6-4.9	3.1	1.8	4	2.9-36	12	16	4	1.1-3.5	2.4	1.1	4
Total Bacteria (col./100 m/ℓ)	<0.1-3				1.6-39	--	--	4	<0.1-26	--	--	4
Fecal Coliform (col/100 mℓ)	10-950				0-450,000	--	--	4	<100-19,000	--	--	4
Total Alkalinity (mg/ℓ $CaCo_3$)	35-55	45	9.5	4	46-123	74	36	4	205-266	240	26	4
Manganese (mg/ℓ)	<.003-.023	.008	.010	4	.006-.174	.066	.078	4	.005-.062	.032	.027	4

Table 2. Continued.

	La Sa Fua River				Geus River			
	Range	Mean	Standard Deviation	Number	Range	Mean	Standard Deviation	Number
Temperature °C	26.0-30.0	27.8	1.2	12	25.8-28.8	27.1	1.0	12
Turbidity (NTU)	0.3- 4.0	6.4	1.1	15	0.3-22	4.2	6.6	15
Suspended Solids (mg/ℓ)	0.4-66.0	12	21	15	<0.1- 4.2	1.7	1.2	15
Specific Conductance (μmhos/cm)	250-410	350	46	16	190-390	300	58	16
pH	7.0- 8.8	7.9	0.5	12	6.7- 8.5	7.6	0.5	12
Dissolved Oxygen (mg/ℓ)	7.6-10.9	8.5	0.9	12	5.2-9.0	7.6	1.2	12
Chloride (mg/ℓ)	10-22	14	4.2	8	10-26	17	4.8	12
Total Hardness (mg/ℓ $CaCo_3$)	72-170	127	30	8	63-143	104	31	8
Calcium Hardness (mg/ℓ $CaCo_3$)	48-112	92	23	8	62-102	78	20	8
BOD_5 (mg/ℓ)	0.1-2.2	1.1	0.8	8	0.2- 2.9	1.0	0.8	8
TKN (mg/ℓ)	0.04-0.22	0.13	0.06	8	0.04-0.19	0.10	0.04	8
Nitrite + Nitrate Nitrogen	.002-.082	.020	0.026	9	.005-.054	.027	.017	9
Total Phosphorus (mg/ℓ)	.040-.070	.052	.012	8	.040-.062	.051	.007	8
Orthophospate-phosphorus (mg/ℓ)	.021-.044	.033	.008	8	.015-.051	.033	.013	8
Silica-Silicon (mg/ℓ)	6.14-19.3	11.4	5.8	8	5.89-21.2	12.0	6.09	8
Chlorophyll a (mg/m_3)	<0.01- 2.18	1.24	0.88	8	0.42- 3.70	1.50	0.094	8
Carotenoids (mg/m_3)	<0.01- 6.72	1.43	2.20	8	0.05-12.6	2.44	4.19	8
Oil and Grease (mg/ℓ)	0.0 - 0.7	0.1	0.4	4	0.0 - 0.5	0.1	0.2	4
Total Bacteria (col. $x10^6$/100 mℓ)	<3.0 - 1.8	--	--	4	<0.1 - 1.0	--	--	4
Fecal Coliform (col/100 mℓ)	0 -2,200	--	--	4	0 -2,800	--	--	4
Total Alkalinity (mg/ℓ $CaCo_3$)	112-169	148	26	4	65-144	112	35	4
Manganese (mg/ℓ)	<.003-.092	.038	.041	4	<.003-.092	.033	.041	4

Added rainfall then serves to dilute concentrations, particularly those derived from groundwater sources. Examples of parameters which responded to rainfall are shown for a river and an urban runoff site (Figures 7 and 8). Both turbidity and suspended solids rose dramatically in response to rainfall (Figures 7 and 8). Twenty-four hours after rainfall ceases, turbidity and suspended solids returns to near normal levels (in the rivers). In urban runoff sites recovery was not as swift, probably due to the fact that the time required to replace the volume of water contained in the basins with new flow was longer. The particular water quality findings of each diatom collection site will be described in separate sections that follow.

Perez Acres

Perez Acres ponding basin waters contained low concentrations of dissolved salts. This was indicative of waters that consist predominately of rainfall runoff. Concentration ranges of chlorides (4.4-25 mg/ℓ), total hardness (26-49 mg/ℓ $CaCO_3$), specific conductance (61-332 μmhos/cm), silica-silicon (0.061-0.980 mg/ℓ), nitrite plus nitrate-nitrogen (0.001-.070 mg/ℓ), and phosphate-phosphorus (0.001-0.022 mg/ℓ) all indicate that pond waters were mainly derived from surface rainwater runoff and not from groundwater resulting from tap water use in the subdivision (i.e. car washing or lawn watering). Guam's groundwater averages typically between 500 and 1200 μmhos/cm specific conductance.

The nutrient concentrations were very low (Tables 2, A-1 through A-4) even when compared to the river water in undeveloped areas. This occurs despite or because the pond surface is nearly completely covered by <u>Hydrilla verticillata</u>. As an indication of a euthropic condition, chlorophyll a in the waters ranged from 0.50 to 19 mg/m^3, with a mean concentration five times that observed in the southern rivers. It is evident that nutrient materials are quickly taken up by the resident biomass in the pond.

The previous urban runoff study (Zolan et al, 1978) showed the nitrite-nitrogen comprises a very small portion of the combined nitrate plus nitrite fraction of nitrogen in runoff waters. For this reason nitrite was not measured separately. The water quality in Perez Acres characterizes the quality that would be expected in a tropical euthropic pond habitat. The previous urban runoff study (Zolan, et al. 1978) revealed similar water quality (during 1976-1977). The fish, <u>Gambusia affinis affinis</u>, and the toad, <u>Bufo marinus</u>, were still abundant in the pond.

Exceptional traits of the water quality in the Perez Acres ponding basin included a mean pH of 8.5, which would favor alkalophilous or pH-indifferent diatoms. High dissolved oxygen concentrations (ranging up to 17.2 mg/ℓ) frequently were above saturation levels (Tables A-1 through A-4) during the day. At an early morning (0830) sampling, the dissolved oxygen concentration was 0.9 mg/ℓ, indicating that it probably fell to very low concentrations at night due to the euthrophic nature of the pond. BOD_5 concentrations were low (0.1 to 4.9 mg/ℓ) for a site receiving urban runoff. Silica-silicon concentrations were only 5 per cent of those observed in the southern rivers. Fecal coliform concentrations had a narrow range (10 to 950 col./100 mℓ sample). Perez Acres can best be described as an alkaline pond with only a slight to moderate level of pollutants.

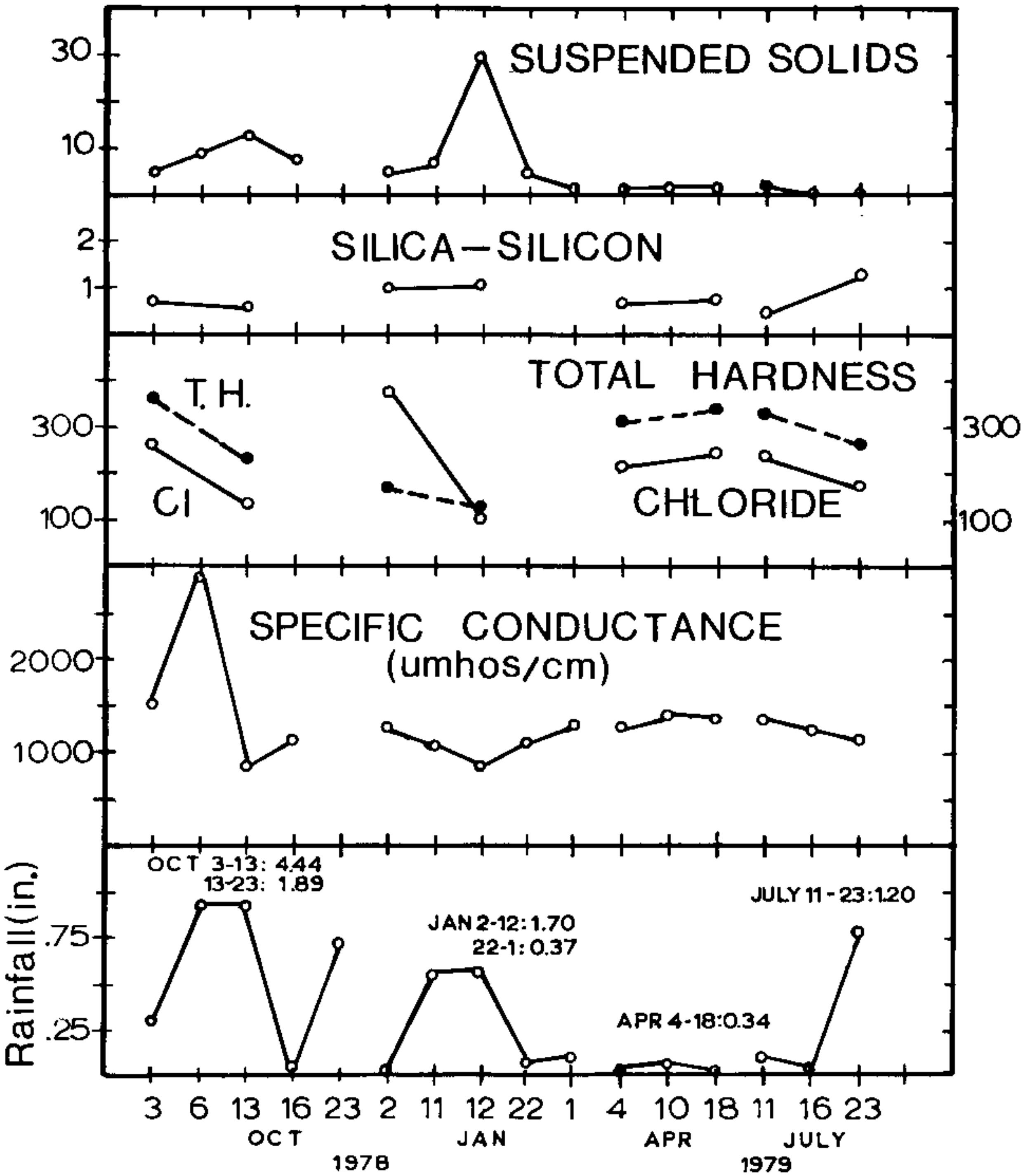

Figure 7. Selected water quality parameters compared to rainfall activity (48 hour total previous to sampling date) for the Sereno Avenue Sampling Station. Rainfall totals for the entire sampling period are presented above each rainfall curve. All parameter units are in miligrams per liter except as noted.

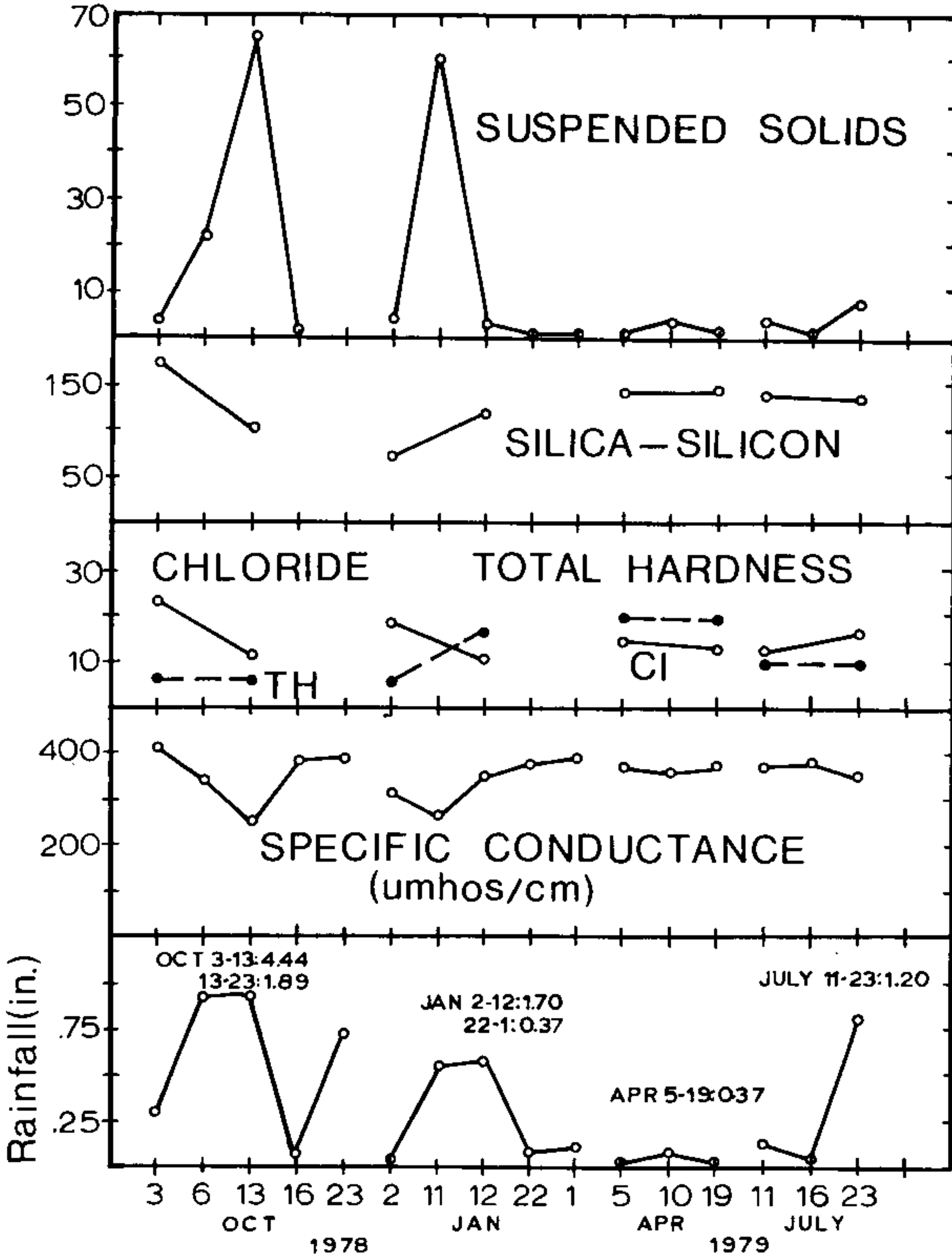

Figure 8. Selected water quality parameters compared to rainfall activity (48 hour totals previous to sampling date) for the La Sa Fua River. Rainfall totals for the entire sampling period are presented above each rainfall curve. All parameter units are milligrams per liter except were noted.

Chalan Passajeros

The water in the Chalan Passajeros drainage basin was extremely high in orthophosphate-phosphorus (PO_4-P). Concentrations ranged from 0.467 to 9.87 mg/ℓ PO_4-P. Conversely, nitrite plus nitrate-nitrogen concentrations were low with five of nine analyses having concentrations of 0.015 mg/ℓ or below (Table 2, A-1 through A-4). Large blooms of blue-green algae (including Oscillatoria, Anabaena, and Spirulina spp.) lined all submerged surfaces periodically in the basin. Another feature of the Chalan Passajeros drainage basin waters was elevated temperatures due to the shallowness of the ditch (<1m) and the cement lining which radiated heat derived from sunlight to overlying water. Temperatures ranged from 25.1°C to 34.6°C with a mean temperature of 30.4°C. This combination of high temperature and excessive phosphorus concentrations was probably the main cause of the periodic dominance of blue-green algae in the basin. The basin waters were very variable in quality because the basin volume is small (approximately 1000 m^3 at the sampling site) and susceptible to rapid influence from rainfall activity. Chlorphyll a ranged from <.01 to 108 mg/m^3. The mean chlorophyll a concentration was 18 mg/m^3. Concentrations of BOD (ranging from 20 to 168 mg/ℓ), oil and grease (ranging from 2.9 to 36 mg/ℓ), fecal coliform bacteria (ranging from 0 to >450,000 col./100 mℓ sample), and TKN (ranging from 0.26 to 0.80 mg/ℓ) indicate that there was a significant amount of organic material present in the waters.

Chalan Passajeros basin waters were also extremely high in turbidity (ranging from 3.9 to 120 NTU) and suspended solids (ranging from 4.6 to 96 mg/ℓ). Oxygen concentrations were generally well below saturation levels (range of 2 to 107%, with a mean of 48% saturation). Samples in January and July (Tables A-2 and A-4) revealed nearly complete oxygen depletion during midmorning hours (0900-0940). Waters were neutral in pH with a range of 6.6-7.4 pH units and a mean of 7.0. Variable chloride concentrations, (ranging from 5.9 to 40 mg/ℓ), hardness (from 34 to 105 mg/ℓ), specific conductance (from 104 to 468 μmhos/cm) indicated that rainfall flow into the channel was augmented by flow from tap water usage at the airport from plane washing. This was also shown in phosphorus concentrations which were statistically correlated (r=0.97) to increases and declines in specific conductance. The waters of the Chalan Passajeros collection site are best characterized as being a light industrial effluent (due to high phosphorus concentrations) occassionally mixed with rainfall runoff waters with a low to high pollutant load.

Sereno Avenue

The storm drainage ditch at Sereno Avenue contained waters of higher chloride and dissolved salts than any other sampling location. Chlorides ranged from 113 to 379 mg/ℓ with a mean of 223 mg/ℓ chloride. The other four stations did not exceed 40 mg/ℓ chloride. Specific conductance ranged from 860 to 2890 μmhos/cm with a mean of 1340 μmhos/cm. Specific conductance at the other four stations did not exceed 470 μmhos/cm. Total and calcium hardness ranged from 112 to 369 mg/ℓ and from 112 to 274 mg/ℓ respectively. Mean concentrations of total and calcium hardness were 273 and 219 mg/ℓ $CaCO_3$ which indicates very hard water. The mean total alkalinity of four samples analyzed was 240 mg/ℓ $CaCO_3$. The high concentration of chlorides and dissolved salts in the drainage ditch results from two causes: 1) Water constantly flows from the storm water culvert, indicating a constant input of tap water into the ditch (tap water in northern control Guam is from groundwater sources which contain some seawater contamination). 2) The ditch is nearly at sea level and receives water from several groundwater springs (likewise containing some seawater). The higher levels of chloride and other dissolved ions in the ditch would favor colonization of diatoms which are indifferent to or favor moderate chloride and dissolved salt concentrations.

Nitrite plus nitrate-nitrogen concentrations at the Sereno Avenue storm drainage ditch were much higher than at other stations. Concentrations of nitrite plus nitrate-nitrogen ranged from 0.044 to 1.30 mg/ℓ with a mean concentration of 0.696 mg/ℓ. This is more than twenty times the mean concentrations observed at the other sites. As stated previously, almost the entire amount of nitrite plus nitrate measured is nitrate. TKN concentrations ranged from 0.19 and 0.73 mg/ℓ and were three times higher than those observed in the rivers and within the same range as observed in the urban runoff sites. The high nitrate-nitrogen concentrations in the water result mainly from the groundwater sources (Guam well waters vary from 1 to 5 mg/ℓ NO_3-N). Mean phosphorus concentrations were 0.104 mg/ℓ and 0.156 mg/ℓ for mean concentrations of PO_4-P and TP respectively. These mean phosphorus concentrations in the Sereno Avenue basin exceeded by three times the river water phosphorus concentrations.

BOD_5 concentrations ranged from 0.6 to 27 mg/ℓ. Oil and grease was lower than expected with a range of 1.1 to 3.5 mg/ℓ. Dissolved oxygen concentrations showed some evidence of greater oxygen demand than can be met by the system with concentrations ranging from 0.6 to 6.4 mg/ℓ and a mean of 3.8 mg/ℓ DO. These concentrations of DO ranged from 8 to 83 percent saturation. Chlorophyll a concentrations were higher than those seen in the southern rivers but less than the other two northern study sites (Table 2). Concentrations of chlorophyll a ranged from 0.9 to 6.5 mg/m^3 with a mean of 2.6 mg/m^3 chlorophyll a. This concentration was lower than expected since the banks of the storm drainage basin and the waters contained large quantities of Hydrilla verticillata (in patches). Because the ditch constantly flows, an extensive phytoplankton bloom cannot develop here as in Chalan Passajeros. The fact that waters are constantly flowing makes the basin flow dynamics more similar to the river study sites. However, because of higher nutrient and BOD concentrations at the Sereno Avenue drainage basin one would expect to find the dominant diatoms to be those that favor polluted conditions.

La Sa Fua and Geus Rivers

Because the water quality of the two southern rivers investigated is so similar, the results from the water analyses will be presented together. Both rivers had slightly alkaline pH (mean pH of 7.9 and 7.6 for the La Sa Fua and Geus Rivers respectively). In this regard, the rivers differed from Perez Acres (which had more alkaline waters) and the Sereno Avenue storm drainage ditch (which had a mean pH of 7.0 with a range of 6.6 to 7.4). The rivers tended to be 1 to 3 degrees (°C) cooler than any other station with mean temperatures of 27.8 and 27.1°C for the La Sa Fua and Geus Rivers, respectively.

Despite the fact that the waters sampled were pooled waters, they still showed supersaturation with DO concentrations ranging from 5.2 to 10.9 mg/ℓ. La Sa Fua River waters averaged 107% saturation while Geus River waters averaged 94% saturation. The stations had DO concentrations in excess of 60% saturation regardless of the time of sampling.

Chloride levels were low (range of 10 to 26 mg/ℓ) for both river sites and their mean concentrations did not differ much from the mean Perez Acres or Chalan Passajeros chloride concentrations (Table 2). Hardness concentrations were higher (range of 63 to 170 mg/ℓ) for both rivers indicating that the spring source for the water contains little chloride though it does contribute calcium. The main spring sources for the La Sa Fua and Geus Rivers are located at approximately 200m and 50m above mean lower, low water (sea level), respectively. Calcium hardness ranged from 48 to 112 mg/ℓ in the rivers. Specific conductance ranged from 190 to 410 μmhos/cm, again, fairly similar to stations at Perez Acres (which was lower) and Chalan Passajeros (slightly lower).

The only major difference in water quality between the river stations was in regard to turbidity and suspended solids. The La Sa Fua River was much more turbid and carried a higher suspended solid load after periods rainfall than the Geus River (Table 2). High turbidities in the rivers (up to 40 NTU) must be considered a natural occurrence whenever it rains more than 0.5 inches within a 12-hour period (Figure 8). The fact that savannah and not rain forest comprises much of the watershed above the sampling station on the La Sa Fua River may explain why this river had the higher turbidities after rainfall. Also, some erosion of the southwest side of the La Sa Fua water shed took place when the water pipe was laid to pump water from the PUAG dam below Route 2. Erosion crevices half a meter deep occur along the pipeline. This eroded area may also explain some of the increased turbidity and suspended solids in the La Sa Fua. During non-rainfall periods, turbidity in the two rivers is undistinguishable. Dry weather turbidity ranges from 0.5 NTU to 1.5 NTU (the range of both rivers for April, 1979). Because of the shallowness of the rivers (averaging <1m), any reduction in diatom photosynthesis due to turbidity should be minimal. The increased turbidities after rainfall persisted only a short time after rain stopped. Turbidities in the rivers for January 11, 1979 were 22 and 18 NTU following rainfall activity recorded at Fleet Weather Central. The next day turbidities fell to 2.2 and 3.1 NTU after cessation of rainfall in the area.

Nitrite plus nitrate-nitrogen concentratons were very low in the rivers (0.002 to 0.082 mg/ℓ in the La Sa Fua; 0.005 to 0.054 mg/ℓ in the Geus River). Mean concentrations of NO_2 plus NO_3-N were 0.020 and 0.027 mg/ℓ in the La Sa Fua and Geus Rivers, respectively. This is below the PO_4-P concentrations found in the rivers. PO_4-P concentration ranged from 0.021 to 0.044 mg/ℓ and from 0.015 to 0.055 mg/ℓ in the La Sa Fua and Geus Rivers. The mean PO_4-P concentration was 0.033 mg/ℓ for both rivers. This is three times higher than observed at Perez Acres. If either the concentration of nitrate or phosphate serve as limiting factors for the flora of the rivers, nitrate concentration is the probable limiting one since it fluctuates to very low concentrations (0.010 mg/ℓ) whereas the phosphate concentrations remain fairly constant (Table A-1 through A-4). Total phosphorus (TP) concentrations were about 50 percent higher than PO_4-P concentrations indicating that a considerable fraction of organically bound phosphorus exists. In the euthrophic Perez Acres pond, the non orthophosphorus component comprises over 70 percent of the total phosphorus. At Chalan Passajeros and Sereno Avenue where waters are flowing (sporatically at Chalan Passajeros), the phosphorus concentrations are comprised of mainly PO_4-P with the non-PO_4-P component, including organically bound phosphorus, comprising less than 35 percent. TKN concentrations in the rivers was very low (0.04 to 0.22 mg/ℓ TKN). The rivers were clearly unique in comparison to the urban runoff sites where TKN concentrations ranged from a low of 0.15 mg/ℓ at Perez Acres to a high of 0.80 mg/ℓ at the Sereno Avenue storm drainage ditch (Table 2).

Another parameter which clearly separates river water from urban runoff and groundwater strictly from limestone substrata is silica-silicon content. Whereas silica-silicon concentrations in urbanized area surface waters ranged from a low .061 mg/ℓ at Perez Acres to be high of 1.60 mg/ℓ at Sereno Avenue, silica-silicon concentrations did not fall below 5.89 mg/ℓ in the rivers. Mean silica-silicon concentrations in the rivers was 11.4 and 12.0 mg/ℓ for the La Sa Fua and Geus Rivers, respectively (Table 2). Concentrations of silica ranged as high as 21.2 mg/ℓ SiO_2-Si. This high silica concentration may serve to favor those diatom species which flourish or require high SiO_2 concentrations. Whether there are diatoms which favor habitats only on the basis of high silica content is not known. However, species of Rhopalodia and Gomphonema genera, which were more abundant in the rivers, are large diatoms with heavily silicified frustules.

BOD_5 concentrations were very low in the rivers with mean concentrations of 1.1 and 1.0 mg/ℓ for the La Sa Fua and Geus Rivers, respectively. This is approximately a third of the Perez Acres site concentrations, which was the least polluted of the urban runoff sites. Total bacteria counts fluctuated from <0.1 to 1.8 million per 100 mℓ sample. Total bacteria concentrations fluctuated at all stations (Tables A-1 through A-4) to the extent that their significance is uninterpretable. Fecal coliform counts indicated that the rivers do receive some fecal contamination (probably as the result of deer). Counts at the river stations ranged from 0 to >400 per 100 mℓ sample. Chalan Passajeros and Sereno Avenue study sites showed considerably more contamination (Table 2). The high counts seen at the Sereno Avenue station (up to 19,000 per 100 mℓ) may have resulted form the small sewer pipe (4 to 6 inches diameter) which periodically discharges into the drainage ditch. As stated previously, a sewer-like smell occurred at the site on some occassions.

Chlorophyll a concentrations in the La Sa Fua and Geus Rivers ranged from 0.01 to 3.70 mg/m^3 with mean concentrations of 1.41 and 1.96 mg/m^3 for the La Sa Fua and Geus rivers, respectively. This range is much narrower than those seen in the northern storm drainage basins (Table 2). The Sereno Avenue study site (with a chlorophyll a concentration range of 0.87 to 6.50 mg/m^3) is more comparable to the rivers in that waters there are continuously flowing. Because of very high carotenoid pigment concentrations on one particular sampling date (Oct. 13, 1978) the mean carotenoid concentrations for the rivers exceeded that for the Sereno Avenue station. If this day is not included, the rivers generally have lower carotenoid concentrations than the Sereno Avenue station.

Four sets of manganese samples were run (one sample per quarter) for each station. Manganese did not appear to be a major contaminant in any study site with the exception of Chalan Passajeros (up to .174 mg/ℓ). Perez Acres ponded water was very low in manganese (mean of four samples .008 mg/ℓ) compared to the rivers which had mean concentrations of .038 and .033 mg/ℓ manganese.

Diatom Assemblages

Perez Acres

Glass slides exposed in Perez Acres ponding basin showed less diatom growth (in terms of number of cells per unit area) than other study sites. The relatively scant diatom growth on the slides may have resulted from the lack of water movement in the pond. Densities ranged from less than 2 to 598 individuals per 10 mm^2 of slide surface (the total available surface is 1875 mm^2). At lower densities there were insufficient diatoms per slide to count 750 individuals from one slide. Other slides from the same collection were then counted until an accumulative total of 750 individuals was obtained. However, the October and July 1979 samples still had fewer than 750 individuals present combining the four exposure slides.

Tables 3 and 4 list the 18 diatom species observed in the Perez Acres and other samples. The most abundant species belonged to the genera Gomphonema: Gomphonema parvulum, (Plate, figure 20), G. intricatum and G. affine (Plate, fig 19). G. parvulum was the dominant diatom in the April sample (86 per cent of the total) and comprised 48 to 50 percent of the remaining three samples. Other species comprising the diatom assemblage in Perez Acres are Nitzschia palea (Plate, figure 9), an occassional dominant, Nitzschia amphibia, (Plate, figure 10) Cocconeis placentula (Plate, figure 4) and Achnanthes montana. The remaining species individually did not exceed 1 percent of the total counted in any sample. Rhopalodia gibba (Plate, figure 22) and Amphora coffeaeformis (Plate, fig. 8) which are common in the rivers were also observed in digested plant material taken from the Perez Acres ponding basin. However, they were not observed on the slides. Whereas all 18 diatom species were recovered from one sample of plant material (January), no slide had more than 6 species. This probably resulted from the fact that the plant material was exposed a longer period of time and was exposed to other plant surfaces which increased likelihood of colonization. Plant surfaces also provide a variable settlement surface, which would allow diatoms favoring different surfaces to colonize them more readily.

Perez Acres ponding basin appears by observation to be eutrophic but contains low concentrations of dissolved inorganic phosphorus and nitrogen (PO_4-P and NO_3-N) in the waters. Whereas PO_4-P and NO_3-N concentrations in Perez Acres pond are below those observed in the natural waters of southern rivers, TKN concentrations were two to three times higher in the Perez Acres pond than in the rivers. Gomphonema parvulum is known (Lowe, 1974) to be a facultative heterotroph (utilizing unmineralized nutrients such as ammonia or even amino acids when the mineralized form is unavailable). Gomphonema parvulum may then be favored in this environment because the mineralized nutrient concentration (NO_3-N, PO_4-P) is low and retention time is short.

Table 3. Species of diatoms which colonized glass slides during the study at each sampling site. Sample designations 1, 2, 3, and 4 denote quarterly samples collected October 1978, January 1979, April 1979, and July 1979 respectively.

	Perez Acres				Chalan Passajeros				Sereno Avenue				La Sa Fua River				Geus River			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Achnanthes affinis Grun.									√		√									
A. exigua Grun.									√	√	√		√	√	√	√	√	√		
A. lanceolata (Breb.) Grun.						√											√	√	√	√
A. montana Krasske		√	√	√		√							√	√	√	√			√	
Amphora coffeaeformis Ag.													√	√	√		√	√	√	
Cocconeis placentula Ehr.													√	√	√	√			√	√
C. scutellum Ehr.															√					
Cocconeis sp. 1										√										
Cyclotella meneghiniana Kutz.						√				√	√	√					√			
Cymbella augustata (Wm. Sm.) Cl.		√																		
Cymbella turgidula Grun.													√							
Epithemia argus (Ehr.) Kutz.															√					
Gomphonema clevei Fricke						√	√	√					√	√	√	√	√	√	√	√
G. intricatum var. *vibrio* (Ehr.)Cl	√	√	√													√				
G. affine (Kutz.)		√	√	√																
G. parvulum (Kutz.) Grun.	√	√	√	√		√					√		√		√	√			√	
Navicula cryptocephala Kutz.									√	√	√	√	√			√				
N. cusipidata (Kutz.) Kutz.				√									√							
N. gregaria Donk.									√	√	√	√								
N. pupula Kutz.														√						
N. pygamea Kutz.									√	√	√	√								

Table 3. Continued.

	Perez Acres				Chalan Passajeros				Sereno Avenue				La Sa Fua River				Geus River			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Nitzschia amphibia Grun.		√	√			√		√			√		√							
N. frustulum (Kutz.) Grun.						√			√	√	√	√								
N. gandersheimiensis Krasske													√	√		√				
N. palea (Kutz.) Wm. Sm.		√	√	√	√	√	√	√	√	√	√	√	√		√	√				
N. sigmoidea (Nitzsch.) Wm. Sm.									√		√									
Rhopalodia gibba var. *ventricosa* (Kutz.) Müller						√							√	√	√	√		√		
R. gibberula (Ehr.) Müller						√			√				√	√	√	√				
Synedra ulna var. danica (Kutz.) V.H.											√		√	√					√	
Thalassiosira fluviatilis Hust.													√					√		

Table 4. Species of diatoms which were found attached to plants, rocks, or bottom sediments at the sampling sites. Substrata from the Geus River were not analyzed. The letters P, R, and S denote the epiphytic, epilithic and epipelic habitats respectively. Those diatoms that commonly appeared in all habitats equally (indifferent to substratum) are indicated by the letter I. Unclassified diatoms were too low in numbers to classify.

	Perez Acres				Chalan Passajeros				Sereno Avenue				La Sa Fua River				Predominant habitat*
Quarter ⟶	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Achnanthes affinis Grun.										X	X	X		X			
A. exiqua Grun.						X		X		X	X	X		X			P, I
A. lanceolata (Breb.) Grun.										X			X	X			I
A. linearis Wm. Sm.						X		X		X							
A. montana Krasske		X			X			X		X		X	X	X			P
A. hauckiana Grun.					X	X											
Achnanthes sp. 1									X								
Amphora coffeaeformis Ag.		X				X		X				X	X	X			I
A. ovalis (Kutz.) Kutz.														X			
A. submontana Hust.						X		X		X		X	X				R
Caloneis ventricosa (Ehr.) Meist						X						X	X				
Cocconeis placentula var. *lineata* (Ehr) VH.		X				X		X					X				P
Cocconeis sp. 1									X		X	X					
Cyclotella meneghiniana Kutz.										X	X	X					I
Cymbella augustata (Wm. Sm.) Cl.		X															
Cymbella turgidula Grun.								X				X	X	X			
Diploneis puella (Schum.) Cl.						X											
Epithemia argus (Ehr.) Kutz.		X												X			
Gomphonema clevei Fricke					X	X		X					X	X			P
G. intricatum var. vibrio (Ehr.) Cl.		X							X								
G. affine (Kutz.)		X									X	X	X	X			P
G. parvulum (Kutz.) Grun.		X				X		X			X	X	X	X			P

Table 4. Continued.

	Perez Acres				Chalan Passajeros				Sereno Avenue				La Sa Fua River				Predominant habitat*
Quarter →	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Hantzschia amphioxys (Ehr.) Grun.		X				X		X				X					I
Mastogloia sp. 1													X				
Navicula cincta (Ehr.) Ralfs												X					
N. consor A. S.								X									
N. cryptocephala Kutz.					X	X		X		X	X	X	X	X			S, R
N. cusipidata (Kutz.) Kutz.		X				X		X		X		X					S, R
N. pupula Kutz.													X				
N. pygamea Kutz.		X						X		X	X	X	X				
N. secura Patr.						X											
N. viridula (Kutz.) Kutz.						X											
Navicula sp. 1		X						X				X		X			
Navicula sp. 2												X					
Nitzschia amphibia Grun.		X						X				X					P, S
N. clausii Hantz.													X	X			
N. fonticola (Grun.) Grun.						X		X		X		X	X				
N. frustulum (Kutz.) Grun.					X	X				X	X	X					
N. gandersheimiensis Krasske								X									
N. linearis (Ag. ex Wm. Sm.) Wm. Sm.		X											X	X			
N. palea (Kutz.) Wm. Sm.		X			X	X	X	X	X	X	X	X	X	X			P, S
N. sigmoidea (Nitzsch.) Wm. Sm.												X					
Nitzschia sp. 1									X					X			
Pinnularia braunii (Grun.) Cl.									X								
Rhopalodia gibba var. ventricosa (Kutz.) Müller		X			X			X		X		X	X	X			P
R. gibberula (Ehr.) Müller						X	X	X		X		X	X	X			P
Stephanodiscus sp. 1					X	X		X				X					
Synedra ulna var. danica (Kutz.) V.H.		X						X		X		X	X	X			P
Thalassiosira fluviatilis Hust.		X						X		X	X	X	X				S
Triceracium sp. 1														X			

However, the high plant biomass in the pond may serve as a source of nitrogenous compounds from both plant decomposition and metabolism. G. parvulum is also known to be indifferent to calcium concentration (Lowe, 1974) and to be adaptive to a variety of aquatic conditions.

Species diversity indices (Table 5) on the two quarterly samples which had sufficient diatoms for counting had H values of 0.76 (January 1979) and 0.157 (April 1979). The Simpson Index (D) was .72 and .60 for the same samples respectively. The difference between these two months, particularly April, and the other months was increased chlorophyll a standing crop, higher dissolved oxygen concentrations and a rise in nitrate-nitrogen concentration. In Perez Acres ponding basin, the background nutrient level of nitrate-nitrogen in the water may be below that which is required for normal diatom growth. No other periphyton flora (such as blue green and green algae) colonized the exposed slide surfaces to any major extent.

Chalan Passajeros

The Chalan Passajeros drainage basin contains waters of extremely high phosphorus concentrations (up to 9.87 mg/ℓ PO_4-P). It also contains oil and grease (2.9 to 35.0 mg/ℓ). Diatom populations were found in the October and January sample collections but were absent in the April and July samples, when the entire slide surface was enveloped by a sheet blue-green algae (a mixture of Oscillatoria, Anabaena, and Spirulina spp.). Not only the slides but all available surface areas, including soft sediments and submerged plants, were covered by the blue-green algae. Those samples (October and January) which contained diatoms were dominated by Nitzschia palea. In October, all specimens counted were Nitzschia palea. In January, eleven species were present in the sample (781 individuals), of which 714 were Nitzschia palea. The species diversity (H) was equal to 0.00 for October and 0.60 in January. Species diversity indices could not be calculated for April and July samples since there was insufficient diatom growth on the settling slides. Water quality was not appreciably different in the first two quarterly sample periods. Only rainfall varied, with lower rainfall in last two quarters.

Nitzschia palea has been cited (Lowe, 1974) as a very good indicator of polluted waters. It is an obligate nitrogen heterotroph and is indifferent to water motion and salinity concentration. Previous work (Scheele, 1952; Bock, 1952) has cited its temperature tolerance to 30°C. Temperatures of Chalan Passajeros drainage basin waters ranged up to 34.6°C in the October quarter. The varieties of Nitzschia palea on Guam can tolerate temperatures to at least that range. Given high nutrient concentrations (particularly phosphorus), Nitzschia palea can be expected to be the dominant diatom in diatom assemblages in Guam freshwater habitats.

The waters of Chalan Passajeros drainage basin contained 11 species in the January sample, as many as 19 species in the sediment, and 18 species in plant samples. A total of 32 different species were recorded for all samples. The fact that out of 32 species only one slide sample showed more than three species reveals that few are able to compete with N. Palea or blue-green algae in slide colonization under conditions similar to those observed during the sample period. The additional species located on the natural substrate samples could have been dead frustules from earlier more

Table 5. Species diversity of analyzed samples. The Shannon-Wiener index (H) and the Simpsion index (D) are listed for both glass slide samples and natural substrata.

	Sample Month								Total Species*	Total Species**	Mean Number of Species per Glass Slide (per 750 counts)	Dominant Species***
	October		January		April		July					
	H	D	H	D	H	D	H	D				
Perez Acres (glass slides)	TFTA[1]	TFTA	0.76	.02	1.47	.60	TFTA	TFTA	8	18	5	*Gomphonema parvu*
plant material			2.36	.72								(38-86)
C. Passajeros (g.s.)	0.00	.00	0.60	.16	TFTA	TFTA	TFTA	TFTA	10	33	4	*Nitzschia palea*
plant material			1.57	.54			0.76	.18				(33-100)
rock scrappings			0.40	.10								
sediments												
Sereno Avenue (g.s.)	0.45	.12	0.68	.19	1.13	.39	0.57	.16	13	37	8	*Nitzschia palea*[2]
plant material	1.21	.40	1.13	.32	1.25	.42	2.62	.67				(76-94)
rock scrappings			1.52	.56	1.46	.57	2.38	.72				
sediments			1.36	.46	2.20	.55	2.72	.68				
La Sa Fua River (g.s.)	1.99	.63	0.52	.13	1.68	.60	2.23	.75	20	32	11	*Gomphonema cleve*
plant material	2.83	.80										(36-93)
rock scrappings			1.67	.42								
Geus River (g.s.)	0.31	.09	0.20	.04	0.68	.81	1.04	.50	11	—	5	*Gomphonema cleve* (62-98)

[1]TFTA - Too few to analyze. < 750 counted.
[2]*Nitzschia palea* dominated all substrata collections in the Sereno Avenue substrate samples.
*glass slides only.
**glass slides-natural surfaces combined.
***range in percent of sample - glass slides only.

favorable periods of diatom colonization. Since water quality fluctuates considerably and is dependent upon rainfall and tap water usage on the flight apron areas, water quality conditions affecting development of diatom assemblages fluctuate as well. Regular, moderate, rainfall flushes out pollutants from the basin and creates a more favorable diatom environment. This may explain why diatom development was most favorable during the October and January quarter samples when rainfall was greater.

Sereno Avenue

Additional natural surface samples were analyzed from this station to see how variable the natural surface species diversity was and to determine how the natural substrata samples compared to those of the glass slides. Results of this comparison must take into account that no time limitation was imposed on the natural substrata so a larger species number and diversity would be expected on those substrata. A dye staining test of glass slide collections to see how many diatoms were alive at collection time was also performed according to Owen et al. (1979). This test showed that at least 90 percent of the sample was composed of living diatoms, seven percent were either live or dead, and three percent were definitely dead (empty frustules).

All four quarterly field samples were dominated by Nitzschia palea, which also was the predominant diatom observed in Chalan Passajeros. Diatom densities were higher at this station than in any other station except the July sample of the Geus River. Mean diatom densities were 330 individuals per mm^2 in October, 2,600 individuals per mm^2 in January, 4575 individuals per mm^2 in April, and 240 individuals per mm^2 in July. Diatom species diversity was low compared to the rivers. Shannon-Wiener diversity values fluctuated from 0.45 in October to 0.68 in January to 1.13 in April 1979 and back down to 0.57 in July. The April recording of highest species diversity coincides with the highest diatom density. Water quality factors which were below mean concentrations during April were BOD_5 and NO_3-N. Suspended solids, turbidity, TKN, and chlorophyll a concentrations were higher. The mean BOD_5 of the Sereno Avenue station was 6.1 mg/ℓ. April samples had BOD_5's of 2.3 and 0.6 mg/ℓ. Mean turbidity for Sereno Avenue was 7.0 NTU. April readings were 2.8, 1.8, and 1.2, NTU. Chlorophyll a concentrations of 6.5 and 3.0 mg/m^3 were above the mean concentration of 2.6 mg/m^3. Dissolved oxygen concentrations were 5.6 and 5.7 mg/ℓ which corresponded to 83 percent saturation compared to the mean DO saturation level of 50 percent. Other water quality parameters did not vary much from other months.

The fall in species diversity to 0.57 in July was accompanied by a rise in BOD (8.9 and 4.1 mg/ℓ) and falling dissolved oxygen concentrations (0.6, 0.8 and 2.4 mg/ℓ). Turbidity rose slightly from April readings to 2.2, 2.3, and 5.2 NTU.

Overall, 37 species were observed in the Sereno Avenue samples, compared to 32 seen at Chalan Passajeros. Nitzschia palea dominated all samples including samples collected from natural substrata. Other common diatom species included Thalassiosira fluviatilis (plate, figure 12), Achnanthes exiqua (plate, figure 2), which was common in rock surface scrapings, Navicula pygamea (plate, figure 6), Gomphonema parvulum and Nitzschia amphibia.

N. amphibia and G. parvulum are facultative nitrogen heterotrophs. The habitat and nutrient preferences of some of the remaining observed species have been described (Patrick (1966). Achnanthes exiqua is described as an alkaliphil, tolerant of wide temperature fluctuations (not specified) and euryphotic. Navicula pygamea is reported to favor waters of high mineral content (including brackish) and polluted waters (Patrick, 1966). Thalassiosira fluviatilis is reported (Lowe, 1974) to be mesohalobous (to tolerate moderate dissolved salt concentrations of 500 to 3000 mg/ℓ). The water conditions observed at the Sereno Avenue site are in the range listed for favoring the diatoms observed.

La Sa Fua and Geus Rivers

Diatom collections from the La Sa Fua and Geus River were very similar (Tables 3 and 4). The similarity index computed of combined samples collected showed a .892 degree of similarity between the La Sa Fua and Geus River samples (Table 6). Comparison of the combined La Sa Fua samples with the three sites receiving urban runoff gave similarity indices of .027, .010 and .008 for La Sa Fua-Perez Acres, La Sa Fua-Chalan Passajeros, and La Sa Fua-Sereno Avenue comparisons, respectively. The comparisons of the Geus River species assemblages with those of urban runoff sites yield similarity index values of .008, .004 and <.001 for Geus-Perez Acres, Geus-Chalan Passajeros, and Geus-Sereno Avenue, respectively (Table 6). Intra-site similarity between months showed Geus and La Sa Fua samples to be very consistent (Table 7).

The diatoms from the La Sa Fua River consistently exhibited greater species number per sample (8 to 15) and greater species diversity (H of 0.52-2.23) than any other sire. H ranged from 0.20 to 1.0 in the Geus River. The Simpson Index ranged from .13 to .75 for the La Sa Fua River and from only .09 to .50 for the Geus River. At the two river stations a total of 33 species was observed. Mean diatom density per sample ranged from 4 to 65 frustules per mm^2. These densities are not nearly as high as observed for the Sereno Avenue samples. A check of water quality parameters comparing January (the lowest species diversity) with July (the highest species diversity) did not indicate any parameter exceptionally high or low in concentration. Only pH differed between the two months with a pH of 8.10 in July versus the 7.05 to 7.35 range recorded for January.

Gomphonema clevei (plate, figure 21) was the most abundant diatom in all La Sa Fua samples, comprising 56, 93, 56 and 46 percent of the diatoms collected in October, January, April and July, respectively. At the Geus River, G. clevei comprised 95, 98, 90, and 61 percent for the same months, respectively. The extreme dominance of G. clevei in the Geus samples, resulted in the lower species diversity there. Hustedt (1938) classified G. clevei as favoring low chloride concentrations and alkaline waters. Patrick (1975) describes it as a rheophile.

Other diatoms that were common in both rivers included Amphora coffeaeformis, Achnanthes exiqua, Achnanthes lanceolata (plate, figure 16), Cocconeis placentula and Synedra ulna (plate, figure 23). Occasionally, Rhopalodia gibberula (plate, figure 16), Gomphonema parvulum and Cyclotella meneghiniana (plate, figure 27) may be present in numbers exceeding one per-

Table 6. Similarity of diatom samples using the SIMI index (Stander, 1970). N. D. refers to not determined due to absense or of insufficient numbers of diatoms on collection slides. Range of index is from 0 to 1; with 1 equal to complete similarity, 0 to complete dissimilarity.

	Chalan Passajeros	Sereno Avenue	La Sa Fua River	Geus River
Perez Acres				
October 78	N. D.	N. D.	N. D.	N. D.
January 79	.018 (4/13)[1]	.003 (1/12)	<.001 (1/14)	<.001 (0/11)
April 79	N. D.	.620 (3/14)	.054 (3/13)	.017 (2/12)
July 79	N. D.	N. D.	N. D.	N. D.
Average	.018	.312	.027	.008
Chalan Passajeros				
October 78	---	.999 (1/7)	.011 (1/15)	.000 (0/6)
January 79	---	.996 (2/16)	.008 (4/15)	.007 (2/14)
April 79	---	N. D.	N. D.	N. D.
July 79	---	N. D.	N. D.	N. D.
Average		.998	.010	.004
Sereno Avenue				
October 78		---	.011 (1/15)	<.001 (1/11)
January 79		---	.000 (0/15)	<.001 (1/13)
April 79		---	.014 (3/18)	<.001 (2/16)
July 79[2]		---	.005 (1/16)	.000 (0/8)
Average			.008	.000
La Sa Fua River				
October 78			---	.917 (3/14)
January 79			---	.999 (1/12)
April 79			---	.890 (6/12)
July 79			---	.762 (2/13)
Average				.892

[1]The numbers in parenthesis indicate the number of shared species and the total number of species in the two samples being compared.

[2]Only 144 individuals included in July sample count for Sereno Avenue.

Table 7. Similarity of diatom samples within stations according to the SIMI index. Samples are compared to the composite of the four sampling periods. N. D. refers to those samples which lacked sufficient diatoms to analyze.

	October 1978	January 1979	April 1979	July 1979
Perez Acres[1]	N.D.	/———	——>.758	N.D.
Chalan Passajeros[2]	/———	——> .998	N.D.	N.D.
Sereno Avenue	.998	.999	.986	.998[3]
La Sa Fua River	.966	.956	.953	.880
Geus River	.994	.994	.994	.907

[1]January sample is compared to April.

[2]October sample is compared to January.

[3]Only 144 individuals, instead of 750, where present in the July Sereno Avenue sample.

cent of the population. Table 3 shows the presence of the various species in each quarterly sample.

Lowe (1974) identifies Amphora coffeaeformis as being alkaliphilous and mesohalobous. Only one reference, Fjeringstad (1950) cites which nutrient concentrations A coffeaeformis favors (moderate nutrient levels). Patrick (1966) states that it is only found in habitats with rather high conductivity. Achnanthes lanceolata is listed by Lowe (1974) to be alkaliphilous and indifferent to salt concentrations. Lowe's catalogue also lists A. lancaolata as favoring stream habitats with low nutrient concentrations. Cocconeis placentula favors the same habitat conditions except that it is indifferent to current flow and tolerates a wider range of nutrient concentrations (unpolluted to moderate nutrient concentrations). Synedra ulna is listed as being indifferent to salt concentrations, and current. It also tends to be alkaliphilous (Lowe, 1974). Rhopalodia gibba is listed as alkaliphilous, favoring eutrophic waters. The listing gives R. gibba nutrient habitat characteristics as from unpolluted to moderate nutrient concentrations. It is indifferent to dissolved salt concentrations and current. Most of these salt tolerant species were also collected from slides placed in marine waters in proximity to a river mouth (Zolan, 1980) in Guam. Habitat data on Cyclotella meneghiniana indicates it favors environments low in chlorides and alkaline waters (Lowe, 1974).

CONCLUSIONS

The number of periphytic diatom species in small rivers and streams on Guam is low in comparison to the numbers of species usually observed in rivers of the continental United States and Europe. Whereas in the Guam study species numbers did not exceed 37 for any particular site, species numbers often reach 100 to 200 species for single collections in continental rivers. Even on Guam, the shallow marine habitat possesses some 160 species of periphytic diatoms (Zolan, 1980).

This reduced species pool must be taken into account in the utilization of periphytic diatom assembledges to monitor freshwater environments on Guam. Slide collections also collected a fewer species that were found to occur in the natural substrata. Only one-third to two-thirds of the species observed on the natural substrata (e.g. plants, rocks, sediments) were observed on the slide collections. This factor also reduces the species diversity.

Despite the problem of low species numbers in the environment, and in collections on the artificial substrata, clear differences in the diatom species between the sites receiving urban runoff and the unaffected rivers were evident. The sites receiving urban runoff, had diatom assembledges dominated by Nitzschia palea, a documented indicator of polluted waters. In extreme cases, diatoms are replaced by blue-green algae. Although Nitzschia palea occurred at a river station (La Sa Fua only) it was present at less than 1% of the population. The river periphytic diatom flora was dominated by Gomphonema clevei (at both rivers). In the non-flowing waters of Perez Acres ponding basin, which had lower nutrient concentrations than even the river stations, Gomphonema parvulum was the dominant diatom present. It is reasonable to expect the same dominate species to exist at other areas where the nutrient and water flow conditions are similar to those investigated here. Table 8 summarizes the abundance pattern of the significant diatoms in the habitats studied.

Table 8. Principal diatom assembladges which occur at the habitats investigated. Diatoms are ranked according to importance (numbers and frequency of appearance).

Habitat: Pools in small rivers
(low to moderate nutrient concentration)

Gomphonema clevei Fricke - dominant
Cocconeis placentula Ehr. - occassional dominant
Amphora coffeaeformis Ag.
Achnanthes montana Krasske
Rhopalodia gibberula (Ehr.) Müller
R. gibba var. *ventricosa* (Kütz.) Müller
Cymbella cymbiformis Ag.
Synedra ulna var. *danica* (Kütz.) V. H.

Mean Shannon-Wiener Index of 1.08 ± 0.79, 8 samples

Habitat: Groundwater springs with nutrient enrichment

Nitzschia palea (Kütz.) Wm. Sm. - dominant
Navicula cryptocephala Kütz.
Thalassiosira fluviatilis Hust.
Navicula pygamea Kütz.
Cyclotella meneghiniana Kütz.
Achnanthes exigua Grun.
Rhopalodia spp.

Mean Shannon-Wiener Index of 0.71 ± 0.30, 4 samples

Habitat: Ponded waters from rainfall runoff with low mineralized nutrient concentrations and low dissolved solids

Gomphonema parvulum (Kütz.) Grun.
Gomphonema affine (Kütz.)
Nitzschia palea Kütz. Wm. Smith
Nitzschia amphibia Grun.

Mean Shannon-Wiener Index of 0.56 ± 0.71, 4 samples

The sample similarity index (Tables 6 and 7) show that diatom assemblages for each particular study site, particularly the rivers and the Sereno Avenue location, are consistent over time. This gives validity to the use of indicator species or assemblages to type those waters.

Because there were differences in species diversity indies between the two river stations but only minor water quality differences, other microhabitat parameters (e.g. lighting, current, surrounding substrata) may have a large impact in species diversity as measured by those indices used. In smaller rivers and streams microhabitats form a more significant portion of the total river environment. For this reason environmental monitoring using periphytic diatoms (and/or other organisms) should utilize several control as well as experimental stations to balance the effects of unmonitored microhabitat differences. This is especially true if species diversity indices are to be used.

Water quality parameters which varied at the stations and which may have had the greatest impact on the observed changes in diatom assembledges were temperature, pH, nitrate-nitrogen, total Kjeldahl nitrogen, total phosphorus, orthophosphate-phosphorus, silica-silicon, chloride, hardness, calcium, dissolved oxygen and BOD_5.

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PLATE

1000X and Bright Field Microscopy

Figure 1. *Achnanthes hauckiana* Grun.

Figure 2. *Achnanthes exigua* Grun.

Figure 3. *Achnanthes lanceolata* var. *dubia* Grun.

Figure 4. *Cocconeis placentula* var. *lineata* (Ehr.) V.H. pseudoraphe value

Figure 5. *Cocconeis placentual* var. *lineata* raphe value

Figure 6. *Navicula pygamea* Kutz.

Figure 7. *Navicula cryptocephala* var. *veneta* (Kutz.) Rabh.

Figure 8. *Amphora coffeaeformis* (Ag.) Kutz.

Figure 9. *Nitzschia palea* (Kutz.) Wm. Smith

Figure 10. *Nitzschia amphibia* Grun.

Figure 11. *Nitzschia clausii* Hantz.

Figure 12. *Thalassiosira fluviatilis* Hust.

Figure 13. *Cymbella turgidula* Grun.

Figure 14. *Cymbella augustata* (Wm. Sm.) Cl.

Figure 15. *Diploneis puella* (Schum.) Cl.

Figure 16. *Rhopalodia gibberula* (Ehr.) D. Müll.

Figure 17. *Hantzchia amphioxys* (Ehr.) Grun.

Figure 18. *Nitzschia gandersheimiensis* Krasske

Figure 19. *Gomphonema affine* Kutz.

Figure 20. *Gomphonema parvulum* Kutz.

Figure 21. *Gomphonema clevei* Fricke

Figure 22. *Rhopalodia gibba* var. *ventricosa* (Kutz.) H.&M. Perag.

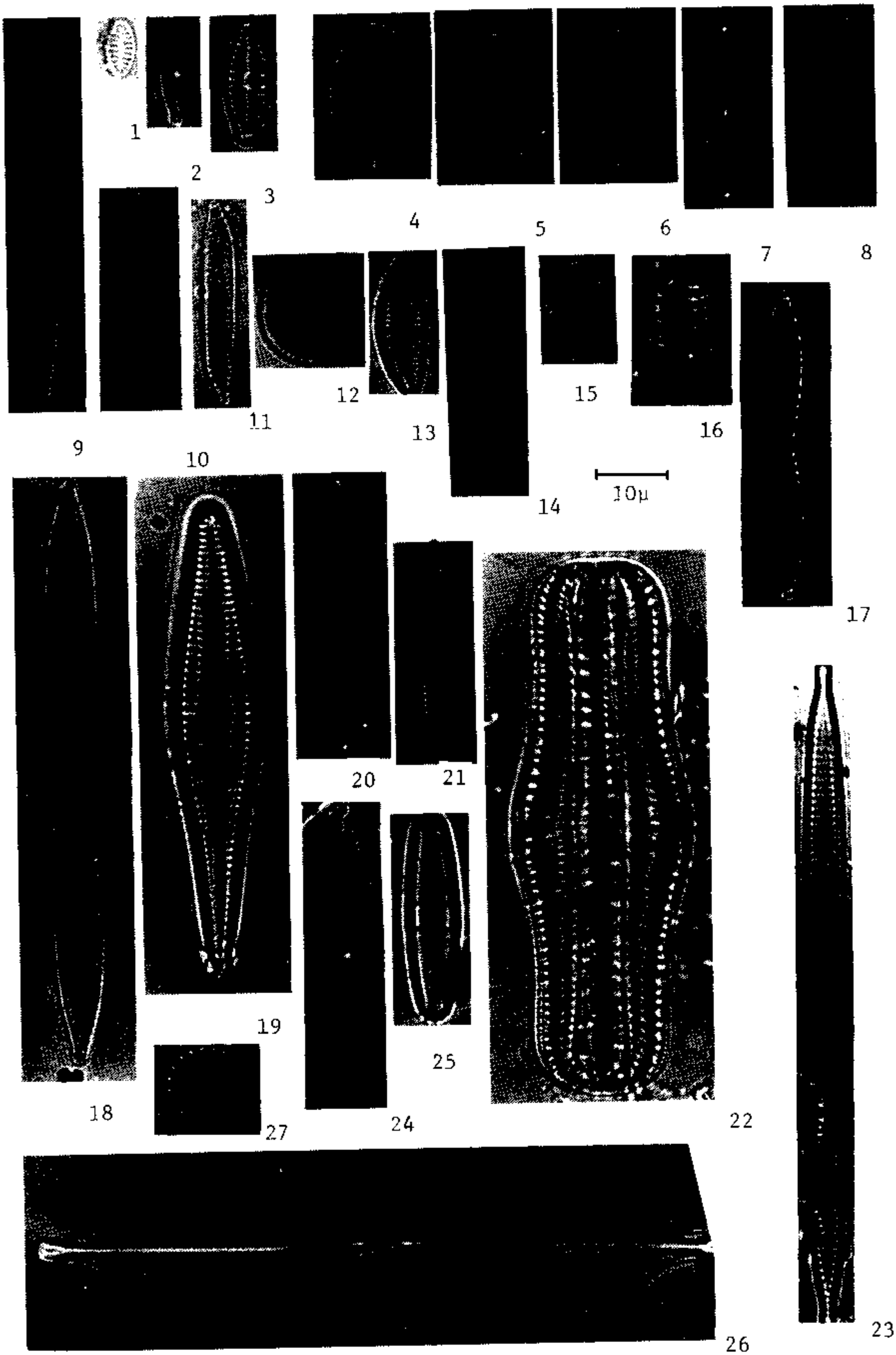
Figure 23. *Synedra ulna* var. *danica* (Kutz.) V. H.

Figure 24. *Pinnularia braunii* var. *amphicephala* (A. Mayer) Hust.

Figure 25. *Caloneis ventricosa* var. *truncatula* (Grun.) Meist

Figure 26. *Navicula cuspidata* (Kutz.) Kutz.

Figure 27. *Cyclotella meneghiniana* Kutz.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APPENDIX

List of Tables

Table A-1. Water analyses results for October 1978 at each sampling station. Sample results in parenthesis were collected October 16 and October 23.

	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
Temperature °C	10/ 3/78	28.8	31.6	30.0	28.6	28.0
	10/ 6/78	29.0	29.8	29.4	28.2	27.4
	10/13/78	30.6	34.6	29.6	27.6	26.5
Turbidity (NTU)	10/ 3/78	2.7	11	3.8	2.0	1.1
	10/ 6/78	2.8	13	7.5	12	2.2
	10/13/78	4.9*(3.5)	16(10)	18(6.9)	40(1.2,4.5)	22(1.4,1.8)
Suspended Solids (mg/ℓ)	10/ 3/78	2.8	10	5.2	3.8	2.4
	10/ 6/78	1.2	5.5	8.9	22	1.2
	10/13/78	3.3(1.2)	4.6(4.5)	13(7.8)	65(0.9)	3.1(<0.1)
pH	10/ 3/78	9.10	8.20	7.31	8.00	8.05
	10/ 6/78	8.80	8.38	7.20	7.71	7.80
	10/13/78	8.70	8.00	7.02	7.85	8.38
Specific Conductance (μmhos/cm)	10/ 3/78	92	200	1530	410	318
	10/ 6/78	93	230	2890	340	260
	10/13/78	61(250)	100(240)	860(1170)	250(380,390)	190(310,340)
Chloride (mg/ℓ)	10/ 3/78	5.6	7.9	265	22	20
	10/13/78	4.4	8.3	138	11	13
Total Hardness (mg/ℓ $CaCo_3$)	10/ 3/78	37	69	369	170	125
	10/13/78	28	34	235	102	67
Calcium Hardness (mg/ℓ $CaCo_3$)	10/ 3/78	37	62	268	112	89
	10/13/78	23	32	189	67	48
Total Alkalinity (mg/ℓ $CaCo_3$)	10/ 6/78	40	46	205	146	106

* percent saturation in parenthesis

Table A-1. Continued.

	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
Dissolved oxygen (mg/ℓ)*	10/ 3/78	4.5(59)	2.0(27)	4.8(64)	7.8(100)	8.3(105)
	10/ 6/78	5.3(68)	6.8(89)	4.2(54)	8.0(102)	7.3(90)
	10/13/78	7.9(105)	7.6(107)	4.3(56)	7.7(97)	8.0(98)
BOD_5 (mg/ℓ)	10/ 3/78	2.7	49	2.9	0.1	0.2
	10/13/78	3.5	20	3.4	0.5	0.3
TKN (mg/ℓ)	10/ 3/78	0.49	0.51	0.67	0.12	0.09
	10/13/78	0.13	0.26	0.26	0.11	0.12
Nitrate-nitrogen (mg/ℓ)	10/ 3/78	0.030	0.072	0.668	0.002	0.026
	10/13/78	0.002(0.008)	0.051(0.005)	0.887(1.30)	0.020(0.027)	0.054(0.005)
Total Phosphorus (mg/ℓ)	10/ 3/78	0.046	2.66	0.57	0.052	0.040
	10/13/78	0.051	0.991	0.74	0.062	0.050
Orthophosphate-phosphorus (mg/ℓ)	10/ 3/78	0.019	1.47	0.028	0.034	0.035
	10/13/78	0.021	0.467	0.032	0.024	0.015
Silica-Silicon (mg/ℓ)	10/ 3/78	0.101	1.58	0.722	6.18	5.89
	10/13/78	0.061	0.464	0.662	6.14	6.69
Chlorophyll a (mg/m^3)	10/ 3/78	5.41	4.46	0.94	<0.01	0.42
	10/13/78	1.86	0.89	0.88	0.80	3.72
Carotenoids (mg/m^3)	10/ 3/78	---	---	---	0.66	0.42
	10/13/78	2.24	0.96	0.96	6.72	3.70
Total Bacteria col./100mℓ	10/ 6/78	$3x10^6$	$1.61x10^6$	$26x10^6$	$1.3x10^5$	$2.6x10^5$
Fecal Coliform col./100mℓ	10/ 6/78	400	0	$1.0x10^5$	0	0
Oil and Grease (mg/ℓ)	10/ 6/78	1.6	2.9	3.5	0.0	0.0
Manganese (mg/ℓ)	10/ 6/78	0.005	0.006	0.062	0.044	0.029

* percent saturation in parenthesis

Table A-2. Water analyses results for January 1979 at each sampling station. Sample results in parenthesis were collected January 22 and February 1, 1979 respectively.

	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
Temperature (°C)	1/ 2/79	25.3	25.1	27.7	27.7	27.3
	1/11/79	28.8	32.5	31.5	20.6	25.8
	1/12/79	29.3	32.0	29.4	27.0	26.6
Turbidity (NTU)	1/ 2/79	1.0	12	1.6	0.7	0.8
	1/11/79	2.8	17	7.0	22	18
	1/12/79	1.2(1.8,1.5)	28(3.9,17)	20(23,1.8)	2.2(0.7,0.3)	3.1(1.2,0.3)
Suspended Solids (mg/ℓ)	1/ 2/79	2.8	28	5.5	4.5	2.5
	1/11/79	4.4	68	7.2	60	4.2
	1/12/79	1.8(2.0,3.0)	28(24,12)	30(5.0,1.6)	2.7(0.7,0.3)	1.5(1.2,1.0)
pH	1/ 2/79	7.19	6.87	6.70	7.35	7.25
	1/11/79	7.19	7.09	6.63	7.20	6.82
	1/12/79	7.75(8.29,9.13)	8.35(7.43,7.60)	6.80(7.27,7.37)	7.05(8.41,8.79)	6.70(8.50,8.42)
Specific Conductance (μmhos/cm)	1/ 2/79	137	470	1310	310	390
	1/11/79	93.5	110	1090	260	190
	1/12/79	220(110,210)	240(320,290)	860(1140,1320)	330(380,390)	240(320,350)
Chloride (mg/ℓ)	1/ 2/79	6.0	26	379	18	10
	1/12/79	6.8	25	113	10	17
Total Hardness (mg/ℓ $CaCo_3$)	1/ 2/79	26	48	176	72	63
	1/12/79	30	93	134	120	91
Calcium Hardness (mg/ℓ $CaCo_3$)	1/ 2/79	25	35	146	48	59
	1/12/79	---	76	112	94	74
Total Alkalinity (mg/ℓ $CaCo_3$)	1/11/79	35	49	245	112	65
Dissolved Oxygen (mg/ℓ)*	1/ 2/79	0.9(11)	0.2(2)	1.2(15)	7.9(98)	8.6(107)
	1/11/79	6.4(82)	6.8(93)	6.2(83)	7.6(94)	7.9(96)
	1/12/79	7.9(102)	2.2(30)	6.4(82)	9.0(112)	7.8(97)

Table A-2. Continued.

	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
BOD_5 (mg/ℓ)	1/ 2/79	4.3	69	4.6	2.2	2.9
	1/12/79	1.3	66	27	0.7	0.7
TKN (mg/ℓ)	1/ 2/79	0.18	0.53	0.19	0.08	0.10
	1/12/79	0.18(0.15)	0.37(0.48)	0.32(0.32)	0.10(0.04)	0.10(0.04)
Nitrate-Nitrogen (mg/ℓ)	1/ 2/79	0.003	0.006	1.01	0.015	0.014
	1/12/79	0.010	0.005	0.932	0.016	0.014
Total Phosphorus (mg/ℓ)	1/ 2/79	0.049	10.85	0.041	0.070	0.062
	1/12/79	0.045	3.39	0.320	0.066	0.061
Orthophosphate-phosphorus (mg/ℓ)	1/ 2/79	0.013	9.87	0.012	0.029	0.017
	1/12/79	0.022	2.01	0.113	0.041	0.023
Silica-silicon (mg/ℓ)	1/ 2/79	0.333	0.937	1.03	5.74	13.3
	1/12/79	0.702	0.524	1.07	16.2	7.50
Chlorophylla a (mg/m^3)	1/ 2/79	1.97	<0.10	2.03	1.45	1.74
	1/12/79	0.53	<0.10	5.35	<0.10	1.59
Carrtenoids (mg/m^3)	1/11/79	0.14	0.33	<0.10	<0.10	<0.10
		0.21	<0.10	0.24	0.10	<0.10
Total Bacteria (col./100mℓ)	1/11/79	7.0×10^5	1.0×10^7	9.0×10^5	1.8×10^6	1.0×10^6
Fecal Bacteria (col./100mℓ)	1/11/79	950	<100	<100	150	83
Oil and Grease (mg/ℓ)	1/11/79	1.6	3.5	1.9	0.0	0.0
Manganese (mg/ℓ)	1/11/79	0.003	0.174	0.014	0.014	0.011

* saturation per cent in parenthesis

Table A-3. Water analyses results for April 1979 at each sampling station.

Parameter	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
Temperature °C	4/4,5/79	27.5	29.3	29.1	26.7	27.1
	4/ 10/79	28.4	28.6	27.7	27.4	26.4
	4/18,19/79	29.8	31.7	29.8	26.0	25.8
Turbidity (NTU)	4/4,5/79	2.4	28	2.8	1.0	1.1
	4/ 10/79	1.6	22	1.8	0.8	1.2
	4/18,19/79	4.2	88	1.2	0.8	1.5
Suspended Solids (mg/ℓ)	4/4,5/79	3.2	25	1.2	0.5	0.1
	4/ 10/79	2.3	20	1.9	3.4	2.8
	4/18,19/79	11	96	2.0	0.4	1.8
pH	4/4,5/79	8.40	6.95	7.20	8.13	7.42
	4/ 10/79	8.52	7.22	7.00	8.10	7.50
	4/18,19/79	9.61	8.55	7.20	7.45	7.65
Specific Conductance (μmhos/cm)	4/4,5/79	210	340	1300	370	340
	4/ 10/79	320	290	1430	360	320
	4/18,19/79	330	460	1370	370	340
Chloride (mg/ℓ)	4/4,5/79	11	33	219	14	13
	4/18,19/79	25	40	244	12	18
Total Hardness (mg/ℓ $CaCo_3$)	4/4,5/79	48	79	316	142	128
	4/18,19/79	49	105	344	140	128
Calcium Hardness (mg/ℓ $CaCo_3$)	4/4,5/79	48	61	264	107	96
	4/18,19/79	49	72	274	108	92
Total Alkalinity (mg/ℓ $CaCo_3$)	4/ 10/79	58	79	267	179	144
Dissolved Oxygen (mg/ℓ)	4/4,5/79	---	1.2(15)	6.4(82)	8.2(102)	7.0(86)
	4/ 10/79	8.10(102)	1.5(19)	4.4(56)	8.6(107)	8.9(108)
	4/18,19/79	17.2(226)	7.3(99)	4.2(55)	8.2(101)	5.7(70)

Table A-3. Continued.

Parameter	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
BOD_5 (mg/ℓ)	4/4,5/79	2.2	42	2.3	1.7	1.4
	4/18,19/79	1.7	>168	0.6	0.4	0.9
TKN (mg/ℓ)	4/4,5/79	0.21	0.69	0.73	0.22	0.08
	4/18,19/79	0.68	0.80	0.19	0.16	0.08
Nitrate-nitrogen (mg/ℓ)	4/4,5/79	0.016	0.015	0.908	0.001	0.042
	4/18,19/79	0.070	0.050	0.447	0.082	0.049
Total Phosphorus (mg/ℓ)	4/4,5/79	0.045	6.25	0.170	0.044	0.048
	4/18,19/79	0.042	9.21	0.083	0.040	0.050
Orthophosphate-phosphorus (mg/ℓ)	4/4,5/79	0.003	5.70	0.148	0.044	0.048
	4/18,19/79	<0.001	7.02	0.083	0.039	0.047
Silica-silicon (mg/ℓ)	4/4,5/79	0.420	1.60	0.689	19.3	21.2
	4/18,19/79	0.583	3.60	0.810	18.9	21.0
Chlorophyll a (mg/m^3)	4/4,5/79	5.14	17.5	6.50	2.18	2.08
	4/18,19/79	19.2	108	3.01	2.15	2.31
Carotenoids (mg/m^3)	4/4,5/79	3.58	14.6	3.81	1.41	1.46
	4/18,19/79	7.97	65.8	1.36	1.26	1.02
Total Bacteria (col./100mℓ)	4/ 10/79	$<1.0x10^5$	$>3.8x10^6$	$2.5x10^6$	$1.7x10^6$	$<1.0x10^5$
Fecal Coliform (col./100mℓ)	4/ 10/79	200	1300	267	61	7
Oil and grease (mg/ℓ)	4/ 10/79	4.3	4.4	2.4	0.0	0.0
Manganese (mg/ℓ)	4/ 10/79	0.023	0.069	0.046	0.092	0.092

Table A-4. Water analyses results for July 1979 at each sampling station.

Parameter	Date	Perez Acres	Ch. Passajeros	Sereno Avenue	La Sa Fua River	Geus River
Temperature °C	7/11/79	30.5	29.8	27.8	30.0	27.0
	7/16/79	31.3	29.2	28.4	28.2	28.5
	7/23/79	28.0	30.9	28.8	29.4	28.8
Turbidity (NTU)	7/11/79	2.7	20	2.3	1.7	1.5
	7/16/79	3.6	120	2.2	2.1	1.3
	7/23/79	2.5	53	5.2	9.0	5.4
Suspended Solids (mg/ℓ)	7/11/79	3.1	23	2.1	3.6	1.7
	7/16/79	4.0	62	0.6	1.0	1.4
	7/23/79	1.4	28	0.5	7.6	0.3
pH	7/11/79	8.60	7.10	6.80	8.10	7.00
	7/16/79	9.12	7.20	6.90	8.10	7.72
	7/23/79	8.30	7.42	6.90	8.08	7.82
Specific Conductance (μmhos/cm)	7/11/79	140	150	1380	370	370
	7/16/79	140	310	1270	380	340
	7/23/79	120	140	1150	350	270
Chloride (mg/ℓ)	7/11/79	16	5.9	240	11	16
	7/23/79	7.9	6.0	183	16	26
Total Hardness (mg/ℓ)	7/11/79	46	53	335	139	143
	7/23/79	43	38	273	133	89
Calcium Hardness (mg/ℓ)	7/11/79	45	49	269	110	102
	7/23/79	42	33	227	91	62
Total Alkalinity (mg/ℓ $CaCo_3$)	7/16/79	72	123	244	169	132
Dissolved Oxygen (mg/ℓ)	7/11/79	8.4(112)	2.0(27)	0.6(8)	10.9(143)	5.2(64)
	7/16/79	11.7(156)	0.5(6)	0.8(11)	9.0(114)	9.0(115)
	7/23/79	5.8(73)	4.9(66)	2.4(30)	9.3(119)	7.3(94)