AGAT SEWAGE TREATMENT PLANT: IMPACT OF SECONDARY TREATED EFFLUENT ON GUAM COASTAL WATERS

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ON GUAM COASTAL WATERS

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ABSTRACT

The purpose of this study was to obtain long-term information on the impact of a secondarily treated sewage effluent on Guam coastal waters. Water samples (coliform, NO_3-N, and reactive PO_4) were analyzed from the effluent in the treatment tank as well as from the receiving marine waters. The marine biota, especially the benthic algae and zooplankton, were quantified in the vicinity of the outfall.

The results of the study of effluent in the treatment plant reveal that nutrient levels are high, with reactive phosphate varying between 170 and 400 μg-at/l ($\bar{X}$ = 260 μg-at/l) and nitrate-nitrogen ranging from 10 to 530 μg-at/l ($\bar{X}$ = 130 μg-at/l). Forty-six coliform samples from the effluent were less than 200 counts per 100 ml. Chlorine levels in the treatment tank varied between 0.2 and 4.0 ppm. Fecal and total coliform counts taken from the raw sewage prior to chlorination yielded counts in excess of 10^5/100 ml.

The effluent discharged from the outfall pipe rises immediately to the surface. Oxygen levels in the surrounding waters reach saturation within a meter of the discharge point. Freshwater diffusion occurs rapidly in the surrounding waters. Surface phosphate levels are reduced to one third of that originating at the point of discharge. Upon reaching the surface, the fate of the effluent depends on wind, wave, and current conditions existing at any given time. Under heavy surf conditions, the effluent is washed toward the seaward edge of the jetty and then deflected north around the jetty. The effluent is carried by the prevailing winds when winds are of sufficient strength (ca. 15 knots) and surf minimal. In the absence of significant swells and wind velocity, the effluent moves on the surface in sluggish eddies, eventually drifting offshore.

The additional nutrient input from the sewage to the marine environment has little effect on the benthic biota, since the nutrients are carried immediately to the surface. Phosphate levels just above the substratum adjacent to the point of discharge are low and similar to the control samples offshore ($\bar{X}$ = 0.40 μg-at/l). The change in the amount of benthic algae, especially *Galaxaura oblongata*, in this area probably reflects a seasonal change as well as relation to antecedent events. Live corals are few and comprise less than 3% coverage. No change in the coral coverage was evident. The fish in the area varied in number and diversity depending on the condition of the sea. Zooplankton, per unit volume displaced, are consistently higher in the control sample obtained from an area south of the outfall just off the reef platform. Copepods and fish eggs dominate both outfall and control samples obtained during the day; shrimp larvae dominate the outfall samples taken at night.

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INTRODUCTION

Past regulations of the Guam Environmental Protection Agency required the placement of sewage outfalls at depths of 60 feet (18 m) and at locations at least 1000 feet (300 m) offshore, and additionally required secondary treatment. This was an expensive procedure because of the broad submarine terrace which occurs in water shallower than 18 meters around Guam.

There was some feeling that outfalls releasing secondarily treated effluent could be placed at shallower depths or locations nearer shore, and still not lead to adverse impact on Guam's marine environment. The primary concern was that the 60-foot depth requirement was arbitrary and might just as easily have been made less stringent. In September 1975, the Water Quality Standards was revised by the Guam Environmental Protection Agency and in this document all mention of the 60-foot depth requirement and 1000-foot distance from shore were deleted. The document did state that secondary treatment was required. The problem, however, still remained as to what the appropriate depth should be for future outfalls.

The only study, to date, on the effect of secondarily treated effluent on marine waters off a western Pacific island was conducted off Moen Island in the Truk Lagoon (Tsuda et al., 1975). The preliminary findings based on data obtained over a seven-day period revealed that the low quantity of effluent (10,000 to 15,000 gallons per day) which was released at a depth of 27 feet (8.1 m) had little effect on the quality of the receiving waters. This fact was evident by the rapid dispersion of nutrients (NO_3-N and reactive PO_4) and coliform bateria within three meters from the point of discharge. The benthic biota adjacent to the point of discharge did not seem affected by the effluent. The majority of studies conducted on sewage outfalls usually related to large volumes of raw sewage discharge (Jones and Randall, 1971; Grigg, 1975) and are reviewed by Johannes (1975).

Thus, the need for a long-term study of the impact of a secondarily treated effluent on Guam shallow coastal waters seemed important at this time to base future depth requirements on scientific observations of an existing sewage outfall. The goals of this study were limited to three objectives - 1) to characterize the effluent in the treatment tank, 2) to follow and characterize the effluent after it was discharged into the marine environment, and 3) to analyze the impact of the discharged waters on the marine biota.

The Agat secondary treatment plant and its outfall were chosen as the site for study because the outfall was located in shallow waters and could serve as a study site where information based on the above objectives could be gathered. In addition, an in-depth study of the water circulation patterns and marine benthic biota at other sites within this same bay (Agat Bay) was nearing completion and has since been published (Eldredge et al., 1977).

Agat Secondary Treatment Plant and Outfall

The Agat Secondary Treatment Plant occupies 1.76 acres of Government of Guam land in the Village of Agat (Fig. 1). This plant which uses the activated sludge process is situated approximately 8 feet (2.4 m) above sea level and is open to the atmosphere. Prevailing winds from the northeast carry odors over the ocean away from the residential area of Agat.

The outfall consists of a 1,900-foot (576 m) long 18-inch (0.45 m) cast iron pipe through which approximately 0.5 to 3 million gallons of domestic sewage are discharged per day. The volume of effluent flowing through this pipe per day is an approximation since there is no permanent instrument which monitors the daily flow rates of the effluent leaving the treatment plant. The actual amount of effluent discharged through the pipe per day is closer to 0.5 million gallons but increases drastically during heavy rains.

The effluent was originally discharged through two diffuser ports 1398 feet (426 m) from shore or 462 feet (141 m) from the seaward edge of the jetty in 18 feet (5.5 m) of water. However, Typhoon June severely damaged the cast iron pipe in November 1975, breaking it at three joints. The effluent is now discharged 60 feet (18 m) from the seaward edge of the jetty in only 8 feet (2.4 m) of water at high tide. The tidal range in Guam coastal waters is about 2.5 feet (ca. .8 m).

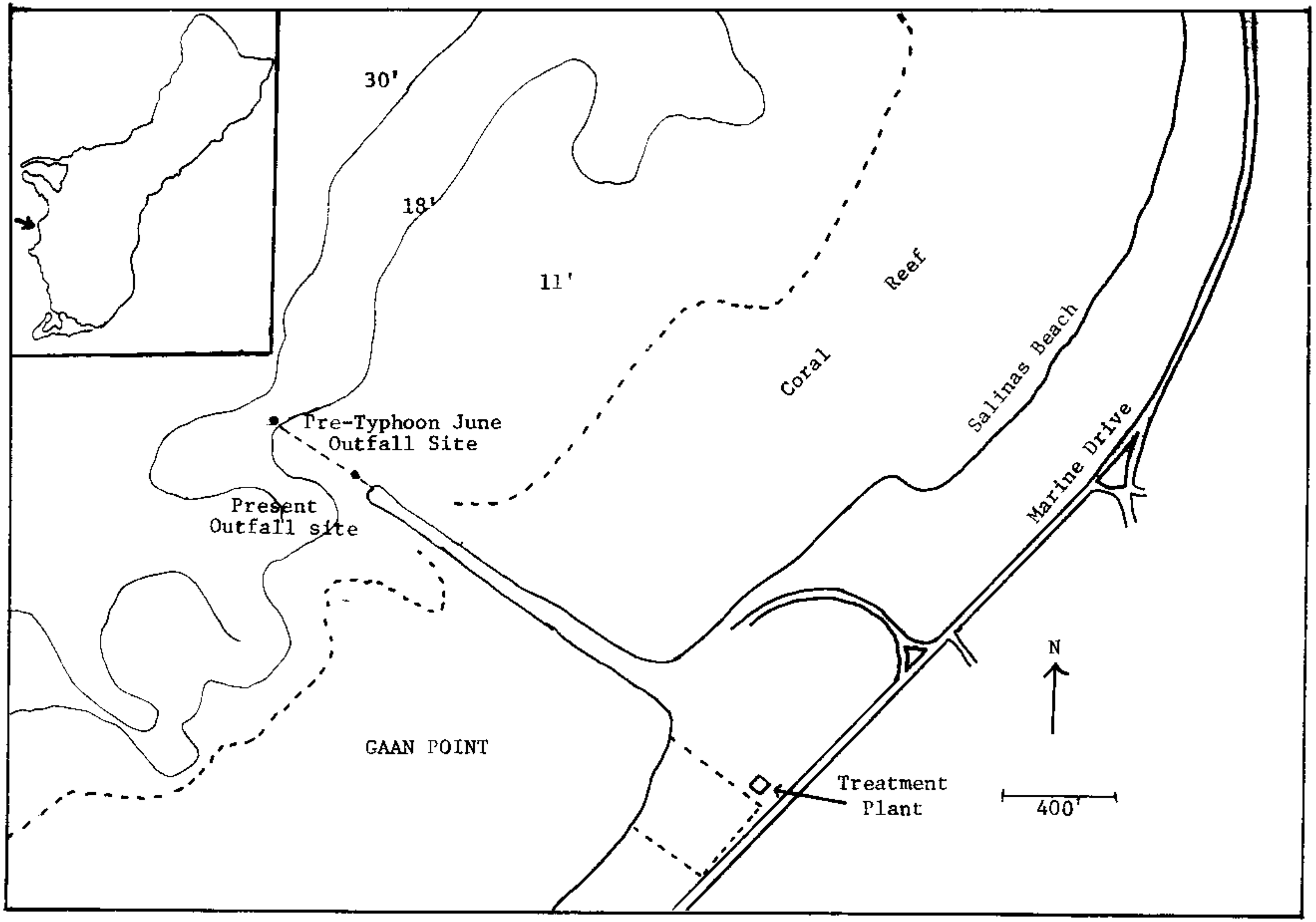

Fig. 1. Agat Sewage Treatment Plant showing location of outfall sites prior to and after Typhoon June.

ACKNOWLEDGEMENTS

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We also extend our gratitude to R. Mesa of the Public Utility Agency of Guam for providing us with information on the operation of the Agat Sewage Treatment Plant; and to T. Determan, K. Morphew and J. Cabreza of the Guam Environmental Protection Agency for their constructive comments on an earlier summarized version of this report. Our special thanks to Terry Balajadia for typing this report.

MATERIALS AND METHODS

The major portion of this study reports on the condition existing after Typhoon June (November, 1975) and describes the quality of the effluent being discharged 18 m from the seaward edge of the jetty in 2.4 m of water. The change in the location of effluent discharge after Typhoon June, as well as disruption caused by Typhoon Pamela in May 1976 greatly impeded the overall progress of this study. The opportunity, however, was made available to monitor the biota, especially the benthic algae, at two sites - one where effluent discharge had ceased and the other site nearer to shore where effluent discharge had just begun.

Water Circulation

The original plan to study the direction and speed of water movement at the outfall site called for the releasing of 1-m deep drogues during the course of the entire tidal cycle during different times of the year. However, the damage to the outfall pipe after Typhoon June placed the point of discharge so close to the edge of the jetty that any drogues released here during even mild surf conditions would simply be washed ashore in a matter of minutes. Thus, all reference to the direction in which the effluent would travel under the various sea conditions is based on fluorescein dye studies and the use of reactive phosphate as a tracer. The dye was always released in a fresh water carrier at the point of discharge in 2.4 m of water.

Water Chemistry and Coliform Counts

Initial studies conducted at the original point of discharge in water 18 m deep substantiated the earlier findings (Tsuda et al., 1975) that ambient temperature (28°C), salinity (33°/oo) and dissolved oxygen (6 mg/1) were attained within three meters from the point of discharge. Thus, these parameters were not measured during this study.

Reactive phosphate and nitrate-nitrogen concentrations of the treated effluent from the treatment plant were analyzed. However, only reactive phosphate was analyzed in the marine waters since our interest here was to use this nutrient as a tracer to follow the path of the effluent. Samples for reactive PO_4 analyses were obtained at the point of discharge and at the surface, and at two other sites along the seaward route of the cast iron pipe (Fig. 2). The surface samples were either collected by directly dipping the polyethylene bottles into the water or a sampling bucket. The bottom samples were obtained by unscrewing polyethylene bottles at the desired depth. Surface samples taken about 2 km off the outfall were used as controls. The samples were then stored on ice until they could be frozen the same day in the laboratory for later analysis. Assav for NO_3-N and reactive PO_4 was performed using the method of A.P.H.A. (1975).

Samples for bacteriological analysis (both fecal and total coliforms) were obtained in the field using the same methods in nutrient sampling. In this case, sterilized 500 ml polyethylene

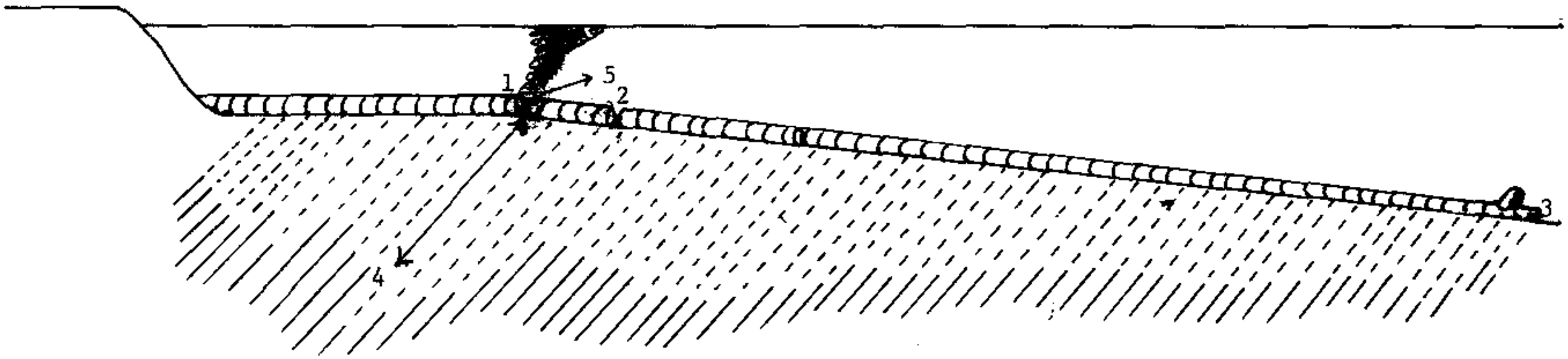

Fig. 2. Side view of the broken outfall pipe showing locations of the phosphate sample stations.

bottles were used. Samples were stored on ice for transport to the laboratory where they were analyzed by the membrane filter technique (A.P.H.A., 1975). Fecal coliforms were cultured on Difco M-FC medium at 44.5 ± 0.5°C; total coliforms were cultured on Difco MF Endo medium at 35.0 ± 0.5°C. Residual chlorine was analyzed using a chlorine tester (Taylor Chemicals, Inc.).

Marine Biota

The reason for conducting any type of floral or faunal analyses in the vicinity of the effluent discharge was primarily to see if any changes occurred which could be directly attributed to the discharge of sewage effluent, and not merely attributed to seasonal variation. Thus, the organisms studied must be one in which these causal differences could be separated. Our objective here was not to generate extensive checklists of marine organisms. Since few corals occur naturally in this area, the primary emphasis was placed on the quantitative analyses of the benthic algae of which some phases of its seasonality is known (Tsuda, 1974) for Guam.

The algal communities at both the previous and present point of effluent discharge were quantified during different times of year using the point-quadrat method. A small gridded quadrat (25 cm x 25 cm) was dropped haphazardly 10 to 20 times at the selected site. The quadrat frame consisted of 25 squares and, thus, provided 16 interior "points" where the grid lines intersected. Each species or the desired algal species (in many cases, only the red algal genus Galaxaura was counted) was recorded at each "point" at which it occurred. Since the fine filamentous-like algae were difficult to identify in the field, specimens were collected and later identified in the laboratory. Percent cover was obtained by dividing the number of points at which the species was recorded as a percent of the total number of points per transect, i.e., 16 x Number of Tosses = Total Number of Points.

One fish census was conducted by enumerating the species and numbers along a 140 m long transect (2 m wide) which ran parallel to the outfall pipe. Subsequent analyses of the fishes in the area were done strictly on a qualitative basis.

Towards the latter part of this study, a sampling program for zooplankton was initiated. Four day and one night zooplankton tows were made with a 0.5 m diameter conical net with 0.4 mm mesh apertures. The tows were made immediately below the water surface in the vicinity of the outfall. Tows made along an unpolluted section off the reef were used as controls. The samples were preserved in 10% formalin, and subsamples were examined and counted on a zooplankton counting tray with a binocular microscope.

RESULTS AND DISCUSSION

Characterization of the Effluent in Treatment Tank

Nutrient levels of the secondarily treated effluent in the treatment tank prior to release in the marine environment were high and variable (Table 1). Reactive phosphate values ranged from a low of 170 μg-at/l to more than a twofold increase of 400 μg-at/l ($\bar{X}$ = 260 μg-at/l) based on samples taken between November 1976 and June 1977. Nitrate-nitrogen values taken over the same time period showed a wide range, 10 μg-at/l to 530 μg-at/l, with a mean value of 130 μg-at/l. There was little correlation between the magnitude of the reactive phosphate and nitrate-nitrogen values obtained during any one day.

The number of samples collected from the wet well, effluent, and marine waters which had coliform levels within various ranges are tabulated in Table 2. These low counts of less than 100,000 per 100 ml are probably due to the effect of chlorine which is injected in the man-hole above the wet well. These values are also lower than expected because of technique error in which sodium arsenite was not added to the samples prior to analysis in the laboratory.

The majority of coliform bacteria are killed during chlorination in the treatment tank as seen by the majority of samples having fecal coliform levels less than 200 per 100 ml. Residual chlorine levels in the tank varied from .2 to 4 ppm ($\bar{X}$ = 1.5 ppm, n = 15). Fecal coliform levels are further reduced in the marine environment.

Table 1. Nitrate and phosphate levels of the treated effluent at the Agat Sewage Treatment Plant.

Date		NO_3-N (µg-at/1)	PO_4 (µg-at/1)
Nov. 29, 1976		260	350
Dec. 16, 1976		-	300
Feb. 17, 1977		38	180
Feb. 22, 1977		530	270
Mar. 8, 1977		38	400
Mar. 28, 1977		52	240
May 17, 1977		10	170
May 25, 1977		170	280
June 3, 1977		33	170
June 7, 1977		57	260
	MEAN	130	260

Table 2. Coliform counts of raw sewage in the wet well, effluent during chlorination in the treatment tank, and marine waters at the edge of the jetty. Data for effluent and marine waters provided by the Public Utility Agency of Guam and the Guam Environmental Protection Agency, respectively.

Coliform Counts (per 100 ml)	NUMBER OF SAMPLES: Raw Sewage (Oct. 1976–June 1977) FC	Raw Sewage (Oct. 1976–June 1977) TC	Effluent (Feb. 1976–Aug. 1977) FC	Marine Waters (July 1975–Oct. 1977) FC
>100,000	6	6	13	0
10,000 - 99,999	0	1	2	0
1,000 - 9,999	4	2	2	5
201 - 999	1	3	4	10
0 - 200	2	0	46	84
Total Number of Samples	13	12	67	99

Fate of Discharged Effluent in Marine Waters

One set of nutrient values obtained prior to Typhoon June on October 28, 1975 indicates that dilution was rapid after release from the discharge ports. Nitrate-nitrogen at the point of discharge (8.5 µg-at/l) was diluted rapidly within three meters (0.75 µg-at/l), and surface values were rather similar to those taken two kilometers offshore (0.40 µg-at/l). Reactive phosphate at the point of discharge (75 µg-at/) dissipated to 4.6 µg-at/l within three meters and was diluted to 2.2 µg-at/l at the surface. The surface value was still ten times that of the control sample (0.25 µg-at/l) taken two kilometers offshore.

At the new point of discharge, the effluent rises rapidly to the surface and is further mixed by the surge caused by the incoming waves. Dissolved oxygen levels in the surrounding waters reach saturation within a meter of the point of discharge. Freshwater diffusion occurs rapidly in the surrounding waters. Jones and Randall (1971) also found that dissolved oxygen, salinity, and temperature were near normal before the plume of raw sewage (ca. 1.5 million gallons/day) reached the surface. The plume, in this case, was discharged in 86 feet (27 m) of water.

As seen in Table 3, the reactive phosphate levels after it reaches the surface varies in concentration depending on the degree of mixing. For the most part, the reactive phosphate values at the bottom are similar to those of the control sample obtained offshore.

Table 3. Phosphate levels (μg-at/l) obtained from Stations 1, 2, 3 and a site offshore as control. Both bottom and surface samples were taken at Stations 2 and 3. See Fig. 2 for location of stations. (ND = Not Done).

Date		Sta. 1 (Pt. of Discharge)	Sta. 2 (Surf./Bot.)	Sta. 3 (Surf./Bot.)	Offshore (Surf.)
Oct. 28, 1976		18	ND	2.2 /ND	0.13
Nov. 4, 1976		17	ND	0.94/1.2	1.2
Nov. 11, 1976		8.4	ND	6.3 /0.36	0.29
Nov. 18, 1976		3.5	ND	0.74/0.29	0.39
Nov. 24, 1976		19	0.42/0.39	0.23/0.23	0.16
Dec. 6, 1976		4.5	7.0 /2.4	3.9 /3.3	3.0
Dec. 16, 1976		1.4	2.4 /0.10	2.2 /0.26	0.45
Jan. 18, 1977		13	5.0 /0.39	0.19/0.16	0.032
Feb. 1, 1977		14	1.9 /0.45	0.26/ND	0.16
Feb. 15, 1977		4.3	1.2 /0.22	0.26/0.23	ND
Mar. 1, 1977		13	6.6 /0.29	0.13/ND	0.19
Mar. 16, 1977		5.3	6.8 /0.48	0.39/0.29	0.32
Mar. 22, 1977		1.1	3.8 /0.22	0.36/0.52	0.32
Mar. 29, 1977		16	3.1 /0.26	0.26/0.13	0.13
Apr. 12, 1977		25	0.23/0.48	0.13/0.19	ND
Apr. 20, 1977		33	9.1 /0.74	0.39/0.16	ND
Apr. 26, 1977		8.9	3.1 /3.1	4.9 /0.16	0.097
May 3, 1977		10	4.7 /0.32	0.26/0.42	0.13
May 10, 1977		25	0.45/0.26	0.19/0.19	0.064
May 18, 1977		36	0.064/0.064	0.000/0.064	0.064
May 26, 1977		12	5.3 /1.7	0.13/0.097	0.064
June 2, 1977		44	7.3 /ND	4.1 /ND	0.84
June 9, 1977		6.3	4.5 /0.22	0.44/0.18	0.18
June 22, 1977		5.5	4.3 /0.32	0.24/0.25	0.18
	MEAN	14	4.1 /0.65	1.2 /0.44	0.40

No chlorine residue could be detected within a half meter of the point of discharge, which probably indicates that residual chlorine is not a detrimental factor to the marine biota. However, the turbidity of the effluent may affect the amount of sunlight that reaches the benthic algae.

Upon reaching the surface, the fate of the effluent depends primarily upon the wind, wave, and prevailing current conditions existing at any given time. An extensive discussion of the annual pattern of water movement in Agat Bay is provided by Dickinson and Moras (1977). Wind seems to be the major factor in the surface water movement.

During the winter months (November to May), Guam lies in the belt of the northeast tradewinds. Easterlies, with a strong northerly component, dominate from November to March, and westerly trades dominate during January and February. From April to June, a southerly component is present. During the winter months, winds commonly exceed 13 knots and calms are rare. If conditions are such that a swell is not generated, the effluent will be carried on the surface with the wind. Table 4 summarizes the reactive phosphate values obtained from late March to June, when the wind generally had a southerly component and the swell was minimal. Under these conditions, the effluent is carried to the northwest.

Often, the strong winds commonly generate a northwest swell (average about 0.5 m high), which probably originates as a north-

Table 4. Phosphate values (μg-at/l) obtained when southerly winds prevail (late March to June) and swell is minimal. See Fig. 3 for sampling stations.

Date	Wind	Swell	PO_4 (μg-at/l) Sta. 1	Sta. 2	Sta. 3
Mar. 29, 1977	18 knots ENE	0.3 m	16	1.2	3.8
Apr. 12, 1977	15 knots E	-	25	0.55	6.1
Apr. 20, 1977	8 knots E	-	33	0.19	8.8
Apr. 26, 1977	12 knots E	0.3 m	9.0	0.16	2.1
May 3, 1977	10 knots E	0.3 m	10	0.52	5.9
May 10, 1977	20 knots E	-	25	0.10	0.71
June 9, 1977	8 knots E	0.3 m	6.3	0.90	2.0
June 22, 1977	10 knots E	-	5.5	0.53	5.4

east swell, but is refracted as it enters Agat Bay. During the winter months, we found a northwest swell was often the case. Dickinson and Moras (1977) found that this swell was of minor importance in surface water movement in Agat Bay. However, swell becomes a major factor in the dispersal of the effluent here because the effluent can be caught in the surf and washed onto the shore. Under especially heavy surf conditions, a portion of the effluent is deflected north around the edge of the jetty and into the adjacent reef flat.

Fig. 3 shows reactive phosphate values at various stations along the point when surf conditions were such that the effluent was deflected onto the reef flat. On this particular day, a dominant northwest swell existed and winds were from the northeast (about 20 knots).

During the summer months, the tradewinds no longer dominate; wind direction is variable and calms are frequent. The swell is often nonexistent and effluent dispersal is a function of wind direction. In the summer, when it is possible to have winds with a southerly component, phosphate levels (see Fig. 2) at a site north of the outfall (Station 4) are higher than those at a site further south (Station 5), sometimes exceeding those to the southwest, the direction of net current movement. When summer winds are from the west, the effluent is blown back onto shore and onto the reef flat north of the jetty.

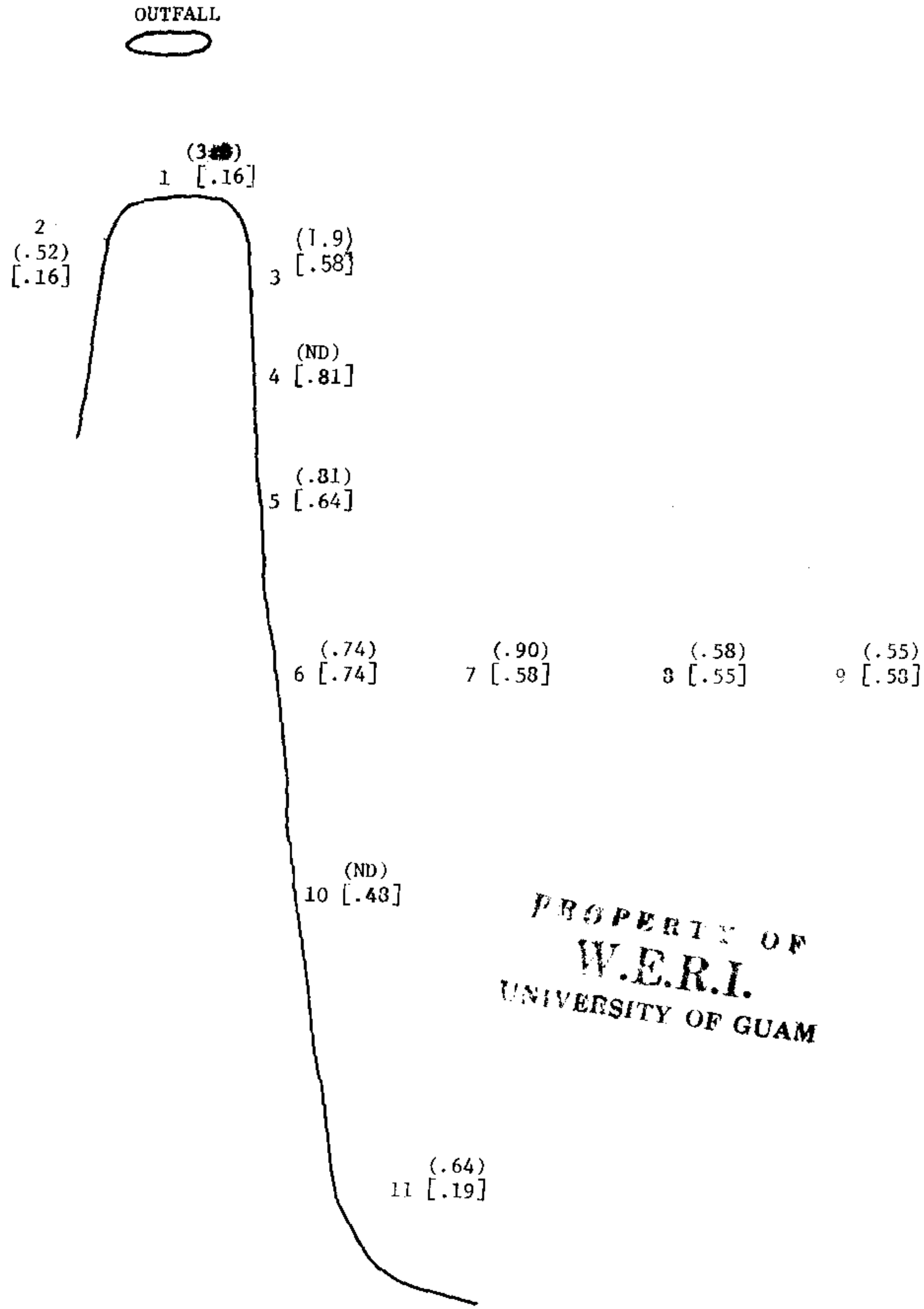

Fig. 3. Phosphate levels (µg-at/l) obtained on north side of jetty during days of moderate surf (Feb. 22, 1977) and heavy surf [Mar. 8, 1977]. Wind was from the northeast. Phosphate levels in the treatment plant were 266 and 400 µg-at/l, respectively, on the two days.

In summary, the fate of the effluent discharged from the Agat outfall is dependent on the swell, wind and current. If there is a significant swell, the effluent is washed onto shore and then deflected to the north of the jetty. When winds are of sufficient strength (about 15 knots) and surf minimal, the effluent is carried on the surface with the prevailing winds. In the absence of significant swell and wind velocity, the effluent moves on the surface in sluggish eddies, eventually drifting offshore.

Impact on Marine Biota

Corals - The marine benthic community in the vicinity of the effluent discharge had few live corals and these covered less than three percent of the substratum. The blue coral *Heliopora coerulea* was the most conspicuous coral. No obvious effect on the corals could be detected from effluent discharge in the area.

Fishes - A fish census carried out in April 1976 along a 140 x 2 m transect revealed 274 individual fishes within 23 species (Table 5). The two most abundant fish were the omnivore *Glyphidodontops leucopomus* (170 individuals) and the herbivore *Acanthurus nigrofuscus* (30 individuals).

Observations of the fishes during the length of the study period indicated that the size of the roving schools of fishes varied depending on the condition of the swells and surfs near the seaward edge of the jetty during the day of observation. There were definitely

Table 5. Number of fishes observed along the south side of the outfall pipe for a distance of 140 m. April 6, 1976 at 1105-1135.

SPECIES	NUMBER OF FISHES
Acanthuridae	
Acanthurus lineatus (Linnaeus)	3
A. nigrofuscus Forskal	30
A. triostegus (Linnaeus)	1
Ctenochaetus striatus (Quoy & Gaimard)	3
Chaetodontidae	
Chaetodon lunula (Lacepede)	1
Labridae	
Cheilinus sp.	1
Epibulus insidiator (Pallas)	1
Halichoeres centiquadrus (Lacepeda)	4
H. marginatus Ruppell	3
Labroides dimidiatus (Cuvier & Valenciennes)	6
Stethojulis bandanensis (Bleeker)	4
Juvenile & unident. labrids	18
Monacanthidae	
Pervagator melanocephalus (Bleeker)	1
Mullidae	
Parupeneus trifasciatus (Lacepede)	3
Pomacentridae	
Glyphidodontops leucopomus (Lesson)	170
Pomacentrus vaiuli (Jordon & Seale)	7
unident. pomacentrids	3
Scaridae	
Scarus sordidus Forskal	1
juv. scarids	13
Serrianidae	
Epinephelus merra Bloch	1
No of Species ----------------------------	20
Total No. of Fish Observed --------------	274
No. of Fish/m^2 --------------------------	0.98

more fishes near the seaward edge of the jetty than along the outfall pipe. It is doubtful that this difference is due strictly to the location of the effluent discharge nearer the surge zone, since fishes were just as abundant here prior to Typhoon June when the effluent discharge was located further seaward. The larger fish community in the surge area is similar to communities in other areas around Guam where fishes, especially schools of acanthurids, congregate in the surge zone.

In a recent study (Chernin et al., 1977), transects ran on the reef flats (perpendicular to shore) 100 m north and 70 m south of the jetty revealed 404 and 447 fishes belonging to 50 species. The labrids and the pomocentrids represented the dominant fishes here. These numbers far exceed the number found at the outfall site.

The outfall pipe which lay on concrete blocks served as a very effective artificial habitat for certain fishes, e.g., turkey fish (*Pterois* sp.) and large squirrelfish (*Adioryx* sp.). This artificial habitat is enhanced even more by the concrete bags which were placed on the pipe during the initial construction, adding a conspicuous vertical dimension to the artificial habitat. During April to June, 1977, a large run of juvenile rabbitfish (*Siganus argenteus* and *S. spinus*) occurred on the reefs of Guam. Large schools of these two species (ca. 5 cm in SL) were still present in the outfall area during July 1977.

Unlike the situation at the Agat outfall, the increased fish community near the Agana Outfall in 27 meters of water seemed to be directly related to the discharge of raw sewage (Jones and Randall, 1971). In this case, the omnivorous larger fishes do feed on the raw sewage.

Algae - The algal community in this area was no different from the algal communities in similar subtidal habitats elsewhere in Agat Bay (Tsuda, 1977). Only 11 species (Table 6) of algae were observed during the three sampling periods (April, 1976; Oct., 1976; July, 1977), which reflected the two algal seasons (Tsuda, 1974), at the present point of discharge. The majority of the algae here were turf-like, e.g., *Sphacelaria tribuloides*, *Gelidium pusillum*, *Jania capillacea*, and *Polysiphonia* sp., and all thalli were less than 2 cm high. The high percent cover (74%) during the winter sample is probably due to the seasonal occurrence of certain algae, e.g., *Lobophora variegata*, which was only present during October 1976 and July 1977. Tsuda and Kami (1973) found that this algal species showed a distinct seasonality on artificial reefs in the subtidal zone.

The added nutrients in the effluent could not affect the subtidal benthic algae, since nutrient levels adjacent to the substratum were low and similar to the control values obtained offshore. However, higher than normal phosphate levels persist on the surface and can wash onto the shallow reef flat north of the jetty (see Fig. 3). During low tides, the added phosphates come in contact with the benthic algae and, thus, may provide the reason why this reef flat is exceedingly rich in algal standing crop and diversity. It is definitely

Table 6. Percent cover of marine benthic algae at present point of effluent discharge located 18 m from the seaward edge of jetty.

SPECIES	% Cover April 1976 (n=20)	Oct. 1976 (n=10)	July 1977 (n=20)
Cyanophyta			
Microcoleus lyngbyaceus (Kutz.) Crouan	10	-	-
Chlorophyta			
Caulerpa racemosa (Forssk.) J. Ag.	-	2	-
Halimeda discoidea Decaisne	2	-	-
Phaeophyta			
Dictyota bartayresii Lamx.	< 1	4	-
Feldmannia indica (Sonder) Womersley & Bailey	-	-	2
Lobophora variegata (Lamx.) Womersley	-	11	9
Sphacelaria tribuloides Meneghini	21	25	-
Rhodophyta			
Ceramium sp.	-	-	-
Gelidium pusillum (Stackh.) Le Jolis	14	24	-
Jania capillacea Harvey	-	8	17
Polysiphonia sp.	-	-	31
TOTAL ALGAL PERCENT COVER	48	74	59

richer than other reef flat sites in this bay.

A more diverse flora with a greater percent cover was evident at the site (Table 7) further seaward where the effluent was discharged prior to Typhoon June. Samples taken during the next two years (April 1976 and June 1977) within the same season also revealed a high percent algal cover. At this period, the effluent was not being discharged in this area. Fig. 4 shows the percent cover of three species of *Galaxaura*, the dominant genus of macroalgae in the area, based on samples taken at periodic intervals. This irregular pattern, barring the conspicuous lack of information for June and August 1976, is probably correlated to a seasonal pattern superimposed by antecedent events (Doty, 1971), such as typhoons and heavy surfs. *Galaxaura* possesses a "top heavy" thallus which is attached to the substratum by a single holdfast and can easily be detached from the substratum.

Zooplankton - The results obtained from the plankton tows are summarized in Table 8. In all cases, displacement volume of the sample taken at the outfall was greater than the corresponding control tow from an area south of the outfall just off the reef flat. These higher displacement volumes are due mainly to accumulated debris, since organisms per unit volume displaced are consistently higher in control samples.

The number of organisms in each sample varies within an order of magnitude, except for the night tow which is an order of magni-

Table 7. Percent cover of those species of marine benthic algae covering greater than 1% of the substratum at the end of the diffuser during May 1975, April 1976 and June 1977. (n=20 tosses per sampling site).

SPECIES	% Cover		
	Effluent	No Effluent	
	May 1975	April 1976	June 1977
Cyanophyta			
Microcoleus lyngbyaceus (Kutz.) Crouan	2	<1	1
Schizothrix calcicola (Ag.) Gomont	4	-	-
Chlorophyta			
Neomeris annulata Dickie	2	-	<1
Phaeophyta			
Dictyota bartayresii Lamx.	1	7	-
Lobophora variegata (Lamx.) Womersley	9	-	12
Sphacelaria tribuloides Meneghini	-	3	-
Rhodophyta			
Actinotrichia fragilis (Forsk.) Boerg.	2	-	1
Amphiroa fragilissima (L.) Lamx.	-	-	<1
Asparagopsis taxiformis (Delile) Collins & Harvey	-	2	2
Ceramium sp.	-	4	-
Galaxaura fasciculata Kjellm	<1	-	1
Galaxaura clavigera Kjellm	1	<1	3
Galaxaura oblongata (E. & S.) Lamx.	35	72	15
Gelidium pusillum (Stackh.) Le Jolis	1	-	-
Halymenia durvillaei Bory	1	-	-
Jania capillacea Harvey	-	-	24
Liagora sp.	2	6	-
Peyssonelia sp.	1	-	13
Polysiphonia sp.	16	-	8
TOTAL PERCENT COVER	78	96	82

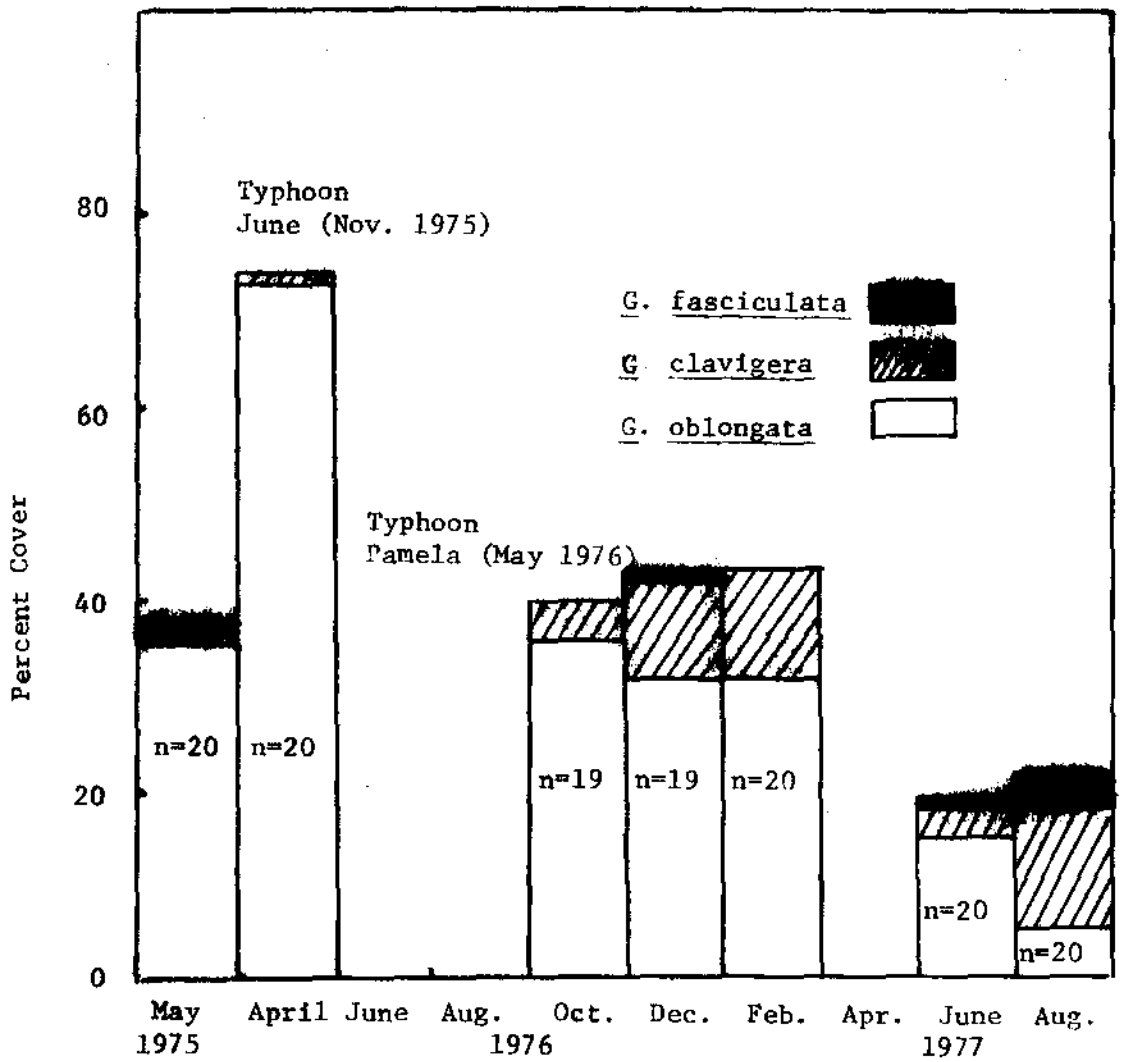

Fig. 4. Percent cover of three species of Galaxaura at the original site of effluent discharge, May 1975 to August 1977.

Table 8. Zooplankton data showing number of organisms per m^3 and percent composition of total catch (in parenthesis) during four day samples (Apr. 20, May 3, May 10 and May 26, 1977) and one night sample (May 23, 1977). (O = Outfall, C = Control).

ORGANISMS	April 20		May 3		May 10		May 23		May 26	
	O	C	O	C	O	C	O	C	O	C
Copepods	3.70 (53.8)	2.09 (65.0)	0.23 (13.8)	7.53 (84.7)	0.10 (1.6)	1.39 (39.3)	0.58 (3.5)	6.68 (18.5)	2.60 (93.2)	0.46 (19.0)
Fish Eggs	2.80 (40.8)	1.00 (31.1)	1.18 (69.5)	0.51 (5.7)	5.62 (90.7)	2.02 (57.1)	0.46 (2.8)	20.30 (56.2)	0.02 (0.7)	1.38 (56.7)
Brachyurans	0.12 (1.7)	0.05 (1.6)	0.23 (13.5)	0.31 (3.5)	0.43 (6.9)	0.04 (1.2)	0.88 (5.4)	2.71 (7.5)	0.03 (1.2)	0.46 (19.0)
"Shrimp" Larvae	0.15 (2.2)	0.07 (2.3)	0.04 (2.3)	0.10 (1.2)	0.02 (0.4)	0.02 (0.5)	11.80 (72.2)	3.15 (8.7)	0.04 (1.6)	0.06 (2.2)
Fish Larvae	0.04 (0.5)	0.01 (0.2)	0.01 (0.6)	0.01 (0.1)	-	0.01 (0.1)	0.31 (1.9)	0.13 (0.4)	0.01 (0.4)	0.01 (0.2)
Chaetognaths	0.06 (0.8)	0.01 (0.2)	-	0.02 (0.2)	0.02 (0.4)	0.01 (0.1)	-	0.13 (0.4)	-	0.04 (1.8)
Larvaceans	0.02 (0.2)	0.05 (1.6)	-	-	-	0.01 (0.1)	-	-	0.02 (0.9)	0.01 (0.1)
Medusae	-	0.01 (0.2)	0.01 (0.1)	-	-	0.01 (0.1)	0.25 (1.5)	0.13 (0.4)	-	0.01 (0.3)
Siphonophores	-	-	-	0.01 (0.1)	-	-	-	-	-	-
Pteropods	-	-	-	0.38 (4.3)	-	0.01 (0.1)	-	-	0.01 (0.4)	0.01 (0.4)

Table 8. Continued.

ORGANISMS	April 20		May 3		May 10		May 23		May 26	
	O	C	O	C	O	C	O	C	O	C
Polychaetes	-	0.01 (0.2)	-	0.03 (0.3)	-	-	-	-	0.02 (0.5)	-
Mysids	-	-	-	-	-	-	0.73 (4.4)	1.71 (4.7)	0.02 (0.7)	0.01 (0.1)
Ostracods	-	-	-	-	-	-	0.72 (4.4)	0.32 (0.9)	0.01 (0.4)	-
Amphipods	-	-	-	-	-	-	0.12 (0.7)	0.36 (1.0)	-	-
Euphausids	-	-	-	-	-	-	0.02 (0.1)	0.13 (0.4)	0.01 (0.2)	0.01 (0.1)
Other Crustaceans	-	0.01 (0.2)	-	-	-	-	0.16 (1.0)	0.07 (0.2)	- -	- -
NUMBER COLLECTED	5,000	2,340	1,230	6,460	4,500	2,580	11,900	26,300	2,030	1,780
NUMBER PER m^3	6.88	3.22	1.69	8.88	6.19	3.55	16.40	36.20	2.79	2.44
VOLUME COLLECTED (ml)	10.9	3.7	2.6	1.6	5.8	1.8	22.6	18.2	4.2	0.2
VOLUME PER m^3 (ml/m^3)	.015	.005	.004	.002	.008	.002	.031	.025	.006	.001
NUMBER/VOL. COLL.	459	632	482	4,040	783	1,430	526	1,440	483	8,880
SHANNON DIVERSITY INDEX	.406	.400	.401	.282	.166	.372	.466	.611	.170	.514

tude higher than daytime tows. Since the distance covered and the volume of water filtered is an approximation based on the boat speed, differences between sample and control tows on a given date are probably not critical. Copepods and fish eggs were abundant in both outfall and control daytime samples. "Shrimp" larvae (72%) dominate the outfall tow taken at night, while fish eggs were abundant (56%) in the control night tow.

The general composition of samples is indicative of those representing offshore waters, although one would expect more chaetognaths in such samples. The offshore nature of the composition seems to indicate that plankton populations are transitory with respect to the outfall site, where they spend little time developing in that area. An indication of species diversity was calculated using the methods of Lloyd and Karr (1968). The Shannon diversity index showed that in most cases (except possibly in the single night tow) species diversity in zooplankton populations is not significantly affected by the sewage discharge.

CONCLUSIONS

Based on the results of this study, it seems that the location of the secondary sewage outfalls of low effluent volume should be based more on the aesthetic value of the surrounding waters than on the detrimental effect the effluent will have on the marine biota. All information obtained on the marine biota in the vicinity of the effluent discharge seemed to indicate no obvious detrimental effect.

The outfall should be located far enough offshore in the path of suitable currents so that sewage will not be washed onto the shore. The exact depth will be dependent on the local condition of the swells, wind and current patterns.

It should be noted that although the low coliform counts in discharged effluent indicate the decrease of possible source of disease, there still exists the possibility of viral contamination of adjacent waters. Enteroviruses (Gerba et al., 1972) are known to be able to survive present sewage treatment and little is known concerning their release into the marine environment through sewage outfalls.

RECOMMENDATIONS

1. If future plans call for the continual operation of the Agat Sewage Treatment Plant, the outfall line should be repaired so that the sewage is released at the original point of discharge. In this way, the effluent will be better dispersed at a deeper depth and less likely be washed in high concentrations onto the reef.

2. Regardless of the outcome of future discussions on the placement of outfalls, the surge zone is <u>not</u> recommended as an ideal location for an outfall since the sewage will definitely wash onto the shore. In addition, contingency safeguards against disease carrying bacteria must be allowed since there are occasions when the raw sewage is released into the marine environment when the treatment plant is overloaded with sewage water.

3. It is very difficult, if not impossible, to interpret data obtained from an environmental study of an outfall and provide concrete comments on the effect of the sewage effluent on the environment when no baseline information of the outfall site is available. Environmental studies must be initiated early in the planning stage of treatment plants, and not at the last moment when construction is to begin. In this way, long term

environmental studies can be conducted and the location of the outfall sites can be based on more concrete scientific data and not on the so-called one week study which seems to be prevalent on Pacific Islands.

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PLATE I

A. View of the seaward edge of the jetty looking toward the southeast.

B. End of the outfall pipe where sewage effluent was discharged prior to Typhoon June at a depth of 5.5 meters.

C. One of the breaks in the outfall pipe caused by Typhoon June in November 1975.

D. Present site of sewage discharge at a location 18 meters from the seaward edge of the jetty in 2.4 meters of water.