AN ANNUAL CYCLE STUDY OF BIOLOGICAL, CHEMICAL AND OCEANOGRAPHIC PHENOMENA ASSOCIATED WITH THE AGANA OCEAN OUTFALL

by

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FINAL REPORT
June 6, 1971

Submitted to:

The Guam Water Pollution Control Commission

UNIVERSITY OF GUAM

THE MARINE LABORATORY

TECHNICAL REPORT No. 1

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SECTION I

INTRODUCTION

Rapid growth of population, industry, and military installations on Guam has produced predictable increases in domestic and industrial wastes. The Government of Guam, military commands and community at large are faced with the problem of disposing of these wastes. Guam's oceanic location has thus far made ocean outfalls the most convenient and inexpensive method of waste removal. This is frequently a rather near-sighted approach.

An assumption is often made that ocean outfalls, coupled with oceanic dilution, will prevent detrimental accumulation of sewage in inshore areas. However, unfavorable ocean currents and incomplete dilution and/or chemical and biological degradation of organic and other noxious substances could combine to bring these wastes into Guam's reef and bay environments. These circumstances might create public health problems and generally obnoxious conditions along densely populated coastal areas. In addition, to public health problems, such accumulations might well cause irreversible damage to our marine ecosystem.

Intensive research programs to aid in the most effective location of ocean outfalls are either limited in scope on Guam or completely lacking. All too often, ocean outfalls reach the design and contract stage or actual construction before any detailed hydrograpic survey or ecological impact evaluation of the site is made, if at all. A report by the Metcalf and Eddy engineering firm (1965) includes an "oceanographic study" of the Agana outfall site. The total duration of the study is 60 minutes, spread over a 3 day period, hardly adequate for locating an outfall. Somewhat more information is available in another report by Pacific Island Engineers (1951) but this too has some limitations to be discussed herein (p. 32).

In an effort to alleviate this problem, the Guam Water Pollution Control Commission contracted the University of Guam Marine Laboratory to conduct a study of the recently completed Agana outfall site (Figs. 1 and 2). It was obviously too late to make a preconstruction site study, but it was possible to attempt to evaluate the effectiveness of the existing outfall.

Funding for the project was administered by the Guam Department of Public Health and Social Services. A memorandum of understanding was entered into on 28 March 1969 by and between the Department of PH&SS and the University. It was agreed that the research portion of the study would run from September 1969 to September 1970 and that the services performed by the University would be to:

1. Follow the travel of materials attributable to sewage, both floating and settleable, such as oil, scum, rags, grit, nitrogen, phosphorus, fecal coliform, and visibility pattern in and around the area of the existing Agana outfall.

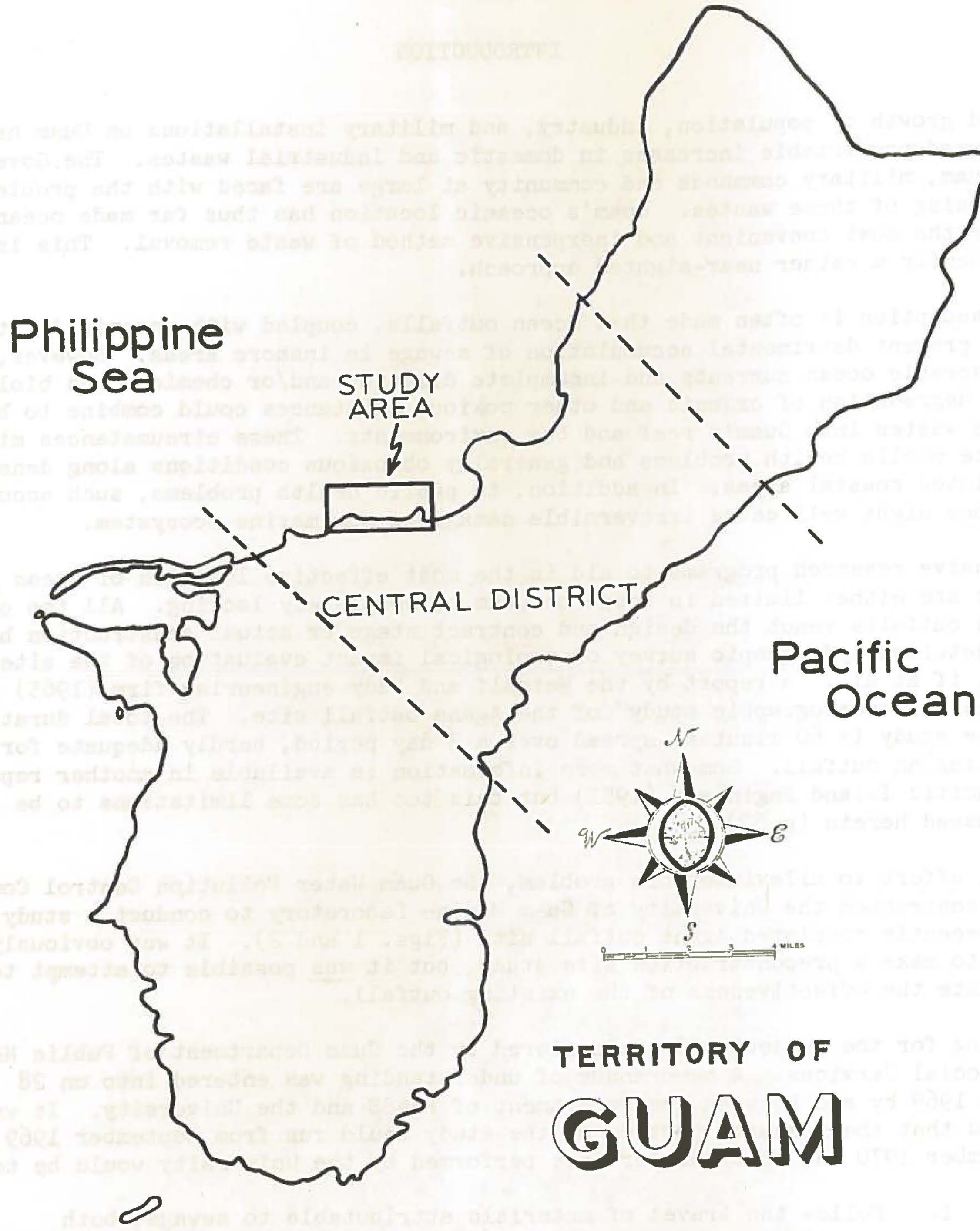


Figure 1. MAP OF GUAM. The Central District Sewage System and study area are shown.

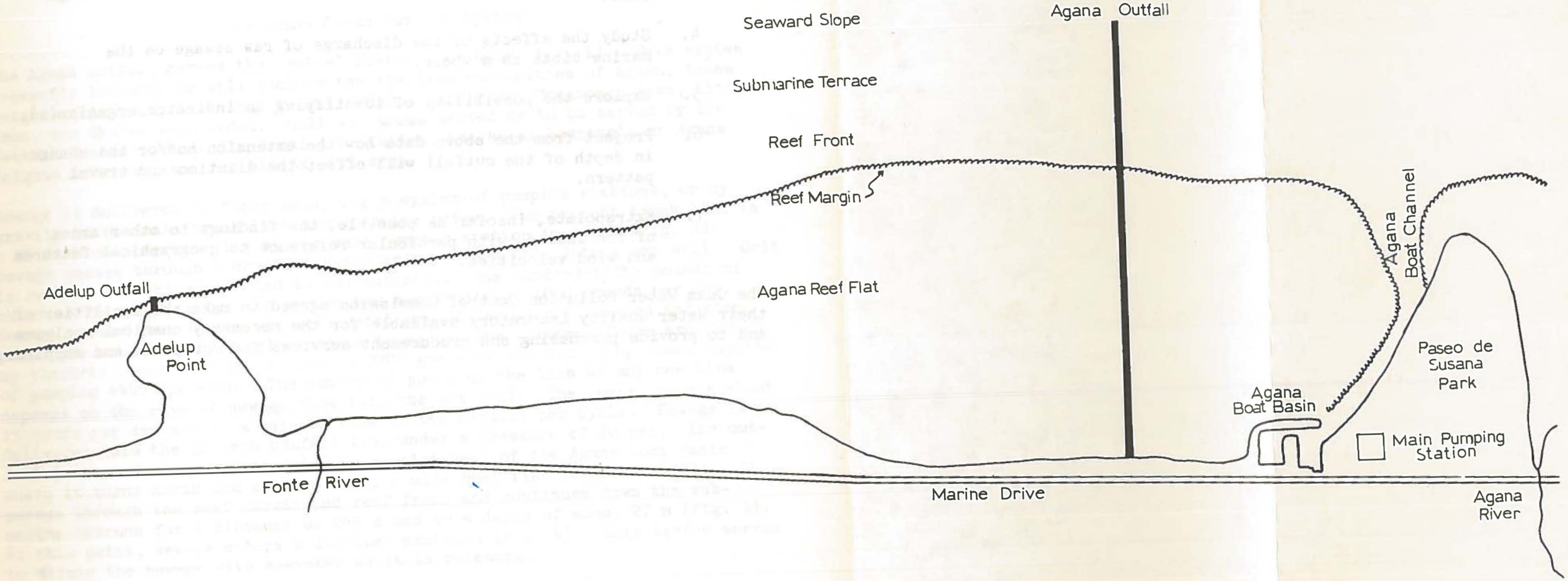


Figure 2. CHART OF STUDY AREA. The chart shows the general limits of the study area, location of the outfall and the reef zones.

2. Delineate the bad odor zone and the oxygen sag line, if any.

3. Continue the study for twelve months from a previously agreed date and to correlate the pattern with the quantity of sewage flow.

4. Study the effects of the discharge of raw sewage on the marine biota as a whole.

5. Explore the possibility of identifying an indicator organism(s).

6. Project from the above data how the extension and/or the change in depth of the outfall will effect the dilution and travel pattern.

7. Extrapolate, insofar as possible, the findings to other areas of the island, with particular reference to geographical features and wind velocities.

The Guam Water Pollution Control Commission agreed to make the facilities of their Water Quality Laboratory available for the necessary chemical analyses and to provide purchasing and procurement services for equipment and supplies

SECTION II

DESCRIPTION OF THE STUDY AREA

The Agana Ocean Outfall System

The Agana outfall serves the Central District of Guam (Fig. 1). This system presently includes or will include the civilian communities of Agana, Agana Heights, Sinajana, Tamuning, Tumon, Dededo, Barrigada, Mongmong, Asan, Piti, Yona, and Chalan Pago/Ordot. Military areas served or to be served by the Central System include the Naval Air Station, the Naval hospitals at Agana Heights and Asan, and the Nimitz Hill area.

Sewage is delivered by force main, via a system of pumping stations, or by gravity to the main trunk line along Marine Drive. The present trunk line is a 30 inch main terminating at the main pumping station in Agana (Fig. 2). Sewage passes through a comminutor for grinding and then into a wet well. Grit is removed and chlorine added to the material. One hundred-fifty pounds of chlorine is used daily, the system has a capacity of 1000 pounds per day. Sewage accumulates in the wet well until preset levels are reached and then pumps are activated by level switches to reduce the volume. There are two 25 hp electric pumps capable of pumping 2200 gpm each and two 50 hp pumps capable of pumping 4400 gpm each. The number of pumps on the line at any one time depends on the rate of sewage flow into the wet well. The pumps operate about 15 hours per day and at a rate of five to ten minutes per cycle. Sewage is delivered into the 36 inch outfall line under a pressure of 20 psi. The outfall is routed along Marine Drive to a point west of the Agana Boat Basin where it turns north and crosses a 588 m wide reef flat (Figs. 2 and 3). It passes through the reef margin and reef front and continues down the submarine terrace for a distance of 249 m and to a depth of about 27 m (Fig. 3). At this point, sewage enters a diffuser manifold (Fig. 4). This device serves to dilute the sewage with seawater as it is released.

The outfall is flushed periodically by allowing a greater than average accumulation of materials to build up in the wet well. Sludge accumulation in the bottom of the wet well is pumped out once per week.

Description of Reef Zones and Limits of Study Area

Agana Reef Flat, Boat Basin and Boat Channel

The reef flat studied in this report is a 2350 m long section located along Marine Drive in Agana (Fig. 2). It is bounded by the Paseo de Susana and the Agana Boat Basin and Channel on the east and by Adelup Pt. on the west. The width of this reef flat ranges from 588 m where the Agana outfall line crosses it to 294 m opposite the Fonte River mouth near Adelup Pt.

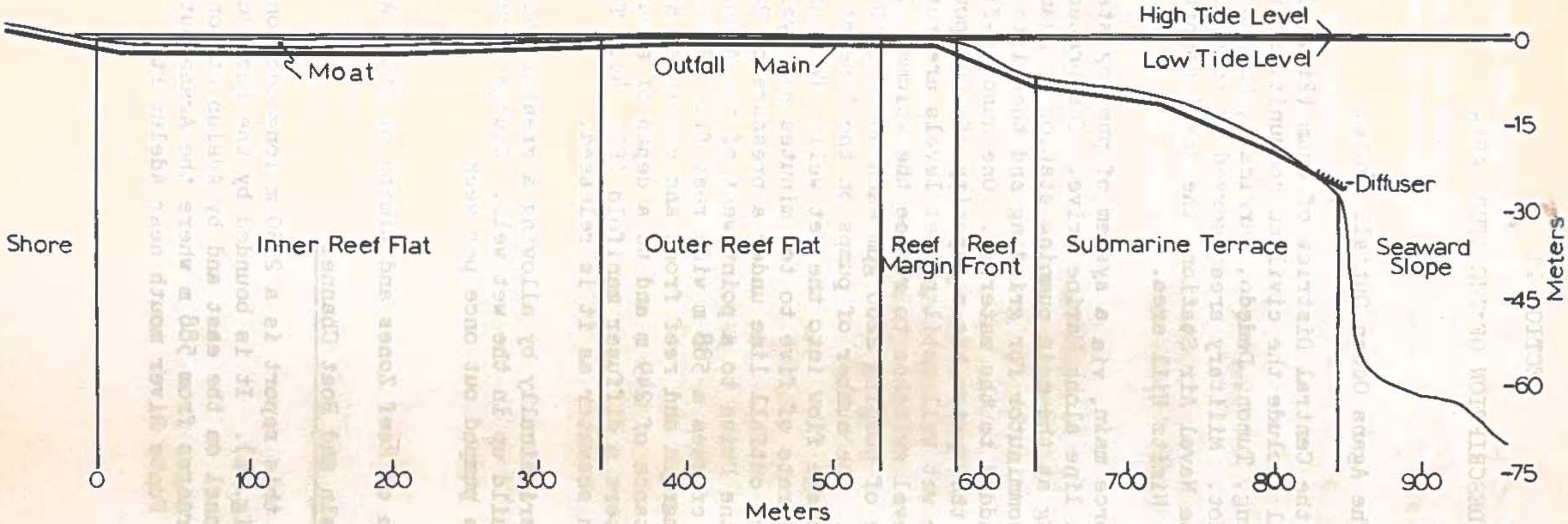


Figure 3. REEF PROFILE. This diagram shows the vertical as well as the horizontal relationship of the outfall main and diffuser system to the reef zones, (Vertical exaggeration is X3.7)

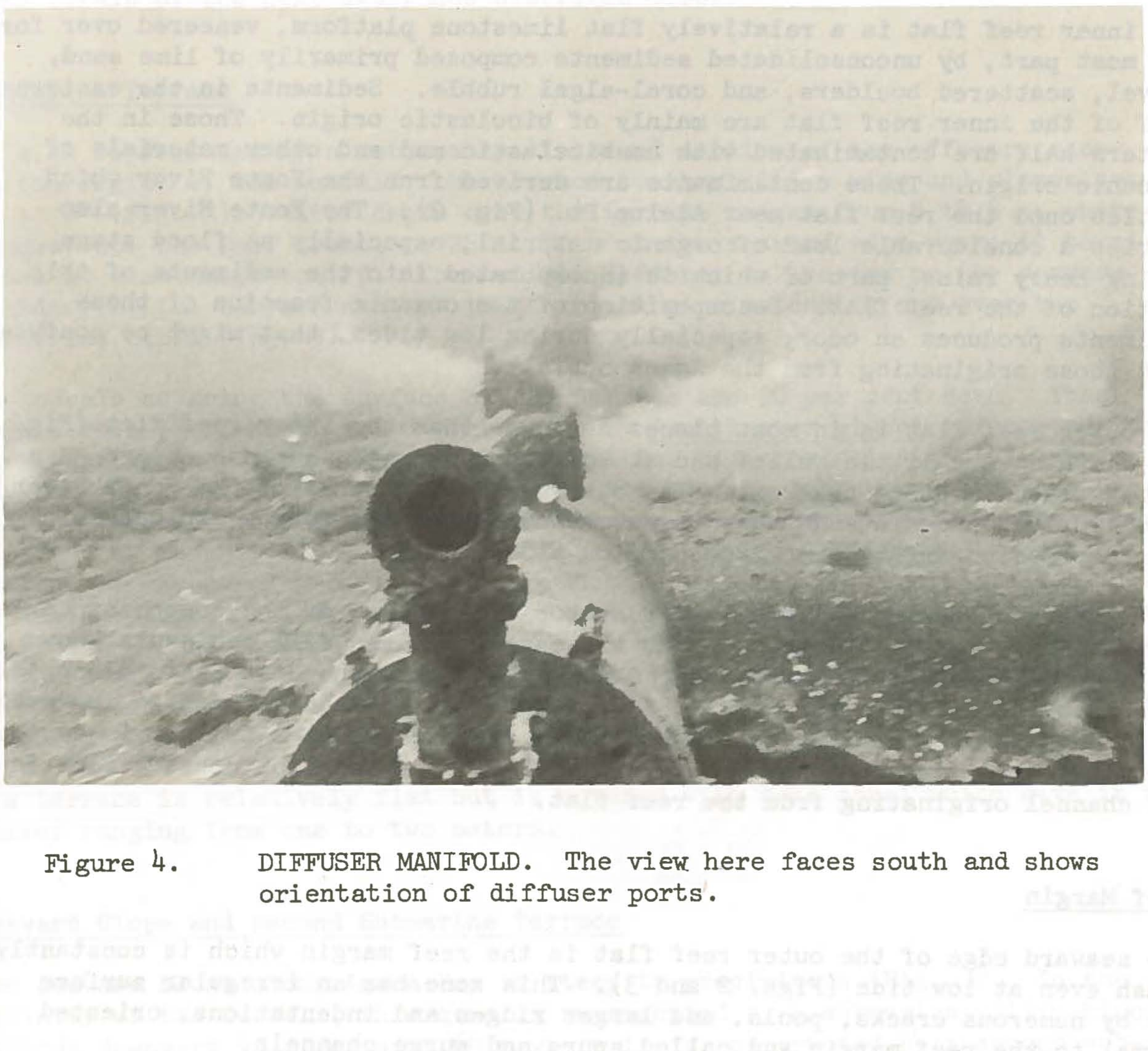


Figure 4. DIFFUSER MANIFOLD. The view here faces south and shows orientation of diffuser ports.

Reef flat is here defined as the shallow,fringing,limestone platform extending from the shore seaward to the wave washed margin. The seaward portion, commonly exposed during lower tides, is called the outer reef flat. The inner reef flat is that portion which retains water during lower tides (Figs. 2 and 3). The impounded band of water on the inner reef flat is referred to as the "moat".

The inner reef flat is a relatively flat limestone platform, veneered over for the most part, by unconsolidated sediments composed primarily of lime sand, gravel, scattered boulders, and coral-algal rubble. Sediments in the eastern half of the inner reef flat are mainly of bioclastic origin. Those in the western half are contaminated with nonbioclastic mud and other materials of volcanic origin. These contaminants are derived from the Fonte River which empties onto the reef flat near Adelup Pt. (Fig. 2). The Fonte River also carries a considerable load of organic material, especially at flood stage during heavy rains, part of which is incorporated into the sediments of this section of the reef flat. Decomposition of the organic fraction of these sediments produces an odor, especially during low tides, that might be confused with those originating from the Agana outfall.

The outer reef flat is in most places narrower than the inner reef flat (Fig. 3). It has very little relief and at low tide, exposed sections appear as a rather flat limestone pavement. The outer reef flat opposite the Fonte River is slightly depressed and there is generally a seaward flowing rip current at this depression during both high and low tides.

The Agana Boat Basin is a small boat harbor dredged out of the southeast corner of the inner reef flat (Fig. 2). To the east is a land fill peninsula known as Paseo de Susana. The Agana Boat Channel runs from the Boat Basin along the western border of the Paseo to the reef margin and provides a passage for small boats into the Philippine Sea. The channel averages about 2 to 12 m in depth. Circulation is very poor in the basin but there is a constant seaward flow in the channel originating from the reef flat.

Reef Margin

The seaward edge of the outer reef flat is the reef margin which is constantly awash even at low tide (Figs. 2 and 3). This zone has an irregular surface cut by numerous cracks, pools, and larger ridges and indentations, oriented normal to the reef margin and called spurs and surge channels.

Reef Front

The reef front begins at the seaward edge of the reef platform where the reef margin abruptly increases in depth or degree of slope (Fig. 3). It is structurally composed of the seaward extentions of the reef margin spurs which are in this zone called buttresses, and surge channels which are in this zone called submarine grooves. The point where these structures terminate marks the seaward boundary of the zone. The depth at which the reef front terminates or grades into the flattened "submarine terrace" along Agana Bay generally ranges between six and eight meters. The only significant reef coral community occurs in this zone. This band of live corals is in sharp contrast with the dead corals of the next two zones described below.

Submarine Terrace

This is represented by a noticeably flattened section of the offshore slope. In the region of the outfall, the terrace is about 165 m wide and slopes seaward 7° to 8° (Fig. 3). Water depth over the terrace ranges from 6 to 8 m, where it grades into the reef front, to 25 to 30 m at the seaward edge where it terminates at a submarine cliff. The outfall diffuser is located on the seaward boundary of the terrace and has the terminal part extending out over the submarine cliff (Fig. 5).

The corals covering the surface of the terrace are 90 per cent dead. These corals were presumably killed previously by *Acanthaster planci* (Linnaeus) the coral-eating starfish, although no observation of infestation of this region has been recorded. Dead corals were reported during a pre-construction survey made by Metcalf and Eddy (1965) which predate records of starfish infestation reported by Chesher (1969) and Randall (1971, unpublished thesis). Small buttons of new coral growth on the terrace show that some resettlement of corals is taking place. A large section of a structural steel boom, left at the outfall site by the construction company, has numerous coral colonies developing on its surface. Several colonies of *Pocillopora* are at present greater than 15 cm in diameter. The fauna and flora of the terrace is poorly developed when compared to "live coral" areas of a similar type.

The terrace is relatively flat but is covered with dead coral which give it a relief ranging from one to two meters.

Seaward Slope and Second Submarine Terrace

The seaward slope along Agana Bay is steep to precipitous (Fig. 3). In the vicinity of the outfall, this zone is represented by a submarine cliff which extends downward to a depth of 60 m where it is interrupted by a second submarine terrace. The floor of this terrace is composed of coral knobs, knolls, and mounds with local patches of bioclastic sediments interspersed between.

Figure 5. TERMINUS OF DIFFUSER ON SEACLIFF. Depth is 27 m.

SECTION III

GENERAL METHODS

Physical Parameters

Temperature

Temperature was measured to the nearest 0.5°C using hand held mercury in glass thermometers. Outfall temperatures were measured *in situ* at diffuser ports by SCUBA divers. Temperatures taken downcurrent from the outfall and on the reef flat were taken with the same thermometers, using Van Dorn samplers for "bucket" temperatures. Additional measurements were made near the outfall with a recording thermistor, housed in a Hydro Products Model 502 *in situ* current meter.

Currents

Currents were measured on the submarine terrace with one meter and ten meter drift crosses (Fig. 6), and a Hydro Products Model 502 *in situ* current meter (Fig. 7). The current meter was placed four meters from the bottom and a distance of 20 m south of the diffuser manifold. This device continually recorded current direction and velocity and plotted the data on a paper tape. Current direction was recorded to the nearest degree magnetic and velocity to the nearest 0.15 kt. Flourescine dye was used to study current patterns on the reef flat.

Sediment

Settleable materials were measured with a 0.25 m^2 grid along a transect line strung east and west of the diffuser (see p. 18).

Suspended Materials

Test materials and equipment ordered for the determination of suspended solids failed to arrive and only visual estimates could be made.

Odor

Crude estimates of distance and direction from the outfall were recorded at the extreme limits of detectable odors.

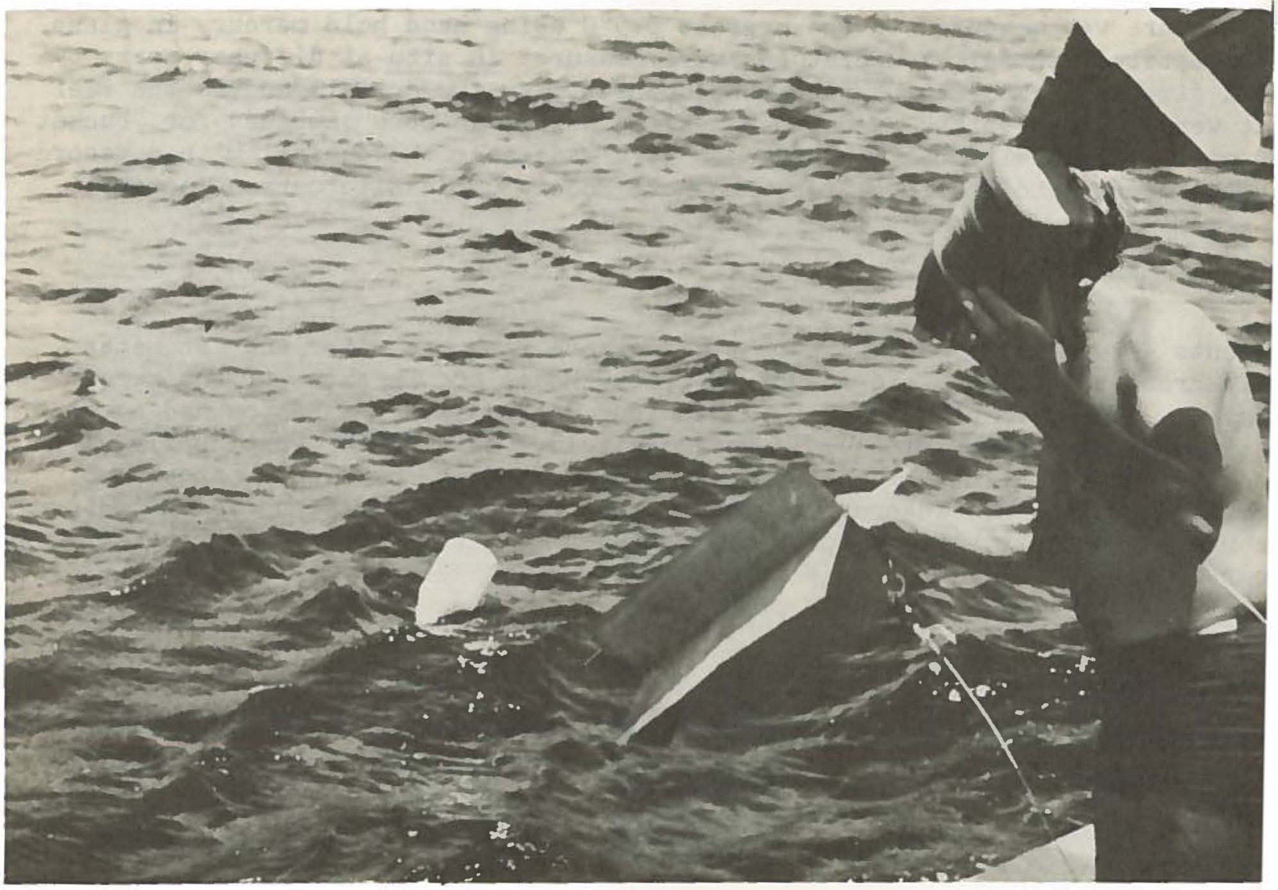


Figure 6. DRIFT CROSS CAST. A permanent station buoy (white) is already anchored in place as a reference. The drift cross with buoy (in hand) and marker flag is dropped along side the reference buoy.

Figure 7. IN SITU CURRENT METER.

Light Penetration and Visibility

Attempts were made to measure optical density with a secchi disk when the submarine photometer, ordered, failed to arrive. The secchi disk proved useless due to lack of sensitivity. Most of the time the disk was on bottom before it passed from sight, yet water in the sewer boil was obviously murky.

Wind and Sea Conditions

Wind and sea directions were determined from compass headings. Wind velocity was obtained from a portable anemometer and wave height was estimated.

Chemical Parameters

Water samples for chemical analyses were taken with two-liter Van Dorn samplers, either messenger tripped from the research vessel or manually tripped by SCUBA divers (Figs. 8 and 9). Analyses of water samples were done by the Guam Water Pollution Control Commission's Water Quality Laboratory.

pH

Was measured with a Photovolt Corporation pH meter but the data proved to be of no value as an indicator of pollution.

Nitrate

The Brucine Method was used to analyze nitrates (Standard Methods, 1965). This method requires the addition of sodium chloride to the blanks, standards and samples to allow for the effect of salinity. We discovered that this was not being done and were forced to eliminate all nitrate data.

Phosphate

The Stannous Chloride method was used to measure orthophosphate (Standard Methods, 1965). Lab difficulties were encountered because of salinity interference and the data is too unreliable for use.

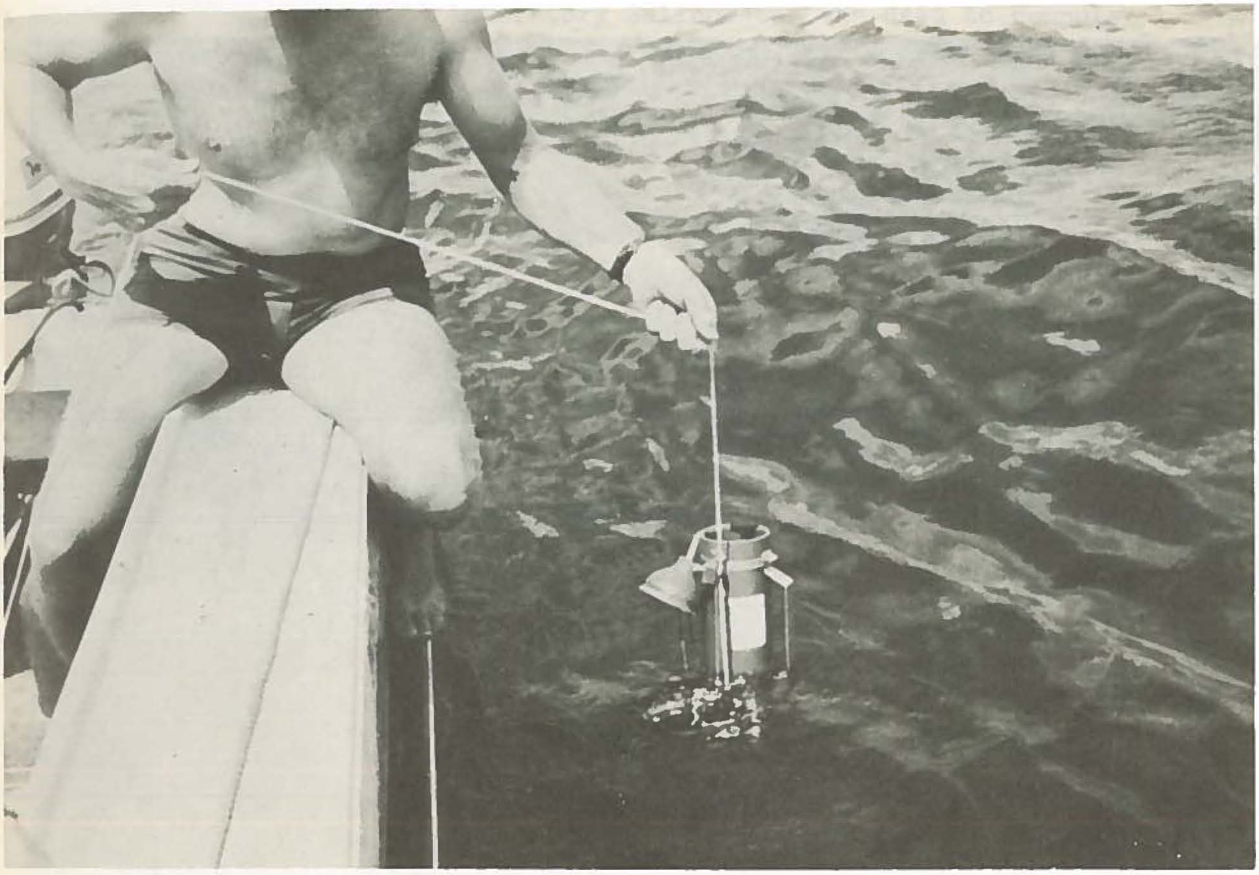


Figure 8. VAN DORN SAMPLER. The device will be messenger tripped at 10 m.

Figure 9. DIFFUSER SAMPLE BEING TAKEN. The Van Dorn Sampler is hand tripped in the diffuser port.

Dissolved Oxygen

Dissolved oxygen was measured with the Winkler (Azide modified) method (Standard Methods, 1965).

Salinity

A Bissett-Berman Model 6220 Laboratory Salinometer was used to compute salinities.

Biological Parameters

Coliforms

Both total and fecal coliform contamination were analyzed using the multiple tube fermentation technique (Standard Methods, 1965).

Effects on Marine Organisms and Potential Pollution Indicators

SCUBA observations of dominant organisms were made to evaluate any major detrimental affects. This method was crude but served as a reasonable measure of the direct effects of sewage discharge on the benthic community. Investigation of a potential algal indicator organism is outlined in the Appendix.

SECTION IV

SAMPLING PROGRAM AND RESULTS

Section II points out that sewage discharges from diffuser ports in 27 m of water and 249 m north of the Agana reef margin (Figs. 2 and 3). The research problem was then to discover the fate of this effluent after discharge. Does all or part of the material settle to the bottom as sludge, does all or part of it become suspended and drift away more or less at the same depth as discharged, or does all or part of the sewage rise to the surface? These were the immediate questions to be answered. Other questions could not be posed until the foregoing were resolved.

It was discovered early in the research, by direct observation with SCUBA, that sewage discharged from the diffuser manifold rises rather quickly to the upper layers of the water mass (Fig. 10). The primary reasons for this are the low density of the freshwater carrying the sewage and waste oils (both cooking and lubricating varieties).

Sediment Study

Although no great accumulation of sludge or other settleable materials, attributable to the outfall, was found in the immediate vicinity of the diffuser manifold, there were enough to attempt quantification in order to establish a baseline for future investigations. To this end, a series of transects were run by SCUBA divers from east to west (Fig. 11). Quadrats, 0.25 m^2, were placed every three meters on the transect line and examined for settleable materials attributable to the outfall (Figs. 12a and b). Greatest accumulation of sediment observed was less than one centimeter in thickness and was restricted to the shadow of the effluent plume as it rose to the surface. This thin veneer of settleables consisted mainly of cellulose material, bits of cloth, cigarette filters, metal foil, and a fine gray granular substance with a density only slightly greater than seawater. Accumulation of these settleable materials was greatest during periods of calm seas and low current velocities of the water mass over the submarine terrace. During periods of normal sea and current conditions, the ground surge of water, due to wave action, even at depths of 27 m, tended to keep these low density materials in suspension where they were carried away by currents.

Combined results of the two transects show that particulate settleables first increase and then tend to diminish as distance from the diffuser ports increases (Fig. 13). The high initial velocity of the effluent reduces the number of large particulates in the immediate vicinity of the diffuser ports (Transect Station 1. Figs. 11 and 13).

Immediately seaward of the outfall a submarine cliff (seaward slope) drops off sharply to a second submarine terrace at a depth of 60 m. We anticipated that

Figure 10. RISING SEWAGE PLUME. The first two ports are facing east and the plume is being deflected up and over by the westerly current.

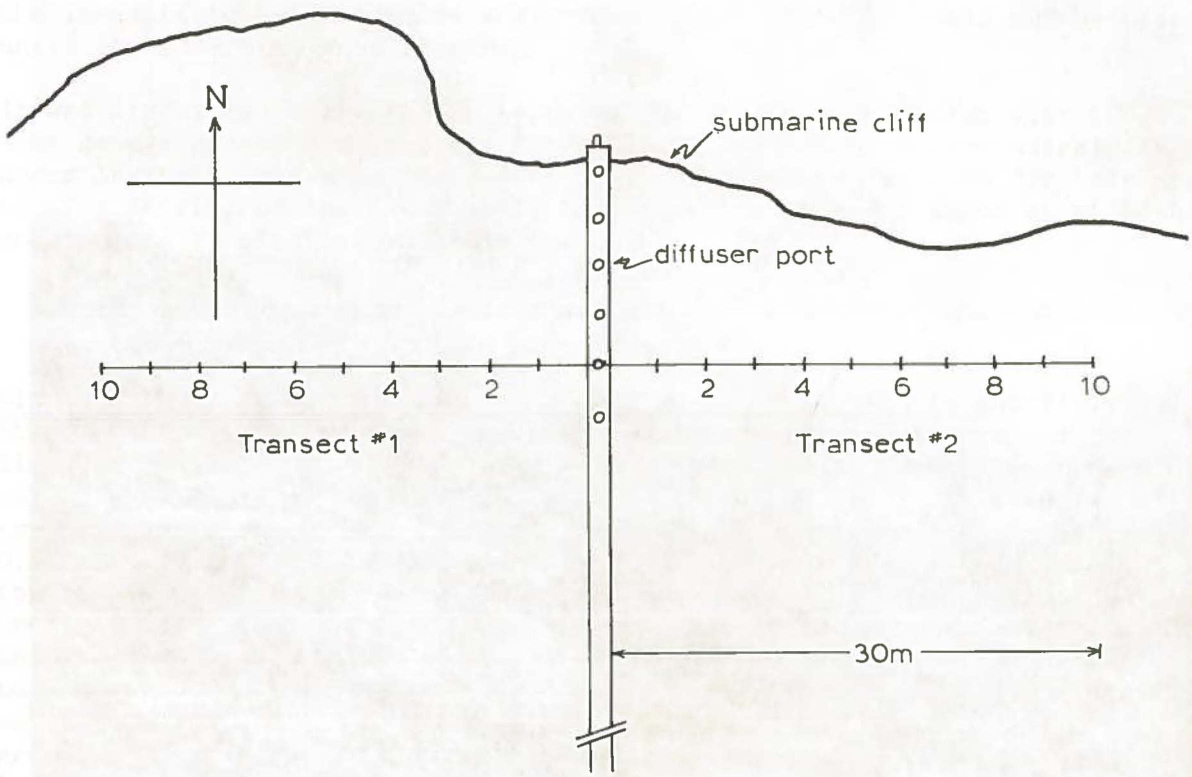


Figure 11. OUTFALL TRANSECT STATIONS. These stations were used in the sediment study, the plume study and the algal study (Appendix).

a.

b.

Figure 12. a. LAYING TRANSECT LINE, b. TRANSECT GRID. The grid is being studied for sediments attributable to the outfall. Note the suspended sewage particles in foreground.

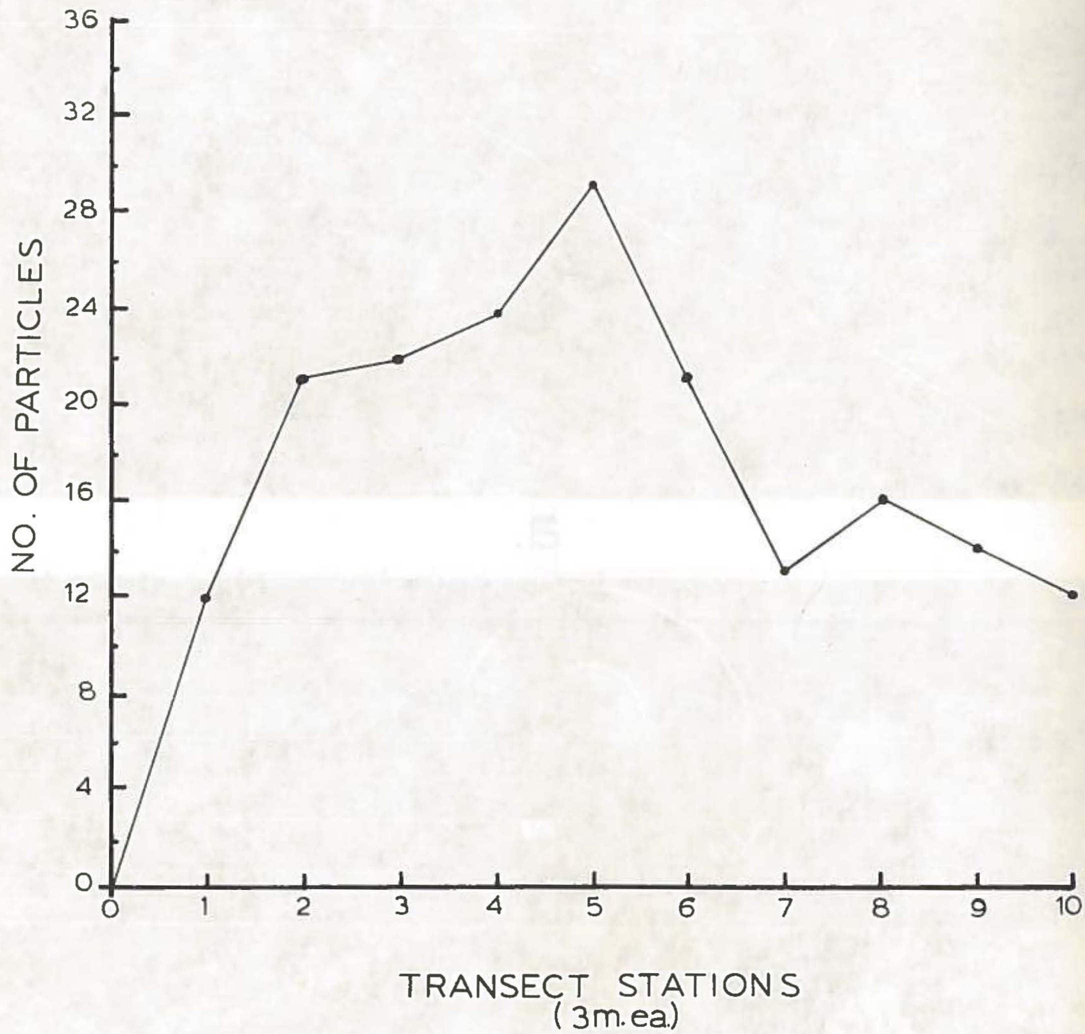


Figure 13. SEDIMENT TRANSECT DATA. The number of particles refers to the number in a single 0.25 m^2 grid. The index items recorded in the grid were: toilet tissue, paper towel, newspaper and cloth fragments; cigarette filters and numerous items related to feminine hygine. We were rewarded with a one dollar bill on one occasion.

sewage sludge or particulate material might accumulate at the base of this submarine cliff but observations with SCUBA reveal that accumulations here are no greater than those found in the immediate vicinity of the diffuser at the upper margin of the cliff. Visual observations shoreward of the diffuser manifold showed no increase in particulate accumulation. Additional observations for accumulation of settleable material were made at all the "permanent" stations (p. 44). No significant amount of settleable material, attributable to the outfall, was observed at these stations.

Plume Study

Chemical and Physical

Since a high percentage of the effluent rose toward the surface (Fig. 10), it was necessary to determine to what extent mixing occurred. A study of the sewage plume between the diffuser ports and the surface was initiated. Transect lines were established immediately under the plume to provide a horizontal component (similar to sediment study, Fig. 11). This was necessary because of the tendency of the plume to bend in the prevailing currents as does a column of smoke. The vertical component was controlled by a SCUBA diver using a float on a marked line to measure from the bottom to the plume center. Water samples were taken every three meters on the horizontal and at the intersect point of the plume center on the vertical. Figure 14 shows the sample positions and general shape of the outfall plume. Samples were taken with diver-held Van Dorn samplers and carried to a boat, anchored over the outfall, where samples were bottled and labeled for later analyses. Dissolved oxygen samples were fixed *in situ*.

Observations of visible solids indicate that the majority of the materials accumulate in a suspended or floatable state in the upper one to three meters of water. Further visual observations show that these surface concentrations then drift "downstream" with prevailing currents. The sediment transect study (Fig. 13) and downstream observations by SCUBA divers show a slow "rain" of particulate matter from the surface layers as sewage drifts away from the outfall. No method was devised to measure the rate of settling from this surface layer.

By using temperature, dissolved oxygen, and salinity values of the raw sewage (samples taken at diffuser port) and comparing them to values obtained from other parts of the sewage plume, the degree of mixing and sewage entrainment in the receiving waters was estimated. Figure 15 indicates that mixing of sewage effluent with seawater takes place rapidly and within a short distance of the diffuser ports. Normal values of the above parameters from a control station offshore (Sta. 4D, Fig. 26) show an average salinity of 33.7 °/oo and an average oxygen of 6.40 mg/l. Temperature in the diffuser ports never varied more than a half a degree above ambient temperature and was normal within one to two meters of the outfall.

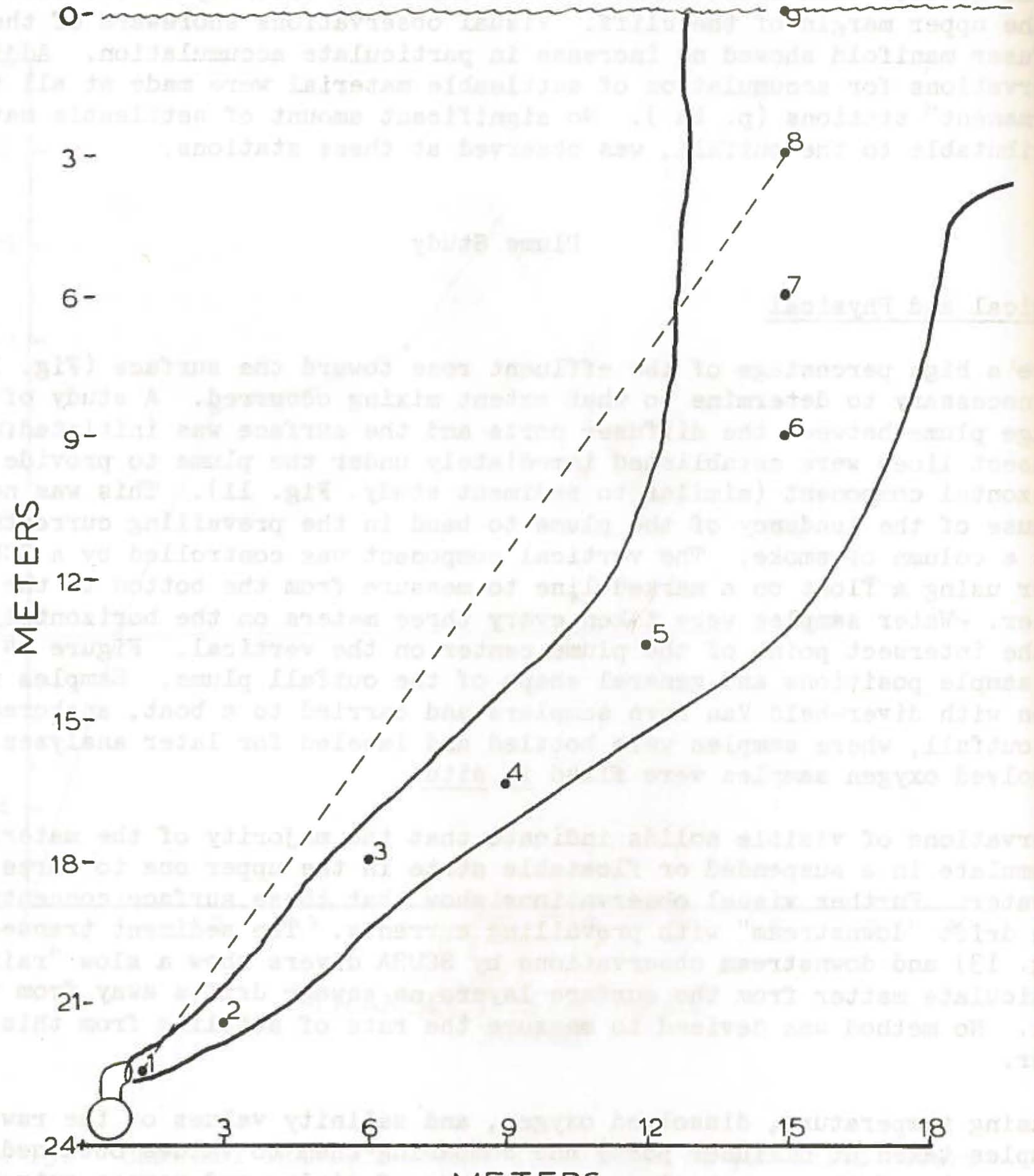


Figure 14. PLUME DIAGRAM. Sample stations are shown within the plume and the dotted line shows the measurement of the direct distance of the station from the diffuser port that is used in Figure 15.

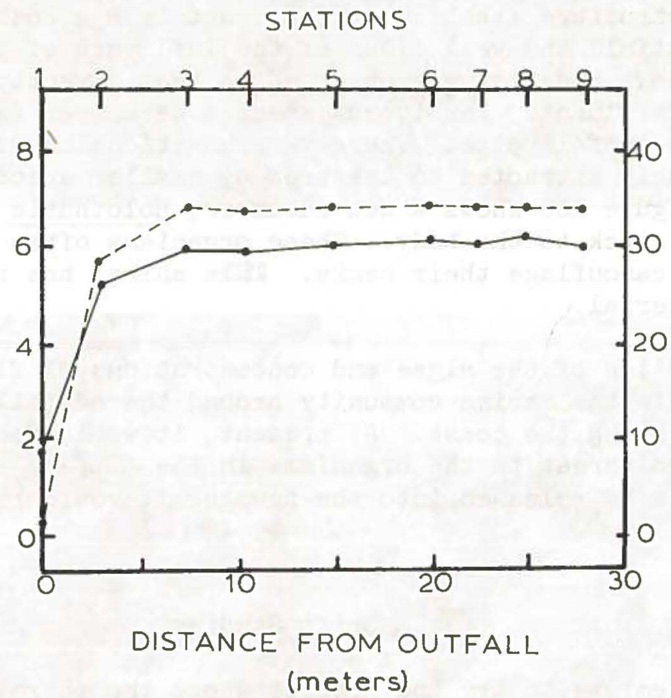


Figure 15. PLUME DATA. Distance from the outfall refers to the straight line distance, see Figure 14.

Biological

Coliform counts tended to be higher at the diffuser ports and on the surface than in the midwater portions of the plume. This somewhat contradictory phenomenon is discussed in more detail later (p. 45).

As a part of the plume study, additional visual observations were made with SCUBA gear to ascertain what effect, if any, the effluent had on marine organisms in the immediate vicinity of the outfall.

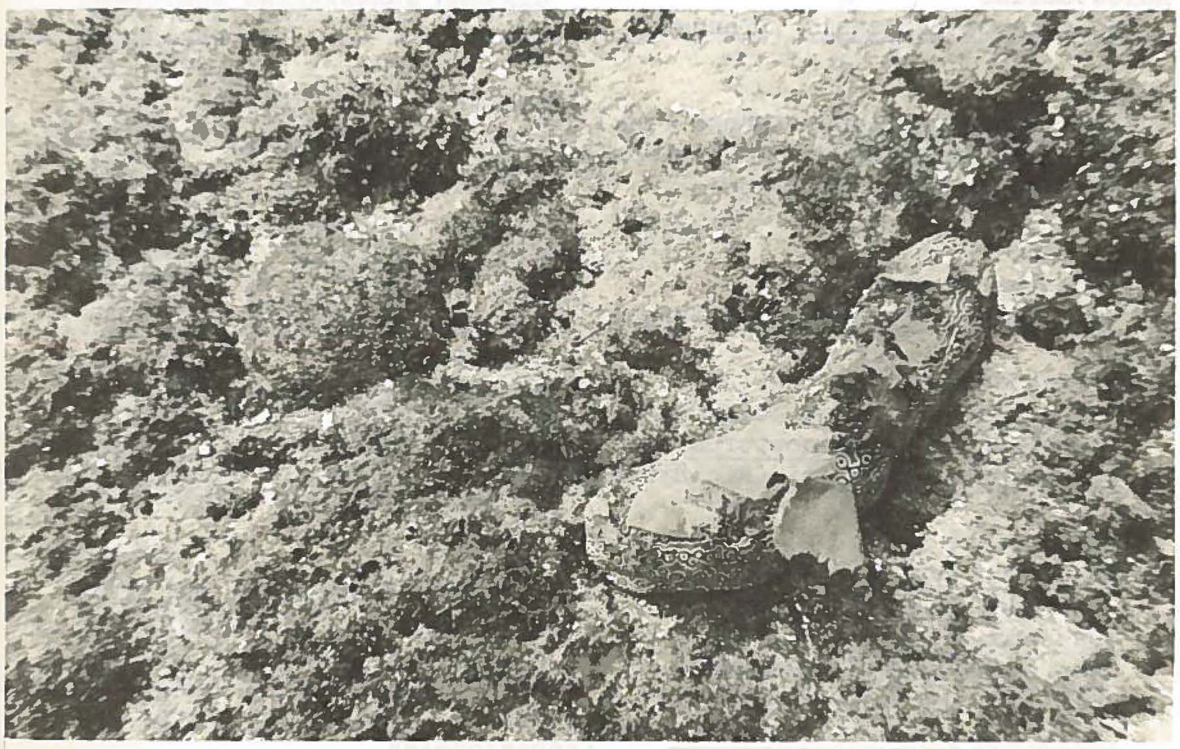
A discussion of differences in algal composition is found in the Appendix. The most obvious change in the fauna was the rather large accumulation of fishes in the plume area itself (Fig. 16a). Over 59 species were observed in the area (Table 1) and these organisms seemed to be attracted to the plume and diffuser structure itself. A fish count from a control station 500 m east of the outfall and well clear of the influence of the effluent, shows only 47 species. Species were observed to feed directly on particulate matter in the effluent. Herbivorus species were seen feeding on the algae growing on the outfall pipe. There were additional aggregations of predatious species, probably attracted to the area by smaller species feeding in or near the plume. Figure 16b shows a sea cucumber, Holothuria argus (Jaeger), with toilet tissue stuck to the body. These organisms often use bits of the substratum to camouflage their backs. This animal has selected a most unnatural cover material.

With the exception of the algae and concentrations of fishes, there was little to differentiate the marine community around the outfall from those in control areas farther along the coast. At present, it would seem that ordinary domestic waste is no threat to the organisms in the outfall area. However, should toxic materials be released into the sewage, it would result in a considerable fish kill.

Drift Studies

The next problem was to try and predict where the entrained material drifted and how far, before losing its identity through dilution and chemical and biological degradation. Did it drift "safety" out to sea or back into inshore waters where it might well become a public health problem? to answer these questions, it was necessary to design several sampling programs. First, the current regimes in the outfall study area had to be determined. Second, a downstream study of the effluent as it drifted along would have to be made to evaluate dilution, degredation, and ultimate destination of the effluent. Third, a series of "permanent" stations had to be established on the submarine terrace adjacent to the reef front to examine background levels, if any, of materials attributable to the outfall both upstream and downstream. Fourth, a study of the water mass on the Agana reef flat would have to be made to determine if pollutants attributable to the outfall were entering the bay over

a.



b.

Figure 16. a. FISH AGGREGATIONS AROUND PLUME, b. Holothuria Argus with CAMOUFLAGE (toilet tissue).

Table 1. CHECKLIST OF FISHES. Compares the outfall with a control area 500 m east of the outfall. D=Dominant, C=Common, P=Present, R=Rare, -=Absent

Fish Species	Agana Outfall	Controll Area
F. Acanthuridae		
Acanthurus glaucoparieus Cuvier	-	R
Acanthurus nigrofuscus (Forskal)	D	C
Acanthurus pyroferus Kittlitz	C	C
Acanthurus xanthopterus Cuvier & Valenciennes	C	-
Ctenochaetus binotatus Randall	P	P
Ctenochaetus hawaiiensis Randall	R	-
Ctenochaetus striatus (Quoy & Gaimard)	C	C
Naso hexacanthus (Bleeker)	C	-
Naso lituratus (Bloch & Schneider)	C	C
F. Apogonidae		
Apogon sp.	P	P
F. Aulostomidae		
Aulostomus chinensis (Linnaeus)	-	P
F. Balistidae		
Balistapus undulatus (Mungo Park)	P	P
Balistes bursa Bloch & Schneider	C	-
Melichthys vidua (Solander)	P	-
F. Blenniidae		
Escenius bicolor (Day)	-	P
Meiacanthus atrodorsalis (Gunther)	C	C
F. Canthigasteridae		
Canthigaster cinctus Solander	P	-
Canthigaster janthinopterus (Bleeker)	P	-
Canthigaster solandri (Richardson)	P	P
F. Chaetodontidae		
Chaetodon auriga Forskal	P	-
Chaetodon falcula Bloch	P	-
Chaetodon ephippium Cuvier	P	-
Chaetodon lunula (Lacepede)	P	P
Chaetodon mertensii Cuvier	P	P
Chaetodon punctato-fasciatus Cuvier	P	P

Table 1. (Continued)

Fish Species	Agana Outfall	Control Area
F. Chaetodontidae (continued)		
Centropyge bispinosus (Gunther)	C	P
Centropyge flavissimus (Cuvier)	-	P
Forcipiger flavissimus Jordan & McGregor	P	P
Pygoplites diacanthus (Boddaert)	-	P
F. Eleotridae		
Nemateleotris magnificus Fowler	-	R
F. Holocentridae		
Holocentrus caudimaculatus Ruppell	-	P
Holocentrus spinifer (Forskal)	-	P
Myripristis multiradiatus (Gunther)	P	P
F. Labridae		
Bodianus axillaris (Bennett)	P	P
Cheilinus rhodochrous Gunther	C	-
Cheilinus sp.	-	R
Coris aygula Lacepede	P	-
Coris gaimardi (Quoy & Gaimard)	P	-
Epibulus insidiator (Pallas)	P	-
Halichoeres hortulanus (Lacepede)	C	P
Halichoeres sp.	C	C
Henigymnus melapterus (Bloch)	-	P
Hologymnosus semidiscus (Lacepede)	R	-
Labroides bicolor Fowler & Bean	P	P
Labroides dimidiatus (Cuvier &	C	P
Valenciennes)		
Macropharyngodon pardalis (Kner)	P	-
Pseudocheilinus octotaenia Jenkins	P	-
Thalassoma lutescens (Lay & Bennett)	C	-
Xyrichthys taeniourus (Lacepede)	P	-
F. Lutjanidae		
Aphareus furcatus (Lacepede)	-	R
Lethrinus sp.	P	-
Macolor niger (Forskal)	R	-
Monotaxis grandoculis (Forskal)	P	-
Scolopsis cancellatus (Cuvier &	-	P
Valenciennes)		
F. Monacanthidae		
Pervagor melanocephalus (Bleeker)	-	R

Table 1. (Continued)

Fish Species	Agana Outfall	Control Area
F. Mugiloididae		
Parapercis cephalopunctatus (Seale)	C	-
Parapercis clathrata Ogilby	P	-
F. Mullidae		
Mulloidichthys auriflamma (Forskal)	-	P
Parupeneus bifasciatus (Lacepede)	D	C
Parupeneus multifasciatus (Quoy & Gaimard)	P	P
Parupeneus pleurostigma (Bennett)	R	-
F. Ostraciontidae		
Ostracion meleagris Shaw	-	R
F. Penpheridae		
Pempheris oualensis Cuvier & Valenciennes	-	P
F. Platacidae		
Platax orbicularis (Forskal)	P	-
F. Pomacentridae		
Abudefduf lacrymatus (Quoy & Gaimard)	-	C
Chromis leucurus Gilbert	-	R
Pomacentrus traceyi Woods & Schultz	D	P
Pomacentrus vaiuli Jordon & Seale	D	C
F. Scaridae		
Scarus lepidus Jenyns	P	-
Scarus sordidus Forskal	D	C
Scarus venosus Cuvier & Valenciennes	C	P
Scarus sp.	P	-
F. Scorpaenidae		
Pterois volitans (Linnaeus)	P	-
F. Serranidae		
Cephalopholis argus Bloch & Schneider	-	P
Cephalopholis urodelus (Bloch & Schneider)	R	P
Epinephelus emoryi Schultz	-	P
Grammistes sexlineatus (Thunberg)	R	-
F. Siganidae		
Siganus rostratus (Valenciennes)	C	-

Table 1. (Continued)

Fish Species	Agana Outfall	Control Area
F. Tetraodontidae		
Arothron nigropunctatus Bloch & Schneider	-	P
F. Zanclidae		
Zanclus cornutus (Linnaeus)	P	P

Total Outfall Species = 59

D = 5
C = 15
P = 33
R = 6

Total Control Species = 47

D = 0
C = 10
P = 31
R = 6

the reef margin.

General Current Study

1. Drift Cross Data: Thirty-two drift cross casts were made from January to May 1970. Drift cross data show a general tendancy of currents over the submarine terrace to flow in a westerly direction from the outfall (Fig. 17). On occasion, easterly drifts were recorded. During these times, the courses of the drift crosses tended to be erratic and moved at a slower rate and traveled a shorter distance than the more common westerly drifts.

Velocity varied considerably from virtually no movement on some days to 0.75 kts (Table 2). The greatest distance for a drift cross track was 3.0 nautical miles (5.6 km) (Fig. 17, Table 2).

There is some correlation of the shifts in current direction and velocity from west to east with tide changes, but these shifts may not be predicted with any regularity from drift cross data alone.

In General, the one meter and ten meter drift crosses diverge, with one meter crosses moving faster than ten meter ones (Fig. 17, Table 2). These data indicate two possibilities: 1) that the one meter crosses encounter less line friction than the ten meter ones, 2) that the upper one meter layer or more of water is under greater influence from the prevailing winds than the ten meter ones. On at least eight drift cross casts, one or both crosses moved directly into the wind in an easterly direction. On four of these occasions, the ten meter cross drifted to the east, into the wind, while the one meter cross went to the west, with the wind (Fig. 17). It is therefore apparent from the behavior of the ten meter crosses that the deeper water layers may be more responsive to tidal or other current shifting phenomena and that the one meter cross is more likely wind controlled.

A current study by Pacific Island Engineers (1951) utilizing drift bottles and other surface float devices indicated a low percentage of drift toward the shore in this area. Of 158 bottles released at the mouth of the Agana Boat Channel, 47 went ashore. Of this number, 19 landed in Agana Bay along the beach near Adelup Pt. Fifteen landed at Asan Pt. and six at Cabras Is. only six bottles grounded on beaches east of the boat channel. Seventy per cent of the bottles were never recovered and presumably drifted out to sea. Of 278 released at the outfall site itself, 36 went ashore at Asan Pt. and 84 per cent of the bottles drifted out to sea. Even though only a low percentage of the devices reached shore, these results might cast some doubt on this particular site for an outfall location. However, as a result of our work, we feel that many of the floating devices used by Pacific Island Engineers may not have been ballasted enough and were probably blown ashore by the prevailing northeast winds that were in effect on the days they released their devices.

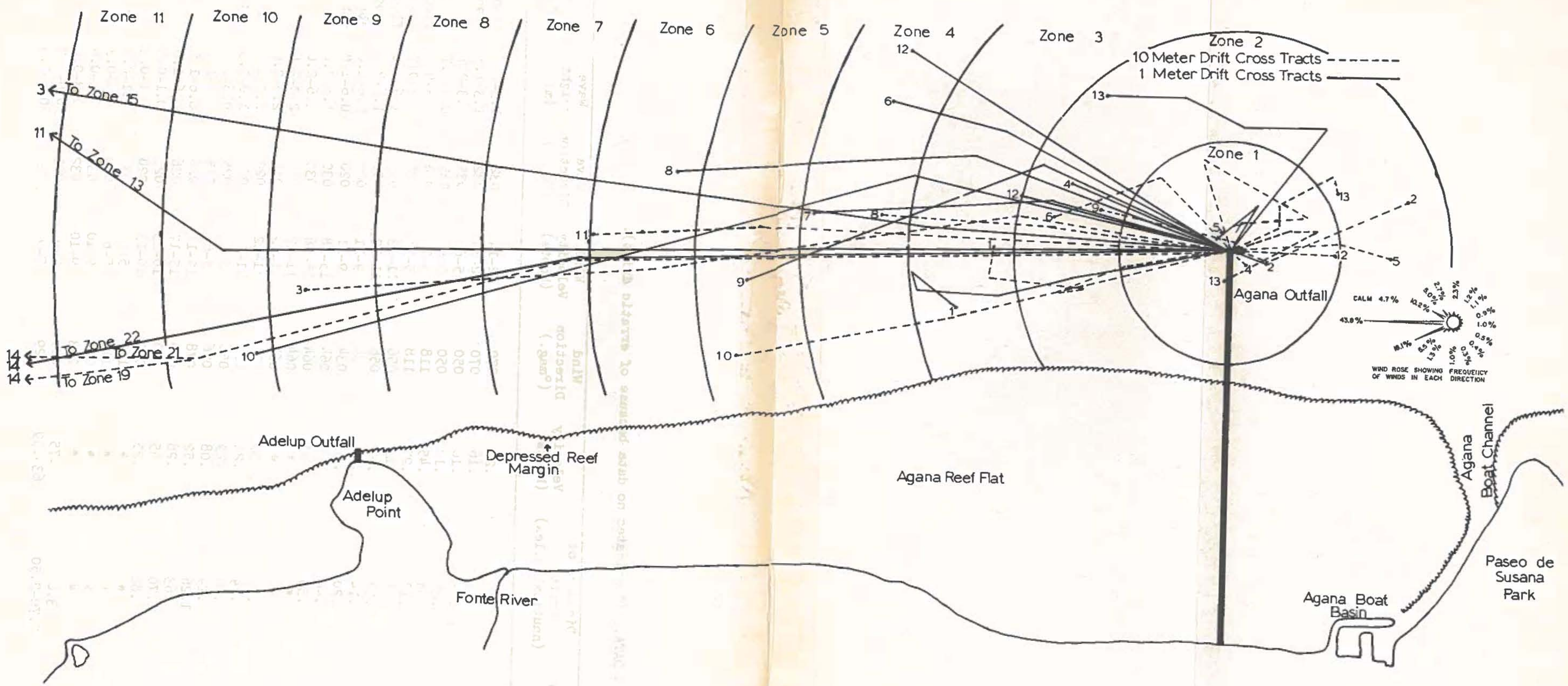


Figure 17. OFFSHORE CURRENT STUDY. Water sample results were averaged in each concentric zone. The numbers at the end of the drift tracks show drift cast dates as follow: (1) January 13, (2) January 27, (3) January 30, (4) February 6, (5) February 16, (6) February 26, (7) March 10, (8) March 16, (9) March 30, (10) April 14, (11) April 28, (12) May 8, (13) May 21, (14) May 26, 1970.

Table 2. DRIFT CROSS DATA. (*indicates no data because of erratic drift).

Date	Drift Cross Cost #	Depth (m)	Distance of Drift (nautical miles)	Velocity (knots)	Wind Direction (°mag.)	Wind Velocity (knots)	Wave Direction (°mag.)	Wave Height (m)	Tide Condition
1-13-70	1	1	.49	.20	070	12-14	032	1.3-1.5	flood to ebb
1-13-70	1	10	.40	.16	070	12-14	032	1.3-1.5	flood to ebb
1-27-70	1	1	.24	.10	050	5-6	035	0.3-0.7	ebb
1-27-70	1	10	.24	.10	050	5-6	035	0.3-0.7	ebb
1-30-70	1	1	1.88	.45	118	5-7	028	0.3-0.7	flood to ebb
1-30-70	1	10	1.18	.27	118	5-7	028	0.3-0.7	flood to ebb
2- 6-70	1	1	.21	.11	056	11-13	006	1.6-2.6	flood to ebb
2- 6-70	1	10	.03	.01	056	11-13	006	1.6-2.6	flood to ebb
2-16-70	1	1	.14	.05	034	9-11	020	0.6-1.0	ebb to flood
2-16-70	1	10	.20	.06	034	9-11	020	0.6-1.0	ebb to flood
2-26-70	1	1	.46	.17	064	15-18	030	1.6-2.0	ebb
2-26-70	1	10	.30	.10	064	15-18	030	1.6-2.0	ebb
3-10-70	1	1	*	*	064	11-12	014	2.0-2.6	ebb
3-10-70	1	10	*	*	064	11-12	014	2.0-2.6	ebb
3-16-70	1	1	.72	.36	034	11-12	020	1.0-1.3	ebb to flood
3-16-70	1	10	.44	.21	034	11-12	020	1.0-1.3	ebb to flood
3-30-70	1	1	.66	.29	056	5-6	025	0.6-1.0	ebb
3-30-70	1	10	.19	.08	056	5-6	025	0.6-1.0	ebb
4-14-70	1	1	1.26	.52	078	15-17	026	0.6-1.0	flood
4-14-70	1	10	.63	.28	078	15-17	026	0.6-1.0	flood
4-28-70	1	1	1.70	.55	040	10-13	028	0.1-0.3	ebb
4-28-70	1	10	.80	.25	040	10-13	028	0.1-0.3	ebb
5- 8-70	1	1	*	*	112	5-6	030	0.1-0.3	ebb
5- 8-70	1	1	*	*	112	5-6	030	0.1-0.3	ebb
5-21-70	2	1	*	*	073	9-10	032	0.3-0.6	ebb
5-21-70	2	10	*	*	073	9-10	032	0.3-0.6	ebb
5-26-70	2	1	3.0	.75	029	7-9	025	0.6-1.0	ebb
5-26-70	2	10	2.70-2.50	.63-.59	029	7-9	025	0.6-1.0	ebb

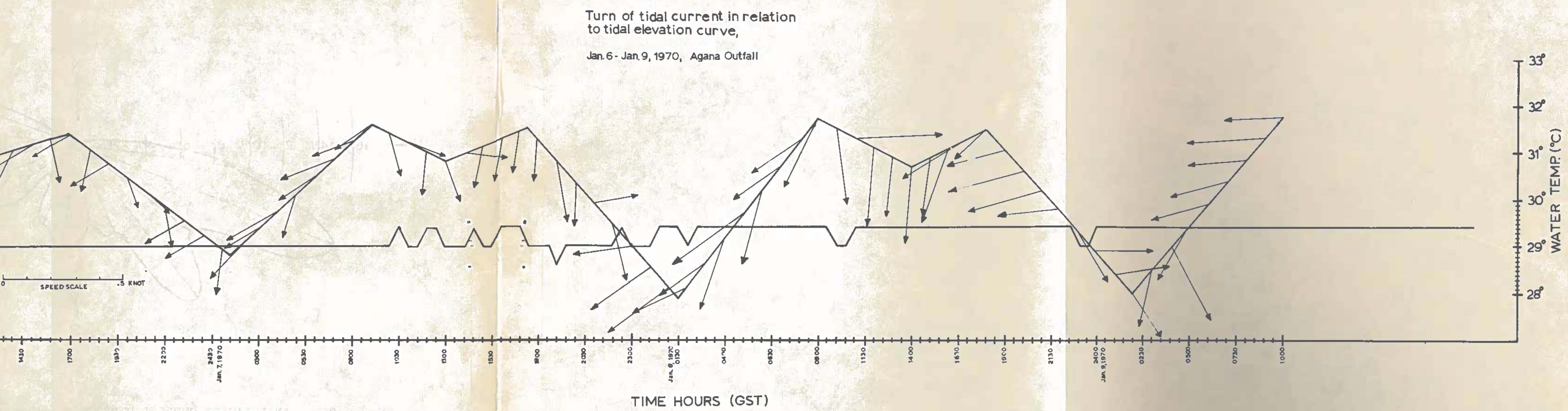
There is a prominant limestone spur to the west of the outfall. This submarine topographic feature tends to divert some of the westerly currents first to the northwest and then back to the southwest (Fig. 17). This is indicative of the effect that submarine topography may have on the currents over the submarine terrace in any given area.

Although on several occasions, during tidal shifts, drift crosses circled slowly toward the shore, they invariably turned and headed east or west and none of them ever reached the reef margin. It is apparent from these drift cross data that the net water movement is to the west of the outfall and effluent tends to pass well clear of Adelup Pt. and move on out into the Philippine Sea. In one instance, one of the crosses was picked up near "Camel Rock" which is due west of Adelup Pt. and on the reef margin (Fig. 17). This aroused some suspicion as to the presence of periodic eddy which could circulate this water mass into the Asan "Bomb Hole" area southwest of Camel Rock. The observation agrees with some of the Pacific Island Engineer's (1951) drift bottle data. There were no significant northerly drifts except during tidal changes when drift cross movements became erratic.

Drift casts made at offshore (B and C stations) transect stations (Fig. 26) tended to agree with the above. However, on occasion, the inshore one meter drift casts (A stations) showed some southerly movements toward the reef. When this occurred, it was usually correlated with unusually large swells from the north and northeast and/or when the wind was from the north. These times are fortunately rare. During the one year study period, the wind direction was primarily from the northeast and averaged about 10 kts. The wind rose on Figure 17 shows a lower percentage of northeasterly winds. But these data are based on overall wind conditions on Guam and not the study area alone. The sea direction was also northeasterly and averaged about 3.5 ft in height.

2. Current Meter Data: The current meter was anchored in such a way as to record current direction and velocity at a depth of 16 m (Figs. 7 and 18). Continuous tapes were recorded representing over 1100 hrs. of sampling time from October 1969 to July 1970. Current direction was found to be related to several factors, the most important being the tidal phase. Guam has semidiurnal tides and during the flood tide, from lower low water to higher high water, there is a strong southwesterly current. After the crest is reached and ebb tide begins, the direction swings briefly through the south to the east or southeast and at times carries over into the next flood (Figs. 19 and 20). Normally however, as the higher low water trough is reached, the current shifts to the south again. During the flood tide from the higher-low water to the lower high water crest, the predominant direction again becomes southwest to south southwest. This southwesterly direction carries over the crest into the early part of the next ebb. It then shifts to a south-southeast and then to an east direction as the lower low water trough approaches. These current shifts may occur in twenty minutes or less.

Figure 18. SETTING CURRENT METER.



E CURRENT METER TAPE. The arrows on the solid line
level) indicate current direction at that stage of
ide. The length of the arrow shows the velocity.
econd solid line represents temperature.

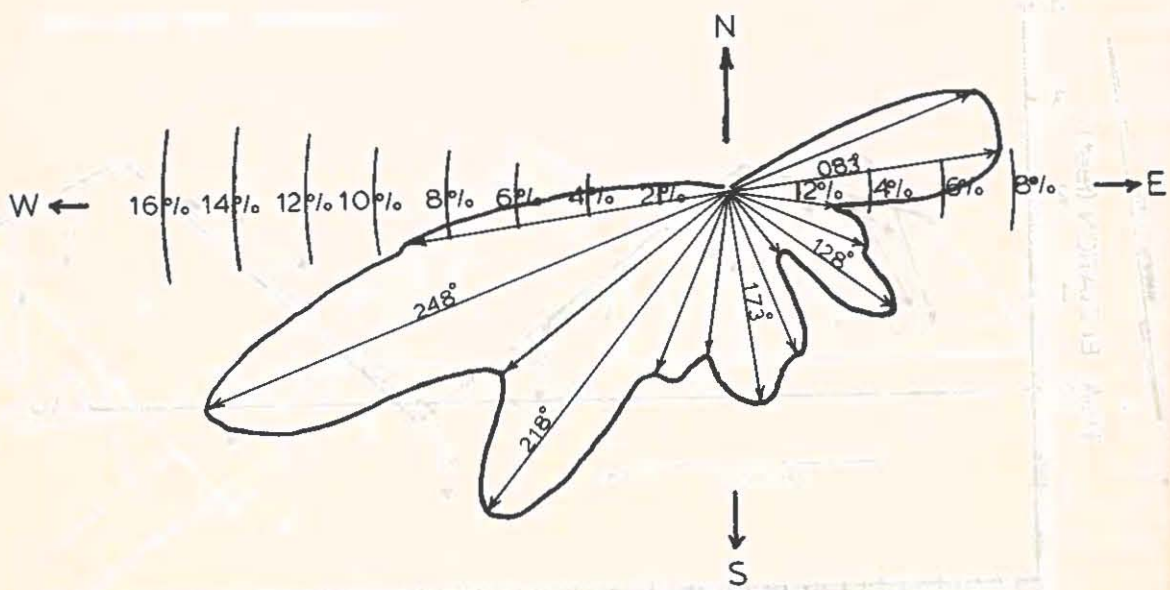


Figure 20. ANALYSIS OF CURRENT DIRECTION. The arrows shows some of the dominant directions of flow. The concentric radii show the percent of the time the current flows in a particular direction. These data are compiled from all the current meter tapes.

They are always characterized by a swing through the south and never through the north. We believe this to be due, in part, to the topographic influence of the submarine cliff to the seaward of the current meter location. This explains somewhat, the flat north side of Figure 20. Velocity ranged from 0 to 0.70 kts with the normal velocity between 0.2 and 0.4 kts (Fig. 21).

Effluent Drift Study

Drift crosses, set for one meter and ten meter depths, were cast directly into the sewage boil as it surfaced near the outfall (Fig. 22). It was assumed that the drift crosses would move along in the same water mass that bore the effluent. By tracking the drift cross buoys, it was possible to obtain the set and drift of the prevailing current and to take samples of the water mass and entrained sewage as it drifted.

Water samples were taken periodically from the surface and from ten meters. Temperature, coliform, phosphate, nitrate, dissolved oxygen, and salinity samples were taken at each sample station. The positions of each drift cross and hence its sample point was fixed periodically by hand bearing compass triangulation from known points along the beach. Wind and sea conditions, cloud cover, and the presence or absence of the odor of sewer gases were recorded. In addition, visual observations were made for macroscopic floating or suspended materials attributable to the outfall. Over 91 water samples were taken between January and May 1970.

The unfortunate problems encountered by the Water Quality Laboratory eliminated both nitrate and phosphate measurements as tracers of the water mass. Due to rapid mixing by the diffuser system, temperature, dissolved oxygen, and salinity were normal within a few meters of the outfall (Fig. 15). The only remaining parameters that could be used as tracers were total and fecal coliform counts. For purposes of recording the coliform data, the area was divided into a series of concentric zones, each 244 m wide (Fig. 17). Mean coliform values for each zone are shown in Figure 23.

The combined data (Fig. 23c) show a rapid decrease in coliforms from high counts of 700/600 mpn/100 ml in zone 1 to zero in zone 6. The Guam Water Pollution Control Commission standards are 200 mpn/100 ml. The combined data show values less than 200 in zone 3.

A somewhat different picture emerges when the 1 m values (Fig. 23a) are compared with the 10 m values (Fig. 23b). The 1 m data follow the combined results closely. The 10 m data show a significant increase in coliform in zone 3 to values considerably higher than zone 1 and 2. We think this is due to the fact that sewage first rises quickly to the surface in zone 1 and then as mixing occurs, and the influence of the freshwater carrier is lost, the more dense organic matter sinks to lower layers of the water mass (Fig. 24). However, these data should be treated as hypothetical since they

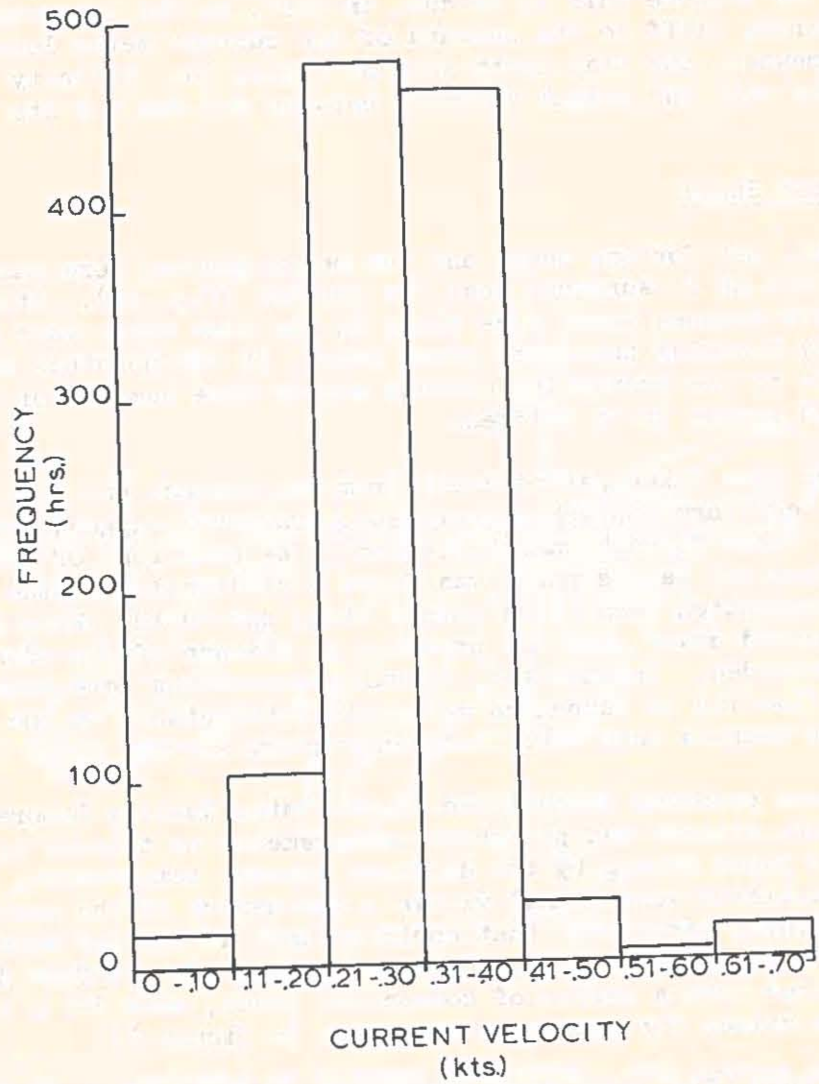


Figure 21. ANALYSIS OF CURRENT VELOCITY. These data are compiled from all the current meter tapes.

Figure 22. AERIAL PHOTOGRAPH OF SEWAGE "BOIL". A pumping cycle has just started. Note the track of the outfall main through the reef margin and across the submarine terrace, (Photograph through the courtesy of Navy Heavy Recon. Squadron VAP-61, now VQ-1).

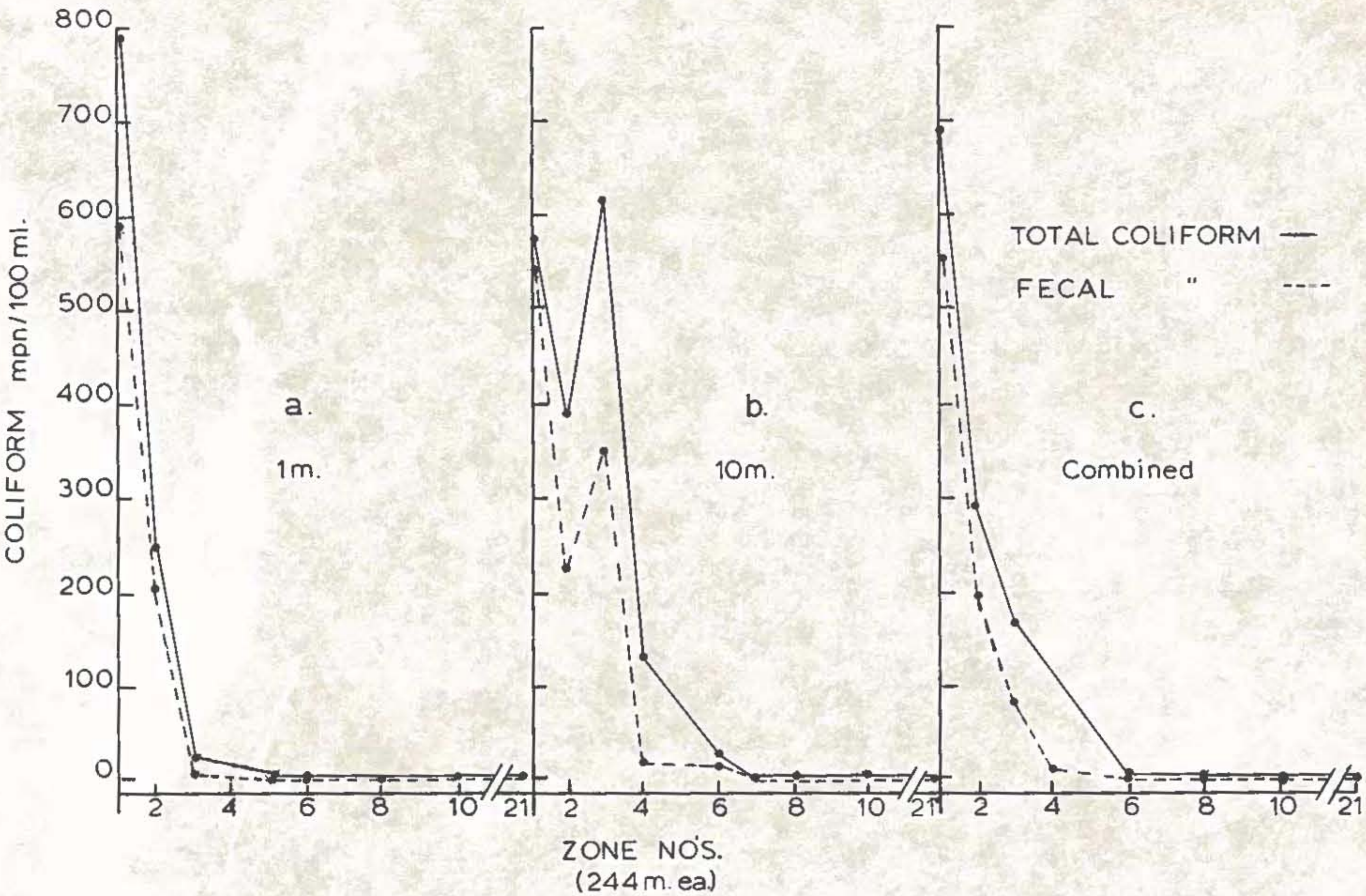


Figure 23. a. 1 m COLIFORM DATA, b. 10 m COLIFORM DATA, c. COMBINED COLIFORM DATA. The zone positions are shown on Figure 17.

Figure 23. a. 1 m COLIFORM DATA, b. 10 m COLIFORM DATA, c. COMBINED COLIFORM DATA. The zone positions are shown on Figure 17.

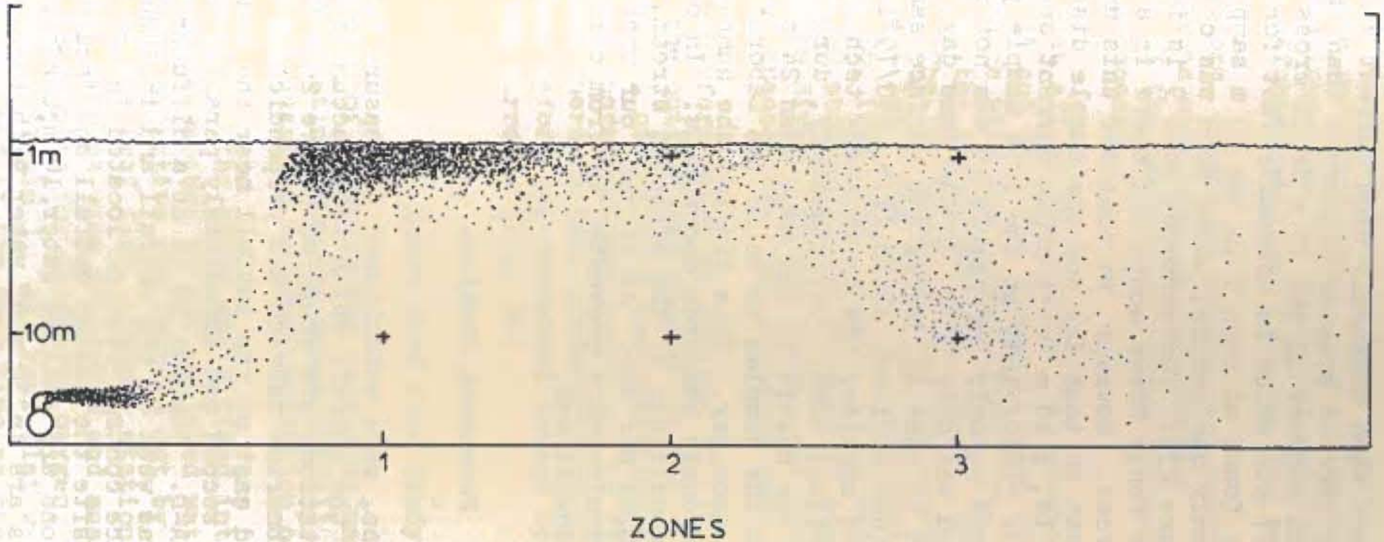


Figure 24. HYPOTHETICAL BEHAVIOR OF PLUME. The stippling shows the relative concentration of coliforms. The dimensions of this figure are not to scale.

are based on so few samples per zone. The 10 m sample counts fall to zero in zone 7 through zone 21 (Figs. 17 and 23b).

It should be noted that on days when unusually high current velocities occur, coliform contamination may be carried greater distances than those indicated on Figure 23. For example, on January 30 the 10 m drift cross indicated that the current was moving at 0.27 kts which is unusually fast for this device. A coliform count of 79/79 was found at zone 9 in the 10 m sample. The surface sample was only 2/2. Since only one sample, above zero was obtained from zone 9, it does not appear in Figure 23b. Furthermore, zone 9 is in the vicinity of the Adelup outfall and the Fonte River mouth and there is a possibility of contamination from these sources. However, we consider this unlikely because of the magnitude of the current on that day and the sample distance offshore (500 m). Similarly on April 14, a 10 m drift cross current speed of 0.28 kts resulted in coliform counts of >1609/>1609 at the 10 m sample point in zone 5. Again, since this was based on only one sample it was not plotted. The surface sample at this station was only 5/0. On the same day, a surface sample of 240/79 was recorded in zone 4. These two surface samples demonstrate how rapidly the entrained effluent sinks (i.e. 240/79 in zone 4 at the surface to 5/0 in zone 5). We consider the drift study technique the most valuable of the various techniques used. Unfortunately, during this period, the Water Quality Laboratory was unable to run more than 24 coliform samples at one time and they required the samples to be in the Laboratory for inoculation no later than 3 p.m. each day. This limited the number of samples and duration of drift and seriously hampered operations. In order to properly sample the downstream conditions of the effluent stream, we would have needed a hundred or more samples per day. As it was, our technique must be labeled hit or miss. Time requirements prevented us from carrying out our sampling procedures farther downstream.

Permanent Stations

A series of permanent stations, were established to measure background levels of materials attributable to the outfall which might accumulate in the general study area. These stations are shown on Figure 26. Four transects were established over the submarine terrace and perpendicular to the reef front. The first was located east of the outfall near the boat channel and included stations 2A-C. The second ran immediately parallel to the outfall line and included stations 3A-D. Station 3D is at a diffuser port (27 m deep). The third transect was west of the outfall and included stations 4A-D. Station 4D is a surface control station located in 120 m of water. The fourth transect was opposite the Adelup outfall and included stations 5A-C. The inshore "A" stations are shallow water, 10 m, surface stations. The offshore "B" and "C" stations are in 30 m of water with the "B" station for surface samples and "C" stations for 10 m samples.

Stations were located from known range marks on the beach crossed with echo sounder readings aboard the research vessel. Each station was buoyed at the beginning of the sampling day and the buoys recovered at the end. The direction of drift was determined by hand bearing compass as drift crosses moved away from the reference buoys. One meter drift cross casts were made at the inshore stations (the "A" stations) and both one and ten meter casts were made at the offshore stations ("B" and "C" stations).

Temperature, coliform, dissolved oxygen, and salinity samples and meterological observations were made at each station. Again, no useful data was obtained from any of the parameters except coliform because of rapid dilution and degradation processes.

Figure 25 shows that all of the inshore "A" stations were low in coliform with the exception of 3A and 5A. The former is part of the transect that crosses the submarine terrace with the outfall line. The latter is a station immediately adjacent to the Adelup outfall. Hence, both of these stations are predictably high. The "B" stations with the exception of 3B (directly over the outfall) are all low. The 10 m ("C") stations remain relatively high all the way to Adelup Pt. (Fig. 25). Again, it is hard to be certain that the high count in the 5C station is not because of contamination from the Adelup outfall or the Fonte River. In any event, all counts are usually below 200 mpn/100 ml west of transect 4. All stations east of the outfall remained low.

Note the reduced coliform count at station 3C (10 m) between station 3B at the surface over the outfall and station 3D the diffuser ports (Fig. 25). We expected a gradient of coliform contamination between the diffuser port and the surface and therefore were surprised to find the existing condition. It is apparent that there is some concentration of coliforms in the sewer boil at the surface before the entrained sewage begins to diffuse and move downstream with the currents (Fig. 24).

Agana Reef Flat Study

The primary objective of studying the reef flat was to determine if effluent charged water, originating from the Agana outfall, moved across the reef margin in sufficient quantity to cause pollution of the reef flat water mass.

To answer this question, the study was divided into two major parts. One study was to determine whether or not polluted water is in fact present on the reef flat. This objective was carried out by a water sampling program on various parts of the reef flat. Sample stations are shown on Figure 26. A total of 81 water samples were collected and analyzed for total and fecal coliform counts, 63 samples for dissolved oxygen, and 47 samples for salinity. These data are shown in Table 3. All reef flat water samples were collected from the same stations and at the same time as the current transect and shoreline station determinations were made.

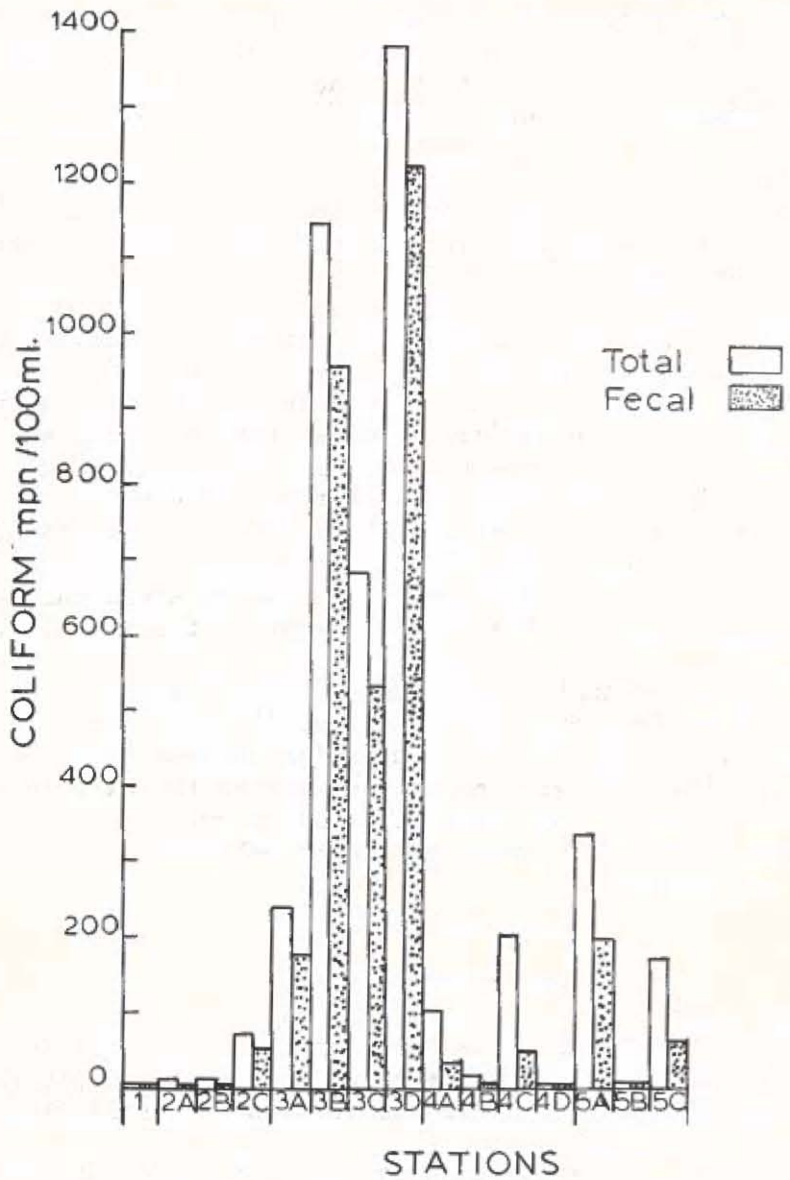


Figure 25. PERMANENT STATION COLIFORM DATA. The station locations are shown on Figure 26.

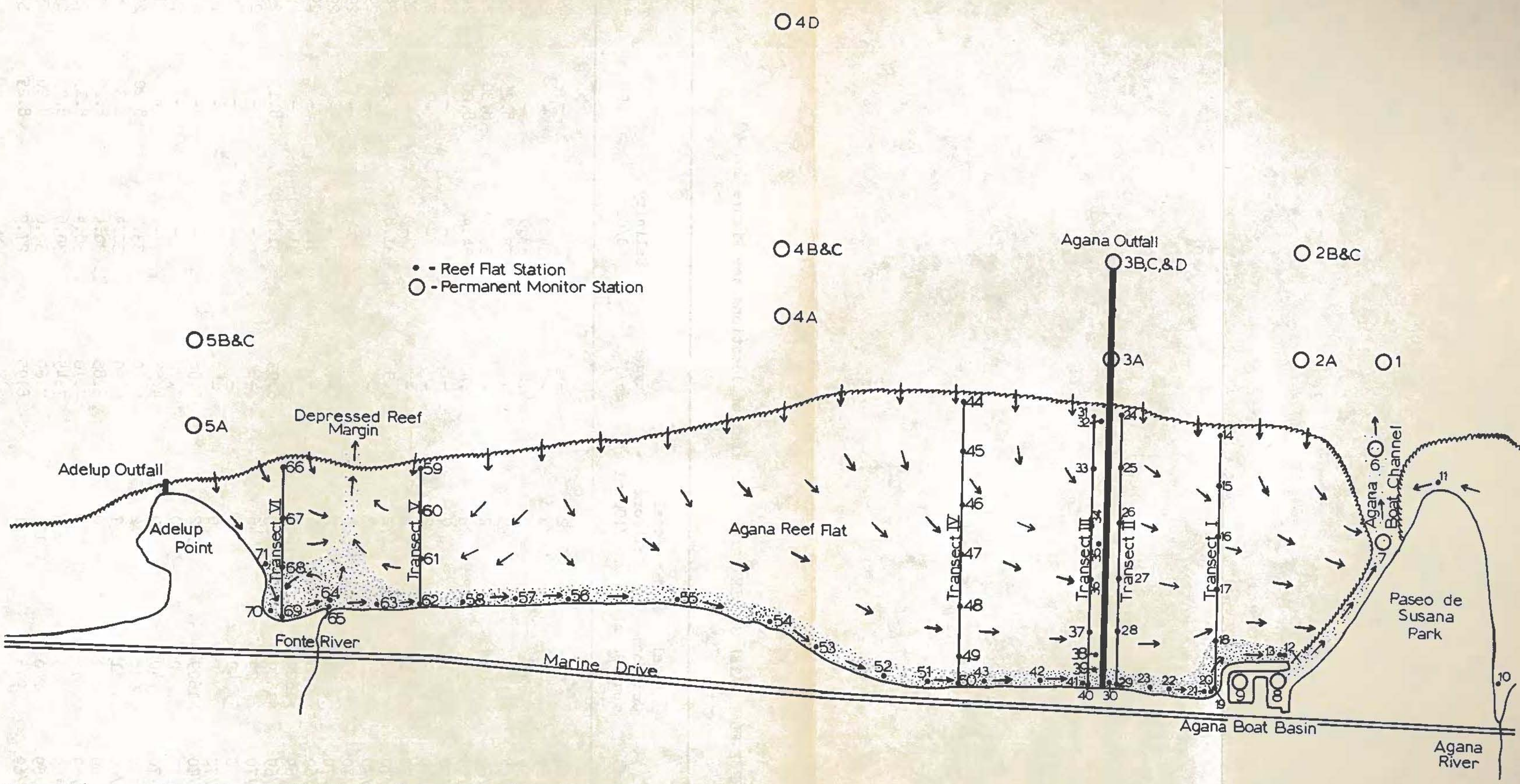


Figure 26. REEF FLAT CURRENT STUDY. The arrows along the reef margin show wave transport of water onto the reef flat platform, the others show the resultant current patterns. The stippled area shows the long shore current at the beach. Permanent and other monitoring stations are shown.

Table 3. REEF FLAT WATER SAMPLE DATA. For station locations see Figure 26.

Station Number	Date	Total Coliform mpn/100 ml	Fecal Coliform mpn/100 ml	Oxygen mg/l	Salinity 0/00	pH	Temp. °C
6	4/ 7/70	2	2	-	-	-	29.0
7	9/30/69	2	0	-	34.0	-	29.8
7	10/14/69	17	2	8.25	33.9	-	29.8
7	10/14/69	33	33	-	33.8	8.25	29.8
7	10/14/69	2	2	-	33.9	8.30	29.0
7	1/27/70	33	23	7.40	34.4	8.20	28.0
7	2/ 6/70	2	0	-	-	-	29.0
7	2/16/70	2	2	-	-	-	29.0
7	4/ 7/70	5	2	-	-	-	29.0
8	1/27/70	542	172	4.5	31.8	7.95	28.0
8	2/ 6/70	130	33	-	-	-	29.0
8	2/16/70	33	8	-	-	-	29.0
8	4/ 7/70	13	2	-	-	-	29.0
9	9/30/69	130	34	-	31.4	-	29.8
9	10/28/69	>1609	>1609	-	31.7	-	29.0
9	11/ 6/69	>1609	918	6.95	31.1	8.15	29.5
9	1/ 3/70	79	46	-	-	-	28.0
9	2/ 6/70	49	9	-	-	-	29.0
9	4/ 7/70	5	0	-	-	-	29.0
10	5/14/70	>1609	542	5.56	-	-	28.5
11	5/14/70	2	0	7.70	-	-	28.5
12	5/14/70	240	79	4.55	-	-	28.5
13	1/ 8/70	918	172	6.20	33.7	8.20	29.0
14	12/ 2/69	11	7	6.20	30.4	8.30	29.0
15	12/ 2/69	2	0	6.85	30.4	8.25	29.5
16	12/ 2/69	17	9	7.10	30.4	8.15	29.5
17	12/ 2/69	5	0	7.45	30.6	8.20	29.5
18	12/ 2/69	240	130	7.60	30.0	8.20	29.0
19	12/ 2/69	918	221	8.95	27.9	8.25	30.0

17	12/ 2/69	5	0	7.45	30.6	8.20	29.5
18	12/ 2/69	240	130	7.60	30.0	8.20	29.0
19	12/ 2/69	918	221	8.95	27.9	8.25	30.0

Station Number	Date	Total Coliform mpn/100 ml	Fecal Coliform mpn/100 ml	Oxygen mg/l	Salinity 0/00	pH	Temp. °C
20	1/ 8/70	918	542	6.10	34.1	8.10	29.0
21	5/14/70	>1609	>1609	5.46	-	-	28.5
22	5/14/70	109	17	4.97	-	-	28.5
23	1/ 8/70	918	348	6.15	33.7	8.20	29.0
24	12/ 2/69	13	8	6.50	30.8	8.15	28.5
25	12/ 2/69	0	0	6.80	30.6	8.20	29.0
26	12/ 2/69	5	0	6.75	30.8	8.1	29.5
27	12/ 2/69	4	4	7.65	30.4	8.25	29.5
28	12/ 2/69	4	0	8.30	30.4	8.30	30.0
29	12/ 2/69	130	17	8.80	29.3	8.30	31.0
30	1/ 8/70	>1609	918	5.95	34.0	8.10	28.5
31	11/25/69	0	0	7.30	-	8.20	30.0
32	10/24/69	>1609	918	-	34.0	8.20	29.5
33	11/25/69	0	0	7.25	-	8.20	30.0
34	11/25/69	5	5	6.20	-	8.23	29.5
35	10/24/69	79	33	-	33.9	8.30	29.5
36	11/25/69	49	13	6.90	-	8.10	29.0
37	11/25/69	172	46	5.60	-	8.00	28.5
38	10/24/69	240	130	-	32.5	8.30	33.0
39	1/ 8/70	2	2	7.20	34.4	8.10	28.5
40	11/25/70	348	79	4.00	-	8.00	29.0
41	5/14/70	130	33	5.42	-	-	28.5
42	1/ 8/70	1609	348	6.00	33.9	8.10	29.0
43	1/ 8/70	1609	542	5.90	33.8	8.20	28.5
44	11/25/69	2	0	8.45	-	8.26	29.5
45	11/25/69	2	0	8.35	-	8.29	30.0
46	11/25/69	0	0	7.95	-	8.22	30.0
47	11/25/69	0	0	8.70	-	8.25	29.5
48	11/25/69	2	0	8.45	-	8.19	30.0

Table 3. (continued)

Station Number	Date	Total Coliform mpn/100 ml	Fecal Coliform mpn/100 ml	Oxygen mg/l	Salinity 0/00	pH	Temp. °C
49	11/25/69	11	4	7.70	-	8.08	30.5
50	11/25/69	33	13	7.10	-	8.05	30.0
51	5/14/70	>1609	>1609	5.24	-	-	28.5
52	1/ 8/70	918	542	6.00	33.6	8.10	28.5
53	1/ 8/70	918	918	6.05	33.5	8.10	28.5
54	5/14/70	>1609	>1609	6.42	-	-	28.5
55	5/14/70	>1609	>1609	4.92	-	-	28.5
56	1/ 8/70	1609	345	6.10	33.9	8.20	28.5
57	1/ 8/70	918	348	6.50	34.0	8.10	28.5
58	5/14/70	542	348	5.67	-	-	28.5
59	2/10/70	0	0	6.90	33.9	-	28.0
60	2/10/70	2	0	7.40	34.2	-	28.0
61	2/10/70	2	0	7.80	34.4	-	28.0
62	2/10/70	130	130	7.60	34.3	-	28.5
63	1/ 8/70	240	130	6.50	34.0	8.1	28.5
64	1/ 8/70	1609	542	6.65	34.2	8.1	28.5
65	5/14/70	1609	918	5.67	-	-	29.0
66	2/10/70	0	0	7.00	33.8	-	28.0
67	2/10/70	2	0	7.20	34.4	-	28.0
68	2/10/70	240	79	7.50	34.0	-	28.0
69	2/10/70	240	79	7.20	30.2	-	27.5
70	1/ 8/70	918	49	6.60	34.0	8.1	28.5
71	1/ 8/70	918	348	7.25	34.2	8.2	28.5

A second part of the study was to determine current patterns and water movement over the reef flat in order to establish sources of pollution if they existed. Current studies were concentrated at the eastern and western parts of the reef flat plus the entire beach zone from the Paseo de Susana to Adelup Pt. This was necessary because potential pollution sources exist at each place. A second sewer outfall is located on the west end of the reef flat at Adelup Pt. and the Fonte River emerges in the same general area (Fig. 26). At the eastern end of the bay, the Agana outfall itself and the Agana Boat Basin are potential points of pollution. Finally, the entire beach area constitutes a possible source because of storm drain outfalls that are found there. The actual study of water movement over the reef flat was determined by introducing dye into the water at stations located along five transects I through VI, which extend from the beach to the reef margin, and at prescribed sample points along the shoreline from Paseo de Susana to Adelup Pt. (Fig. 26).

Reef Flat Current Data

Analysis of the current data show that during either high or low tides, with high surf conditions, water is transported across the reef margin onto the reef flat with each advancing wave crest. The transport of water across the reef flat is much less at low tides and/or at times of low surf conditions. Most of the reef flat studies were conducted during high tides and moderate to heavy surf conditions when maximum movement of water across the reef margin prevails. This build-up of water on the reef flat platform sets up current patterns as the water returns back out to sea (Fig. 26). These current patterns are determined by reef flat topography. On the eastern two-thirds of the reef flat, the water mass moves easterly to the Agana Boat Channel where it then flows seaward (Fig. 26). The topographic factor responsible for the current pattern on this part of the reef flat is the depressed inner reef flat zone which slopes very gently eastward toward the Agana Boat Channel. Current velocity is highest in the deeper region of the inner reef flat. The current pattern is more complex on the western third of the reef platform. Factors tending to complicate the currents in this region are the presence of the Fonte River, which empties onto the reef flat near Adelup Pt., and a depressed section of the reef margin and outer reef flat located just opposite the river mouth (Fig. 26). Movement of water over the reef margin on both sides of the depressed zone takes place as described for the eastern two-thirds of the reef flat. The currents then converge and flow seaward through the depressed reef margin as shown on Figure 26. Water flowing onto the reef flat from the Fonte River diverges, with part of it flowing seaward through the convergent zone and depressed reef margin and the other part forming a narrow band (stippled region, Fig. 26) 15 to 25 m wide which flows along the shore and empties into the Agana Boat Channel near the boat basin.

Reef Flat Coliform and Chemical Analyses

Coliform data from the Agana reef flat sample stations indicate that polluted water levels (fecal coliform 200 mpn/100 ml) are found only at those stations located within 25 m of the shoreline except station 32 at the reef margin which will be discussed later. All other reef flat stations had fecal coliform counts considerably lower than the 200 mpn/100 ml level. Table 3 and Figure 26 show that all the polluted shoreline stations lie within the narrow band of turbid water (stippled area) that receives water from the Fonte River, street sewer drains, and by seepage from the sandy beaches. This band of water moves easterly along the shoreline and empties into the Agana Boat Channel. The shoreline water does not mix well with the reef flat water mass farther from shore because wave transport pushes water shoreward and confines it in a band. Fresh water contamination from the river and other shoreline sources reduces salinity and temperature which further inhibits mixing because of density differences between the two water masses.

There is no indication of a sustained source of pollution from either the Agana or Adelup outfalls by the transport of effluent-charged waters across the reef margin onto the reef flat platform of the study area. Occasionally, when high surf conditions and strong northerly winds coincide, effluent-charged water from these outfalls may be transported onto the reef. Such a situation occurred on October 24, 1969, when a polluted water sample at station 32 was collected (Fig. 26 and Table 3). This was the only polluted sample found on the reef flat other than those from within the shoreline band of contaminated water.

Dissolved oxygen, salinity, pH, and temperature data was of no value in tracing movement of polluted water on the reef flat (Table 3).

The inner part of the Boat Basin (Sta. 9, Fig. 26) reached polluted levels several times and is probably due to the human activity there and the poor flushing action of this facility (Table 3). Pollution levels for the outer Boat Basin (Sta. 8) were high but never quite reached 200 mpn/100 ml which is probably due to better flushing action than that of the inner basin. Station 7, which is located half way out the Agana Boat Channel (Fig. 26), never reached pollution levels even though the polluted shoreline water empties into it at Point X (Fig. 26). This low level coliform count at Station 7 is due to dilution of the polluted water by the large volume of water emptying into the channel from unpolluted parts of reef flat (Fig. 26).

SECTION V

CONCLUSIONS

The study objectives outlined in Section I are followed herein with the exception of the oxygen "sag line" which is considered as a part of objective No. 1.

1. Since we encountered unavoidable laboratory difficulties with regard to chemical analyses, we must consider the use of chemical and biological tracers of the Agana water mass as marginally successful. The weakness of this study enhances the importance of the current studies. Even though the tracing of materials attributable to the outfall may be questionable, a knowledge of prevailing current patterns allows us to infer, with some accuracy, the most likely direction that the effluent will move.

The prevailing water mass movement over the submarine terrace, in the vicinity of the outfall, is westerly. Periodic easterly shifts in direction are caused primarily by tidal changes. In general, the directions are westerly on flood tides and easterly on ebbs, with some variation. The easterly components are considered weak and of short duration. Drift cross data indicate that entrained sewage probably passes well clear of Adelup Pt. and moves out into the Philippine Sea. However, there is some indication that an eddy system exists in the Asan/Piti area that could possible draw some of the effluent into the Asan/Piti reef flats. Further investigation is required to prove the validity of this hypothesis. Such studies would be hindered by the presence of the Adelup outfall which would be a more logical candidate for pollution in the Asan/Piti area. Sewage from this outfall would tend to mask that of the Agana outfall. This problem will end soon with the closing of this system and tying it in with the Agana system.

Reef flat current studies show that wave transported water over the reef margin onto the Agana reef flat platform provides the energy for generation of currents there. The entrapped water escapes the reef flat easterly into the Agana Boat Channel and westerly into the Fonte River channel through the reef margin. A separate, but distinct, long-shore current exists in the first 25 m out from the beach. This system also terminates at the Agana Boat Channel.

Rags, grit, cellulose products, and metal foils tended to settle rapidly out of the plume, but there was no great accumulation of sludge or other settleable material.

It was obvious that the majority of the sewage effluent rises directly to the surface and then drifts off with the prevailing current . Light oils were found consistently in the boil and on calm days could be observed as slicks up to 2.5 nautical miles in length. On May 8, 1970 a large amount of very black oil was released that, within two hours, covered an area two nautical miles in length and nearly 0.5 nautical miles in width.

Small bits of floating solids (1 mm or less in diameter) were encountered frequently at distances up to one nautical mile from the outfall. Scum occurred periodically in the sewage boil but dissipated rapidly "downstream".

Visibility was considerably reduced in the sewage boil but tended to clear up rapidly as the effluent drifted away. As dilution progressed, the entrained sewage settles to lower water layers.

There was a drastic change in dissolved oxygen, salinity and temperature after the effluent cleared the diffuser ports. Most of the values for these parameters were near "normal" before the plume reached the surface. As a result, they proved of little value as tracers.

Total and fecal coliforms show a slow but steady decrease with distance from the outfall. Coliforms are higher at the diffuser ports and in the "boil" than at intermediate points in the plume. This is thought to be the result of surface concentration in the boil. There was practically no coliform contamination east of the outfall. Contamination dropped to zero usually within the first 1200 m to the west. There was a tendency for the coliforms to persist longer at 10 m depths due to gradual sinking of the effluent. On rare days with exceptionally strong currents some contamination was detectable as far as Adelup Pt.

Coliforms from the outfall entered the Agana reef flat on only one occasion. This phenomenon can be expected to occur on days when northerly winds and seas exist. Fortunately these times are rare. Heavy coliform contamination was found in the band of water along the beach. The source of this contamination is the Fonte River, and storm drains and not the Agana outfall.

2. We had no way of quantifying the bad odor zone. The odor of sewer gases was very strong in the boil and diminished rapidly downwind. We were able to detect the gases at least 0.5 nautical miles west of the outfall. Occasional odors are detected along Marine Drive but in each case they were traceable to the pumphouse near the boat basin and to decaying organic sediments from the Fonte River and storm drains. It is possible that on days of strong northerly winds, odors from the outfall will be noticeable on Marine Drive.

3. The increase in sewage flow over the 12 month period was 1.7 to 1.9 million gallons/day. This amounts to a change of only 0.2 million gallons/ day (Fig. 28). We noted no significant changes in the data reported above for this relatively small increase.

4. Due to the destruction of this portion of the reef by Acanthaster planci, the ecosystem is already in a disturbed state. It is not possible to ascertain what effects the new outfall has had on the organisms in this area. The Apendix indicates a definite difference in the algal community of the outfall vs. a control area. Yet there is some possibility that this reflects ecological succession near the outfall following recent damage by construction. See the Appendix for details.

There are definite signs of coral repopulation in the area and large aggregations of fishes are attracted to the sewage plume and outfall structure without apparent harm.

Inspite of the lack of obvious damage to marine organisms, the possibility of long range damage should not be discounted.

5. The only potential indicator organism noted was a species of the alga Cladophora. See the Appendix for details.

6. We believe that the extension of the outfall to the base of the adjacent seacliff would have provided a greater potential for dilution of the sewage. This is due primarily because of the tendency of the sewage to rise. The extension would doubled the depth and increase the dilution of the sewage as it rose to the surface. In addition, we suspect a rather drastic change in current regime just beyond the seacliff (note flat sided nature of Figure 20) that might well insure that the sewage would be carried away from the island. Firm data to support this latter observation is lacking and it should be considered in a future study. At the present rate of flow, extension of the outfall would probably be of little value. However, as the flow rate increases, the extension might make a difference, particularly with regard to dilution and sediments.

7. It is not possible to extrapolate from our findings for other outfall areas. This is due primarily to the fact that there are local variations of inshore currents around Guam because of local eddy formation, topographic features, exposure to wind and sea and many other factors. We were quite surprised by the complicated nature of the inshore currents in the outfall area.

SECTION VI

RECOMMENDATIONS

1. Place all future outfalls on the second submarine terrace. This submarine feature is a fairly persistent topographic phenomenon around Guam, ranging from 30 to 60 m. This would involve very little increase in distance for the present outfall but would double the depth and hence increase the dilution potential.

2. Each proposed outfall site must be studied independently because of current changes caused by local eddys, topographic features, waves and sea exposure. From preliminary data, it would seem that "general or island-wide current studies" are applicable only to currents beyond the first submarine terrace. Inshore water movements over the first terrace show extreme local variability. Oceanographic survey vessels are commonly restricted to deeper offshore waters and therefore are incapable of such studies without small boat support. We are presently working on a similar study at Tanguisson Pt. that also shows considerable local variation in the inshore current patterns.

3. Another study of the effectiveness of the Agana outfall system should be made as flow increases to five or more million gallons/ day.

4. There was a tremendous loss in efficiency in this project because of the need to order equipment and supplies via the Guam Memorial Hospital procurement system. This system is used by the Department of Public Health and Social Services. Any future contracts should allow the research organization to handle its own supply and procurement.

5. If on future studies, the services of the Water Quality Laboratory are to be used, then there is need for considerable increase in coliform capability and greater accuracy in nutrient analyses. Many of the problems encountered by the technicians were involved in the above mentioned procurement problems resulting in unreasonable delays in setting up analytic procedures. This Laboratory would also benefit greatly by the presence of a full-time marine chemist with at least a Master's degree.

As a final note to this report, we would like to emphasize again the fact that during the study period, the outfall has been flowing between 1.7 and 1.9 million gallons/day (Fig. 28). This is only one sixth of the designed capacity of 12 million gallons/day. Each of the above parameters studied can be expected to change considerably as the flow capacity is approached. The data in this report may no longer be applicable as the flow increases beyond about five million gallons per day.

SECTION VII

ACKNOWLEDGEMENTS

We would like to thank the Guam Water Pollution Control Commission for making this study possible. Particular thanks are due to Mr. Robert Hahn, the former Chairman of the Commission, and Dr. O. V. Natarajan for their vision in tying together the facilities of the University and the Commission for the mutual benefit of both agencies.

We also owe our thanks to the technicians in the Water Quality Laboratory for their patience in dealing with our somewhat hectic and demanding sampling program. These include Mrs. Mary Jo Lowe, Mrs. Linda Popper, Mrs. Betty Murray and Miss Julie Calvo.

We are also indebted to our research colleague Dr. Roy T. Tsuda for preparation of the Appendix and to Mr. M. Rodney Struck, Marine Technician, who shared our many unpleasant hours of diving and working in the sewage plume. Mr. Struck provided most of the photographs. We greatly appreciate the assistance of the U. S. Navy (VAP-61), and Mr. Yamanaka of the Agana Pumping station.

SECTION VIII

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SECTION IX

APPENDIX

A Preliminary Study on the Effect of an Ocean Sewage Outfall on a Benthic Algal Community on Guam

by

Roy T. Tsuda

Introduction

A preliminary study of the benthic algal community in the vicinity of the outfall was investigated. The purpose of the study was to define the limits of effect on benthic algae caused by the discharge of effluent and to examine the algae from the standpoint of indicator organisms.

Materials and Methods

Algal collections were made at the outfall and in a control area. The control area was located in 27 meters of water (the same depth as the outfall) about 500 meters upcurrent from the outfall and in an area free from effluent.

The point method was utilized to quantify the algae (Tsuda, 1970) in the two areas. The algae in the outfall area were sampled by placing a quadrat at three-meter intervals along a transect line parallel to the prevailing current as in Figures 11 and 12. Sixteen random drops of the quadrat were made in the control area to obtain information on the relative frequency of individual species. The quadrat frame (50x50 cm) was divided into a grid of 25 squares, each 10x10 cm, providing 16 interior "points" where the grid lines intersected. Each species was recorded at every "point" at which it occurred. From these data, values representing abundance (n/16 X 100 = %) and relative frequency (n/no. of tosses X 100 = %) were calculated.

Results

<u>Algal Composition at the Outfall</u>

Table 4 summarizes the species of algae collected or observed at four different times (October, 1968; March, 1970; August, 1970; May, 1971) over a 44-month period within a 60-meter transect from the point of discharge at the outfall

Table 4. LIST OF ALGAE. Comparison of marine benthic algae on the submarine terrace at the Agana Outfall (polluted) and a control area north of the Outfall (unpolluted).

Algal Species	Control Area	Outfall Area			
	VIII-70	X-68	III-70	VIII-70	V-71
CYANOPHYTA					
Microcoleus lyngbyaceus (Kütz.) Crouan	X	X	X	X	X
Schizothrix calcicola (Ag.) Gomont	X				
Schizothrix mexicana Gomont	X				
CHLOROPHYTA					
Caulerpa filicoides Yamada	X				X
Caulerpa racemosa (Forsk.) J. Ag.				X	
Caulerpa taxifolia (Vahl) C. Ag.			X		X
Caulerpa verticillata J. Ag.				X	
Cladophora sp.				X	X
Derbesia sp.		X			
Dictyosphaeria versluysii W. v. Bosse	X				
Halimeda discoidea Decaisne	X		X	X	X
Halimeda opuntia (L.) Lamx.	X		X	X	X
Neomeris annulata Dickie			X		
Neomeris vanbosseae Howe	X	X	X	X	X
Valonia ventricosa J. Ag.	X	X			
PHAEOPHYTA					
Dictyopteris repens (Okam.) Boerg.	X		X		
Dictyota patens J. Ag.	X		X	X	X
Ectocarpus indicus Sonder		X	X		
Lobophora variegata (Lamx.) Womersley					X
RHODOPHYTA					
Jania capillacea Harvey	X				
Galaxaura marginata Lamx.	X	X	X	X	X
Galaxaura oblongata (E. & S.) Lamx.		X			X
Polysiphonia savatieri Hariot			X		X
Tolypiocladia glomerulata (Ag.) Sch. & Hauptf.	X				
Number of Species	14	7	11	9	12

area and the control area. The first collection was made on October 1968, immediately after the completion of the outfall. At this time, an average of 1.5 X 10^6 gallons of sewage was being released per day (Fig. 28). Only seven species of algae were collected. The low species number is probably due to disturbances caused by construction of the outfall.

Seventeen months later, 11 species were observed in this same area; six months later, nine species; and eight months later, 12 species. The difference in number probably reflects successional changes superimposed on seasonal changes. Only three species (*Microcoleus lyngbyaceus*, *Neomeris vanbosseae*, and *Galaxaura marginata*) were observed during all four periods. *Dictyota patens*, *Halimeda discoidea*, and *H. opuntia* were not seen on October 1968 but were prevalent on the next three dates.

The "coefficient of community" (Oosting, 1956) for the species collected at the outfall and control areas on August 1970 was a low 35%. This definitely indicates dissimilar communities in the two areas. However if the relative frequency of only the common species in the two areas are considered (Table 5), a different viewpoint is obtained and the algal communities appear quite similar. Except for the presence of *Cladophora* sp. and the absence of *Schizothrix calcicola*, in the outfall area, the more frequently found algae were present at both sites. The "coefficient of community" value was considerably lowered due to the inclusion of incidental species (i.e., those represented by a single thallus) in each of the areas.

Algal composition on both sides of the diffuser ports were also compared during three different periods. The "coefficient of community" between the west and east sides varied considerably - March 1970 (58%), August 1970 (100%), and May 1971 (50%).

Factors

It is general knowledge that sewage effluent from an outfall can cause a change in the marine flora at the point of discharge. This can occur because of an increased phosphate/nitrate supply caused by breakdown of organic matter, a decrease in salinity caused by the release of freshwater from the ports, a decrease in dissolved oxygen caused by the additional respiratory demand of bacteria and the oxidation of organic matter, and light reduction from the plume shadow.

The effluent, in a freshwater medium, was observed to rise immediately to the surface at an angle and direction dependent on the velocity of the current (Fig. 14). Current studies made in the outfall area reveal that alternate east/west current changes occur with semidurnal tide changes. The predominant path of the current is towards a westerly direction over a 24-hour period. The influence of the sewage plume is therefore expected to have a greater effect west of the outfall.

Table 5. RELATIVE FREQUENCY (%) OF THE MORE COMMON ALGAE. Comparison of outfall and control areas, observed on August 1970.

Algal Species	Relative Frequency (%) Outfall	Control
Cladophora sp.	79	0
Neomeris vanbosseae	43	30
Dictyota patens	36	30
Halimeda discoidea	27	80
Galaxaura marginata	21	25
Halimeda opuntia	13	25
Microcoleus lyngbyaceus	13	75
Schizothrix calcicola	0	50

Discussion

The first dive made at the outfall on October 1968 revealed that a species of Derbesia was the most conspicuous alga within a six-meter radius of the ports. The fertile thalli were less than one centimeter high. By March 1970, this species had disappeared and no conspicuous alga had taken its place. On August 1970, an unidentified species of Cladophora was the dominant alga in the immediate vicinity of the diffuser ports. This species, less than one centimeter high, was present (Fig. 27) up to 18 meters away from the diffuser on the west side and extended only 12 meters on the east side. Nine months later, this same species of Cladophora had extended its range and was present up to 30 meters west of the diffuser. Virtually no change was noted on the east side.

The 12-meter westerly EXTENSION of the range of Cladophora away from the source of effluent within a nine-month period seems to be correlated with the increasing amount of effluent (Fig. 28) being pumped out through the ports. During August 1970, approximately 1.47×10^6 gallons of sewage per day were being released. The increased amount of sewage pumped during May 1971 would most likely cause a larger plume to develop, thus affecting a greater area of the benthic community. Since the predominant current is in a westerly direction, this could explain why Cladophora extends a greater distance towards the west than it does towards the east. At the point where Cladophora diminishes in abundance, other species, e.g., Galaxaura marginata, Halimeda discoidea, Halimeda opuntia, and Neomeris vanbosseae are found.

The interesting problem here is that the Agana outfall algal community has not yet reached a "climax" situation. This algal community represents a continually changing one and is more favorably referred to as a "continuum" (Curtis and McIntosh, 1951). Hence, though Cladophora sp. is a likely candidate, it may be too early to label it as an indicator organism.

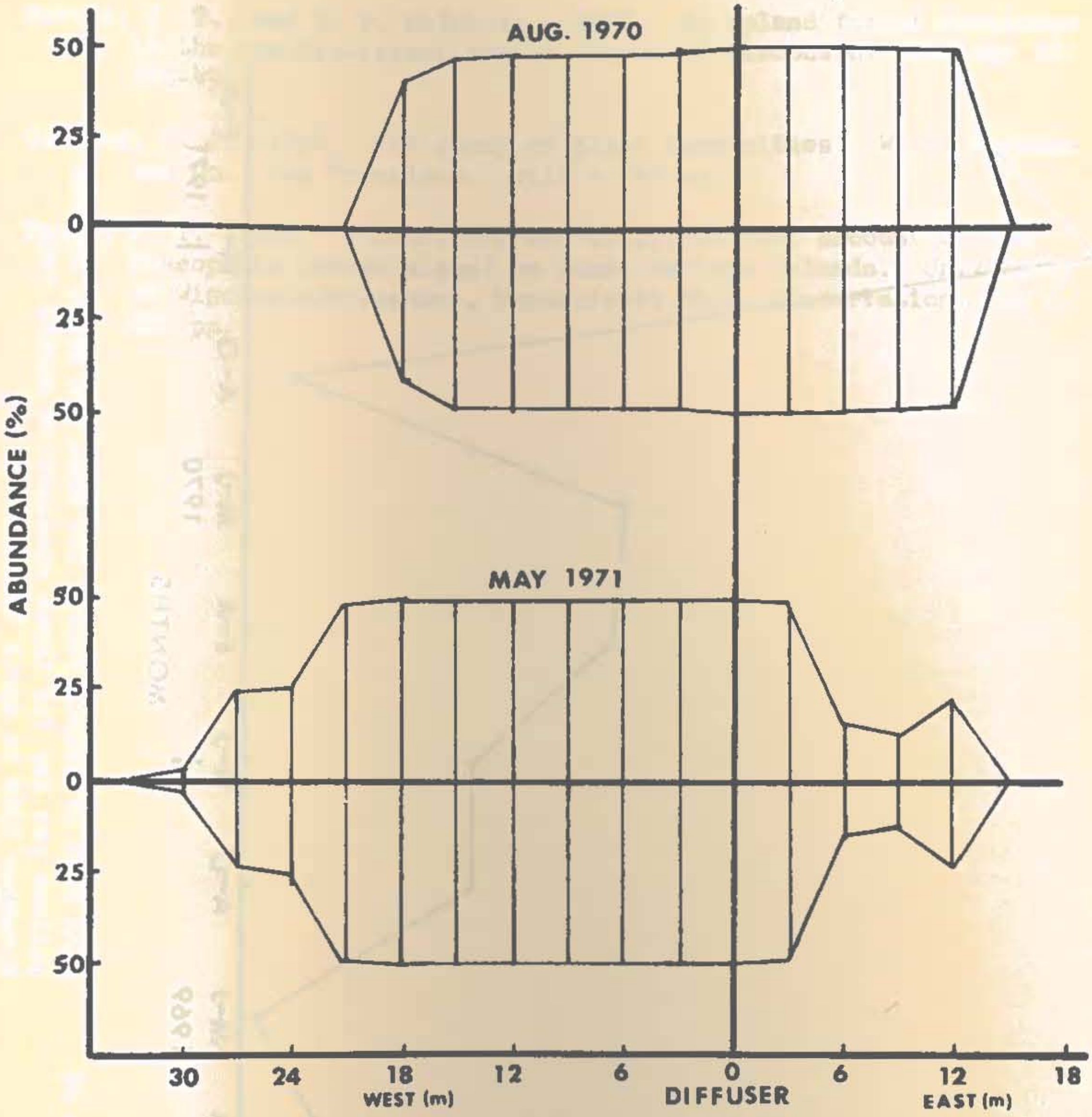

Figure 27. ABUNDANCE (%) OF CLADOPHORA SP. The diagram shows distribution on the east and west sides of the diffuser during August 1970 and May 1971.

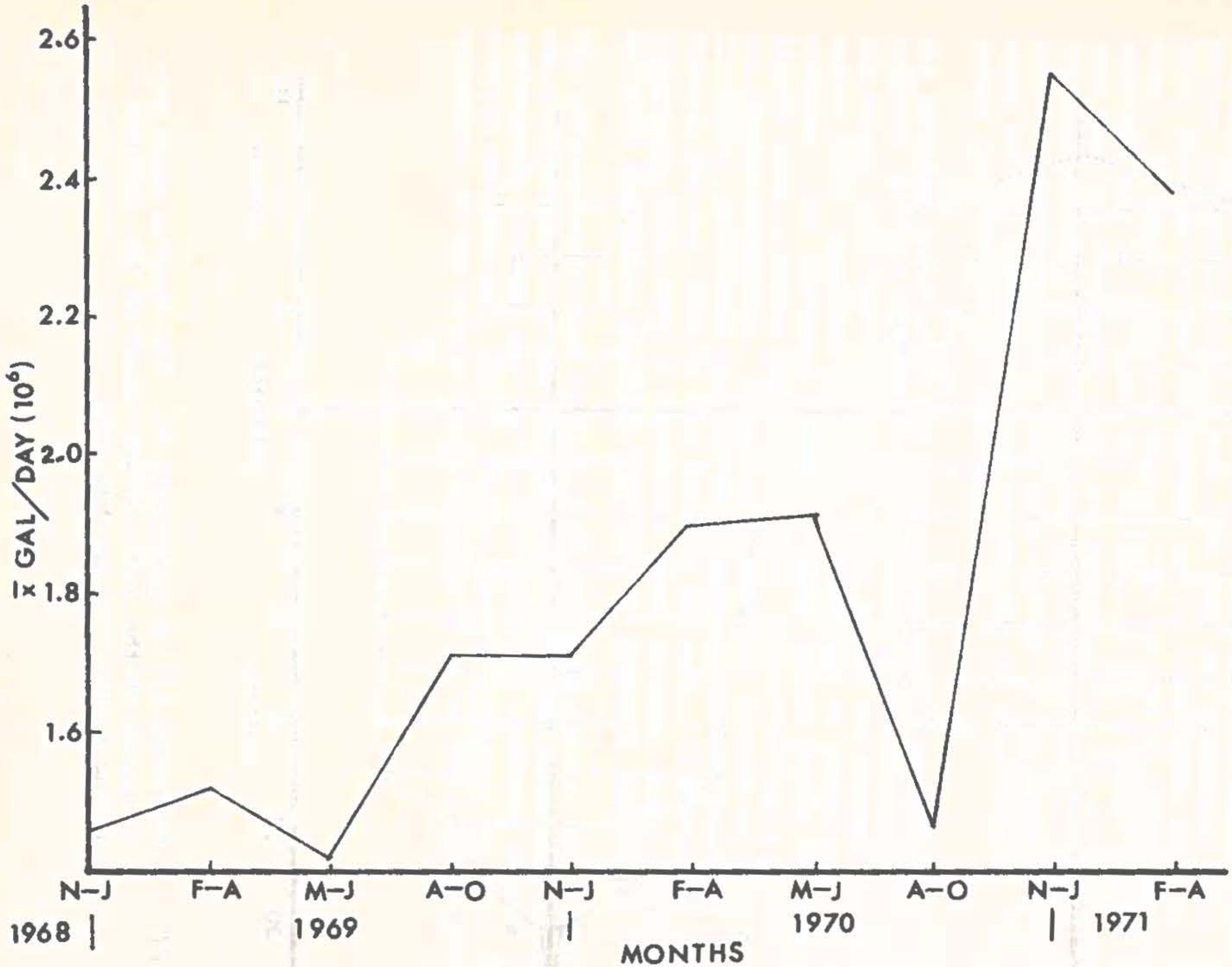

Figure 28. MEAN RATE OF SEWAGE FLOW. The data are based on mean gallons per day for three consecutive months from November 1968 to April 1971.

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