F. WRAY

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Steven S. Amesbury, Roy T. Tsuda, William J. Zolan, and Theodore L. Tansy

Technical Report No. 22

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UNIVERSITY OF GUAM MARINE LABORATORY

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By

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# INTRODUCTION

## Description of Atoll

Majuro Atoll is roughly rectangular, some 21 miles long by 3-6 miles wide, with its long axis oriented roughly east-west (Fig. 1). The mean temperature on Majuro is 81°F (27°C) with little seasonal variation. Yearly rainfall is 140 inches, with October and November being the wettest months. Tradewinds from the east-north-east blow throughout the year.

During World War II, all the islands on the south and east rims of the atoll were joined by a causeway, resulting in a continuous 31-mile strip of land which completely encloses the southern portion of the atoll (Mabbett, 1975). The major part of the population of Majuro as well as the administrative and commercial centers are located on the interconnected islands of Darrit, Uliga, and Dalap (the D-U-D area), on the eastern margin of the atoll. A secondary center of population is located at Laura at the extreme western end of the atoll. Data published in 1971 indicate that the population of the D-U-D area was 7,197 and that in Laura 1,344 (Mabbett, 1975).

With the exception of a few municipal buildings which are provided with leaching fields, none of the sewage from Majuro is treated. Sewer lines from many of the homes and buildings empty into the lagoon through several outfalls. In addition, there is a considerable number of overwater benjos (outhouses) which empty into the lagoon.

The disposal of untreated sewage into the Majuro Lagoon has resulted in the water along the shoreline of the D-U-D area being "grossly polluted" (Austin, Smith and Associates, Inc., 1967). A 1972 study (Mabbett, 1972) indicated that the lagoon was "moderately to severely contaminated" on the basis of bacteriological analyses, and that the bacterial contamination was clearly due to human sources. Mabbett additionally suggested that the enclosure of the southern part of the lagoon by the interisland causeway has impeded flushing, particularly in the D-U-D area.

The recognized need for improved sewage treatment and disposal has resulted in a number of studies and proposals for the design and siting of sewage treatment facilities on Majuro. Austin, Smith, and Associates (1967) have proposed the construction of three sewage treatment plants: (1) a 0.5 million gallon per day (MGD) treatment plant at the northeast tip of the D-U-D area (Rita) with the outfall emptying on the ocean side of the island, (2) another 0.5 MGD plant

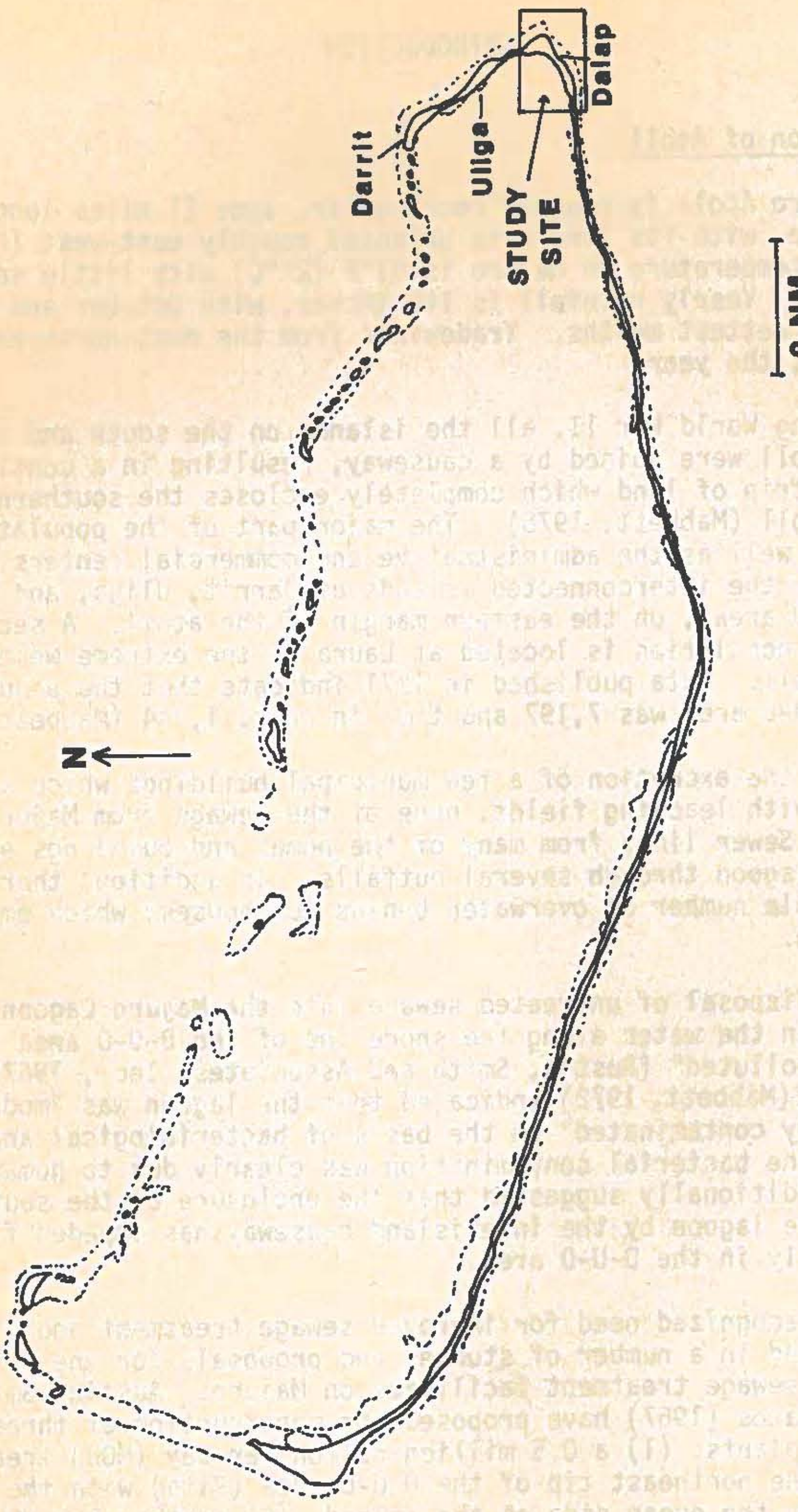


Fig. 1. Map of Majuro Atoll showing study area.

in the D-U-D area across from the hospital which would discharge treated effluent into the lagoon, and (3) a 0.3 MGD plant in Laura emptying into the ocean to the west of the island. The Department of Public Works of the TTPI (1971) indicated a program for the construction of two sewage treatment plants on the D-U-D area but did not specify the locations of these plants.

Tait (1971), on the basis of general patterns of ocean circulation and analogies with characteristics of lagoon circulation at other Pacific atolls, recommended, as a first choice, an ocean outfall on the south side of the western third of the airstrip on Dalap. If a lagoon outfall should be preferred, Tait recommended that its location be on the extreme western tip of Darrit. His recommendations were provisional in that he indicated the need for further local studies of current patterns at the proposed and other possible sites. Mabbett (1972) underlined the need for sewage treatment in the D-U-D area, and recommended an outfall site on the ocean side of Dalap island at the eastern end of the airport runway.

The U. S. Army Corps of Engineers (1972a) considered three alternative sewage treatment strategies: secondary treatment with effluent discharge into the lagoon 1500 feet from shore at a depth of 50 feet, primary treatment and discharge in deep water on the ocean side, and secondary treatment with a shallow outfall on the ocean side. On the basis of present lagoon contamination, construction difficulty, and cost, they recommended the alternative of secondary treatment and a shallow ocean outfall. Their specific design recommendations were for a two-stage aeration (contact stabilization) treatment plant located at the southeast corner of Dalap (the east end of the airport runway) with an outfall discharging 560 feet offshore at a depth of 10 feet into the surf-zone. Wave action at the surf zone is expected to aerate and disperse the effluent, but, if necessary, diffuser piping can be added to the end of the outfall, parallel to the reef face, for greater dispersal. As the need grows, a second treatment plant could be built at the same site to handle a larger volume of sewage.

The most recent study by the U. S. Army Corps of Engineers (1972b), compared a proposed secondary treatment shallow ocean outfall with a deep ocean outfall discharging comminuted raw sewage, and recommended the latter alternative. Although this type of treatment may not be acceptable or feasible in other locations, the Corps of Engineers felt that the conditions at Majuro were suited to this system: 1) Effluent flow is expected to be small, 2) steep offshore bathymetry allows considerable diffuser depth with a relatively small increase in length and cost, 3) the use of seawater, for flushing, increases the effluent density and results in slower rise and greater mixing before the effluent reaches the surface, 4) coliform bacteria are relatively quickly killed in tropical ocean water, 5) wind and current conditions are favorable for the dispersion of the sewage plume,

6) low nutrient content of oceanic waters makes the addition of sewage nutrients less likely to lead to eutrophication, 7) the deep diffuser will afford a high level of dilution before the effluent reaches the surf zone, 8) settleable solids will not accumulate on the steep talus slope extending to great depths below the diffuser, 9) no industrial discharges of heavy metals or industrial poisons are anticipated, and 10) the deposition of sewage may actually increase the abundance of fishes in the vicinity of the plume.

In comparison with the proposed secondary treatment plant with a shallow ocean outfall, the deep water outfall is expected to give 5-10 times better effluent dilution, better BOD removal, and less turbidity. Additionally, there would be no environmental damage from chlorine, as this is neither necessary nor useful with the raw sewage system. The sight and smell of the secondary treatment plant may become a nuisance, whereas the raw sewage systems has no above ground structures and minimal odor. A final consideration, the cost of construction and maintenance of the two types of systems, is shown to be much less for the raw sewage system with a deep outfall. The site recommended for the deep outfall is at the eastern end of the airport runway with the pipe extending approximately 700 ft. in a southeast direction to a depth of 160 feet. Should a secondary treatment plant be decided upon, the Corps of Engineers recommended the site indicated by Tait (1971) at the western end of the runway. Additional current, biological, bacteriological, sociological, and engineering studies were recommended before a final decision is reached.

## Scope of Work

The proposed Majuro wastewater outfall will discharge treated effluent into deep ocean waters that are believed to be in a relatively pristine state. Since it is the Trust Territory Environmental Protection Board's policy that these waters should maintain their existing good quality, the TTEPB contracted with the University of Guam Marine Laboratory to determine the following.

1. What effect, if any, will the discharge of treated effluents have on the ecological condition and water quality at the proposed outfall sites.

2. The extent and magnitude of surface and sub-surface currents at the proposed outfall diffuser sites, so that reliable predictions on plume dispersion and dilution can be developed.

3. Define potential alternate sites for outfall/diffuser location, should currents/tidal flushing at the proposed sites be found inadequate, or result in excessive biological impact.

4. Baseline ecological data that can be utilized for future comparison, evaluation and determination of deleterious effects or impacts on biota and water quality.

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## METHODOLOGY

### Study Site

Majuro was visited from August 23 to 31, 1975. The proposed site on the ocean side of Dalap Island at the eastern end of the old runway was the primary study site. At the request of the District Planner, Mr. Dennis McBreen, some additional studies were made at a possible outfall site at the western end of the runway. The location of the treatment plant and outfall pipe at the eastern end of the runway was determined on the basis of figures presented in the U. S. Army Corps of Engineers September 1972 report which shows the outfall pipe extending approximately 700 feet to the southeast of the treatment plant, to a depth of 160 feet (Fig. 2). An alternate site for a shallow water outfall releasing treated sewage is also shown in this report (their Figure 1), and extends from the eastern end of the runway toward the northeast for 600 feet to the edge of the reef flat. Studies were made at these two potential sites as well as a third site at the western end of the runway.

### Water Chemistry and Microbiology

All water samples except oxygen were collected in 500 ml polyethylene bottles by opening the tightly fitted caps while the bottle was held underwater. Oxygen samples were taken with a Van Dorn sampler. The bottles and sampler were brought onto the boat where temperature, dissolved oxygen, and salinity were recorded with a YSI oxygen meter and a YSI S-C-T meter. Sample bottles for $NO_3$-N and $PO_4$-P were immediately placed in ice and taken to a freezer within two hours to be frozen for later analyses (Strickland and Parsons, 1968) on Guam. Water samples for coliform analyses were held in cold water and processed on the day they were collected. The membrane filter method was used (A.P.H.A., 1971). Fecal coliforms were cultured on Difco-M-FC medium at $44.5 \pm 0.5°C$; total coliforms were cultured on Difco M-Endo medium at $35.0 \pm 0.5°C$.

Fig. 3 shows the location of water sampling for temperature, salinity, dissolved oxygen, $NO_3$-N, $PO_4$-P, and coliforms. Additional coliform samples were taken inside the lagoon at the locations indicated.

### Water Circulation

Periodically, during rising and falling tides, pairs of drogues, 1 m and 5 m deep, were released off the reef margin at both ends of the runway. After appropriate time intervals, depending upon the speed of the current, the positions of the drogues were determined

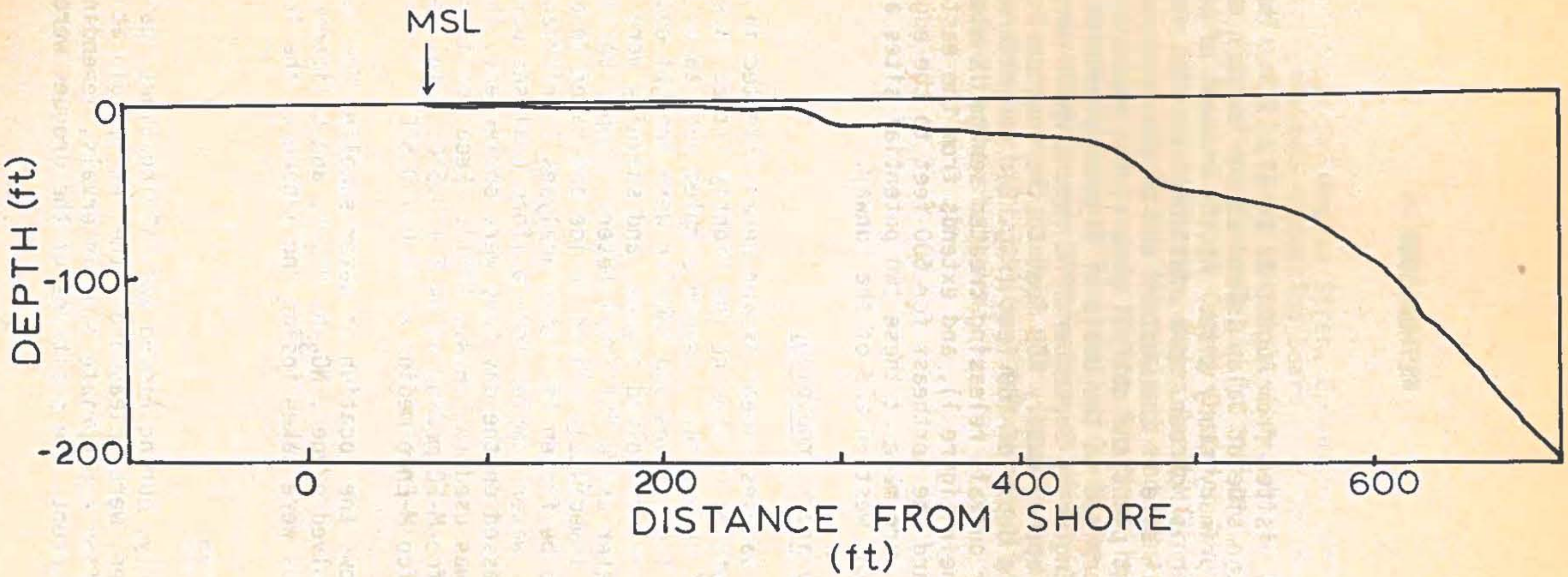


Fig. 2. Bathymetry along proposed deep outfall pipeline (From U. S. Army Copps of Engineers, 1972b).

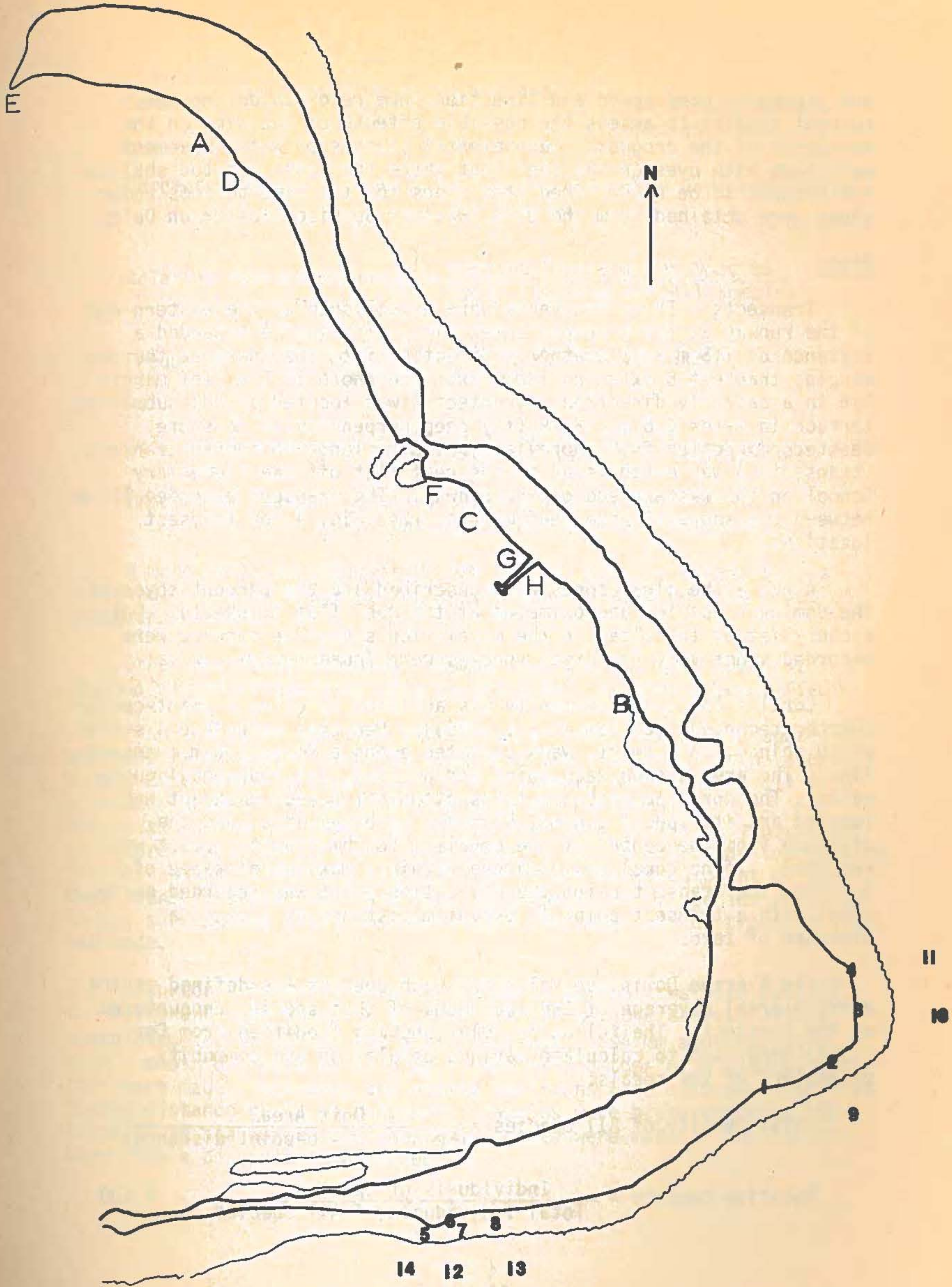


Fig. 3. Sampling sites for physical, chemical and microbiological characteristics of the water.

and plotted. Wind speed and direction were recorded during the current studies to assess the possible effects of the wind on the movements of the drogues. Supplemental studies of water movement were made with dyes on the reef flat where the water was too shallow for drogues to be used. Predicted tides for the time periods under study were obtained from the U. S. Weather Service Station on Dalap.

Biota

Transects - Three transects were established at the eastern end of the runway at the proposed sewer site. Transect A extended a distance of 115 m in a southerly direction from the shore to the reef margin; transect B extended 130 m from the shore to the reef margin but in a easterly direction. Transect D was located on the submarine terrace in water 4-6 m (12-19 ft.) deep perpendicular to shore (eastern direction from shore) and was 50 m long. A fourth transect (transect C) was established on the reef flat off the Elementary School on the western end of the runway. The transect extended 110 m between the shore and the reef margin. See Fig. 4 for transect locations.

Algae - The algal zones were described and the percent cover of the dominant species approximated at the reef flat transects. Only a checklist of the algae on the coral-rich submarine terrace were recorded since very few algal species were found here.

Coral - The coral community was analyzed by using a point-center quarter technique (Cottam et al., 1953). For this technique a series of 10 points, 10 m apart, were selected along a 50 or 100 m transect line. The area around each point was divided into four equal quadrants. The coral nearest the transect point in each quadrant was located and its specific name, diameter or basal area, and the distance from the center of the corallum to the transect point was recorded. If no coral was observed within a maximum distance of 5 m from the transect point the collection point was recorded as no coral with a transect point to organism distance at 5 m and a diameter of zero.

The Average Dominance Value for each species was defined as the average areal coverage of the specimens of that species encountered on the transect. The following relationships (modified from Cox, 1967) were used to calculate various population and community parameters of the corals:

$$\text{Total Density of All Species} = \frac{\text{Unit Area}}{(\text{Mean point-to-point distance})^2}$$

$$\text{Relative Density} = \frac{\text{Individuals of Species}}{\text{Total Individuals of All Species}} \times 100$$

$$\text{Density} = \frac{\text{Relative Density of Species}}{100} \times \text{Total Density of All Species}$$

$$\text{Percent Coverage} = \text{Density of Species} \times \text{Average Dominance Value for Species}$$

$$\text{Relative Percent Coverage} = \frac{\text{Percent Coverage for Species}}{\text{Total Coverage for All Species}}$$

$$\text{Frequency} = \frac{\text{Number of Points at which Species Occurs}}{\text{Total Number of Points}}$$

$$\text{Relative Frequency} = \frac{\text{Frequency Value for Species}}{\text{Total Frequency Values for All Species}} \times 100$$

$$\text{Importance Value} = \text{Relative Density} + \text{Relative Percent Coverage} + \text{Relative Frequency}$$

A more detailed analysis of the overall species diversity was achieved by making a collection in the general area on both sides of the transect line.

Other Macroinvertebrates - Aside from corals, only the most obvious macroinvertebrates were recorded and, at times, quantified.

Fish - A diver equipped with SCUBA or snorkling gear, depending upon the water depth, swam the length of the transect, taking approximately 20 minutes to cover the 100 m distance, and recorded all fish sighted within one meter to either side of the transect line. For transects run on the reef flat during low tide, it was only possible to record fishes on part of the transects, as the water was too shallow for most of the distance. In addition to the transect count on the deep transect beyond the reef margin, a checklist of species observed in the surrounding area, but not within one meter of the transect line, was made.

Plankton - Plankton were collected in paired tows with nets of two different mesh sizes: a #1 mesh net (.4 mm apperatures) with a mouth diameter of 52 cm, and a #15 mesh net (.094 mm apperatures) with a mouth diameter of 23.5 cm. Four paired tows of 5 minutes duration were made. Starting and ending positions were determined so that towing distance could be computed. Samples were preserved with 10% formalin in sea water, and subsample counts were made in the laboratory with a binocular microscope.

## RESULTS AND DISCUSSION

### Physico-Chemical Characteristics of the Water

Temperature, oxygen concentrations, and nutrient concentrations of the water at the proposed outfall sites at Majuro (Table 1) are characteristic of oceanic surface waters in this part of the Pacific (Mao and Yoshida, 1955; Reid, 1962; Mabbett, 1975). The salinity values are unexpectedly low for this area, and perhaps are unreliable. With the exception of these probably spurious salinity values, there is no evidence of significant modification of the offshore water by runoff from the island.

### Microbiological Characteristics of the Water

Fecal coliforms exceeded 200 per 100 ml in four shoreline samples on the ocean side of the island (Table 1). Although no outfalls or benjos were apparent in this area, there were houses in the vicinity. Offshore waters were virtually free of fecal contamination. Lagoon waters, in certain areas, were shown to carry high concentrations of coliforms (Table 2). These results serve to verify those of earlier studies (See Introduction) and are expected, as little has been done to improve the sewage disposal system since those early studies were made.

### Circulation

Drift drogue patterns from both proposed sites indicate the presence of a strong current flowing eastward along the southern margin of Dalap, and swinging northward along the eastern end of the island (Table 3, Fig. 4). This current is probably part of the Equatorial Countercurrent system and its pattern of flow is in general as predicted by Tait (1971), although speeds are higher than he suggested. Patterns of dye movement (Fig. 5) show a general trend for water on the reef flat to move slowly off the reef flat, presumably into the offshore current.

Drogue and dye studies performed by the U. S. Army Corps of Engineers in April 1972 at the east end of Dalap gave notably different results than those reported here. They observed significantly slower current speeds and a periodic southward and westward movement of the water apparently related to the tidal cycle. Wyrtki (1974) reported that the Equatorial Countercurrent undergoes seasonal fluctuations in its strength, being strongest in the fall-winter and weakest during spring-summer. These seasonal shifts are probably responsible for the differences between the current patterns observed

Table 1. Water chemistry and coliform data obtained from shoreline and offshore at northeast end and southwest end of old airstrip. See Fig. 3 for locations.

| Station | Temp. (°C) | Sal. ($^{o}/oo$) | D.O. (ppm) | pH | $NO_3$-N (μg-at/l) | $PO_4$-P (μg-at/l) | Fecal Coliform (per 100 ml) | Total Coliform (per 100 ml) |
|---|---|---|---|---|---|---|---|---|
| <u>Shoreline</u> | | | | | | | | |
| 1 | 30.6 | 25.3 | 6.0 | 7.6 | .2 | .4 | 50 | 0 |
| 2 | 30.8 | 24.8 | 6.9 | 7.7 | .2 | .9 | 20 | 0 |
| 3 | 30.0 | 25.7 | 7.7 | 7.5 | .2 | .8 | 10 | 0 |
| 4 | 32.2 | 26.8 | 7.8 | 7.5 | -- | -- | 0 | 0 |
| 5 | 30.4 | 26.2 | 6.20 | 7.51 | .2 | .4 | 2030 | 0 |
| 6 | 30.5 | 24.2 | 6.15 | 7.60 | .2 | .3 | 515 | 0 |
| 7 | 30.4 | 26.8 | 6.15 | 7.45 | .2 | 1.0 | 905 | 5 |
| 8 | 30.4 | 28.5 | 6.20 | 7.20 | -- | -- | 820 | 0 |
| <u>Offshore</u> | | | | | | | | |
| 9 | 27 | 30.0 | 6.2 | | .3 | .2 | 0 | 0 |
| 10 | 28 | 31.5 | 6.3 | | .2 | .2 | 0 | 0 |
| 11 | 28 | 31.0 | 6.1 | | .2 | .4 | 25 | 0 |
| 12 | 28 | 28 | 6.0 | | .2 | .2 | 0 | 0 |
| 13 | 28 | 29 | 6.1 | | .3 | .2 | 0 | 0 |
| 14 | 28 | 29 | 6.1 | | .2 | .2 | 0 | 0 |

Table 2. Fecal and total coliform (in parenthesis) values obtained by Sanitarians near shoreline in lagoon at eight stations off D-U-D, Feb. 1974-Aug. 1975. See Fig. 3 for locations.

| Station and Location | COLIFORM (per 100 ml) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1974 | | | 1975 | | | |
| | Feb. 27 | Mar. 26 | Aug. 1 | Jan. 16 | May 21 | July 22 | Aug. 27 |
| A. Meico Hotel Beach | 0(0) | 0(0) | 365(1300) | 140(160) | 0(0) | 0(0) | 0(0) |
| B. Police Station | 0(52) | 30(110) | 20(100) | 40(200) | 230(150) | 260(156) | 10(10) |
| C. Labor Camp | 0(350) | TNTC*(64,000) | TNTC(TNTC) | TNTC(TNTC) | TNTC(TNTC) | TNTC(TNTC) | 4300(3700) |
| D. M. I. High School | --- | --- | --- | --- | 15(13) | 10(17) | 0(0) |
| E. End of Rita Village | 0(67) | 1260(830) | 1800(350) | 1000(1400) | 150(75) | 120(70) | 20(0) |
| F. Meico Outfall | 0(118) | TNTC(TNTC) | TNTC(TNTC) | TNTC(TNTC) | --- | --- | --- |
| G. N of Dock | --- | --- | --- | --- | --- | --- | 0(0) |
| H. S of Dock | --- | --- | --- | --- | --- | --- | 8300(1445) |

*TNTC = >50,000/100 ml

Table 3. Data on the distance and speed of 1-m and 5-m drift drogue with wind direction and speed, at both ends of the runway.

| | | | 1 m | | 5 m | | Wind | |
|---|---|---|---|---|---|---|---|---|
| Drift | Start | ΔT (hr.) | Dist. (NM) | Speed (Kt.) | Dist. (NM) | Speed (Kt.) | Dir. | Kt. |
| Northeast End of Runway (Aug. 27, 1975) | | | | | | | | |
| 1 | 0730 | .25 | .07 | .28 | .06[2/] | .24 | 090 | 6.0 |
| 2 | 0745 | .75 | .36 | .48 | .35[3/] | .45 | -- | -- |
| 3 | 0835 | .50 | .62 | 1.25 | -- | -- | 068 | 10.0 |
| 4 | 0920 | .66 | .88 | 1.33 | -- | -- | -- | -- |
| 5 | 1012 | .88 | 1.53 | 1.74 | -- | -- | 098 | 9.5 |
| 6 | 1120 | .42 | .54 | 1.28 | -- | -- | 070 | 7.5 |
| 7 | 1155 | .83 | 1.40 | 1.69 | -- | -- | 078 | 9.5 |
| 8 | 1255 | 1.08 | 1.04 | .96 | -- | -- | 090 | 8.0 |
| 9 | 1405 | .75(.83)[1/] | .91 | 1.21 | .65 | .78 | 045 | 9.5 |
| 10 | 1500 | 1.50(1.17)[1/] | .93 | .62 | .78 | .84 | 060 | 8.0 |
| Southwest End of Runway (Aug. 29, 1975) | | | | | | | | |
| 11 | 0920 | .17 | .09 | .53 | .09 | .53 | 081 | 13.5 |
| 12 | 0937 | .40 | .12 | .30 | .14 | .35 | -- | -- |
| 13 | 1007 | .66 | .36 | .54 | .38 | .58 | 088 | 14.0 |

1/ ΔT for 5-m drogue.
2/ Grounded and retrieved.
3/ Grounded and washed on beach.

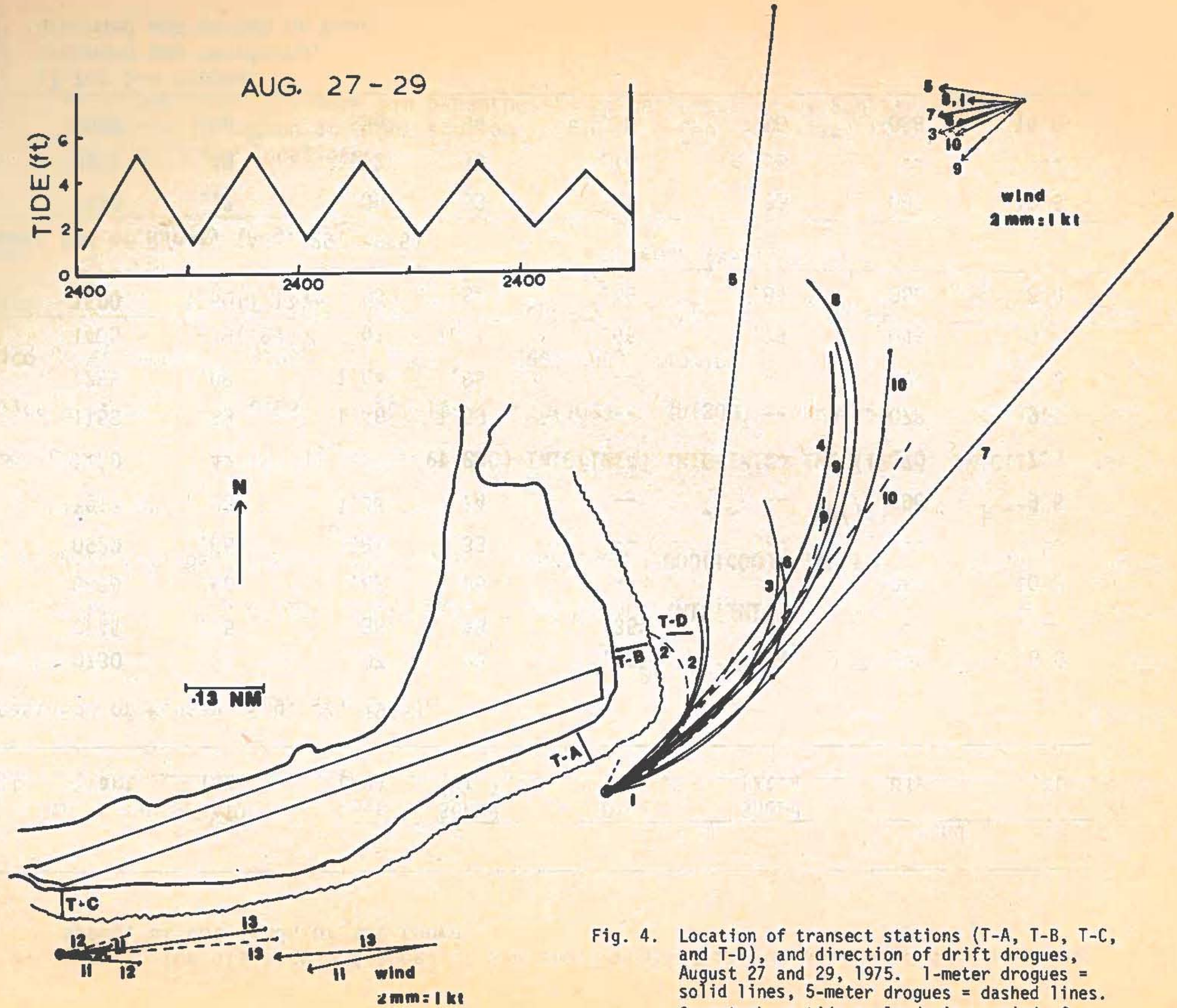


Fig. 4. Location of transect stations (T-A, T-B, T-C, and T-D), and direction of drift drogues, August 27 and 29, 1975. 1-meter drogues = solid lines, 5-meter drogues = dashed lines. Insert shows tide cycle during period of current study.

11 12 ← 11 wind 2mm=1kt

August 27 and 29, 1975. 1-meter drogues = solid lines, 5-meter drogues = dashed lines. Insert shows tide cycle during period of current study.



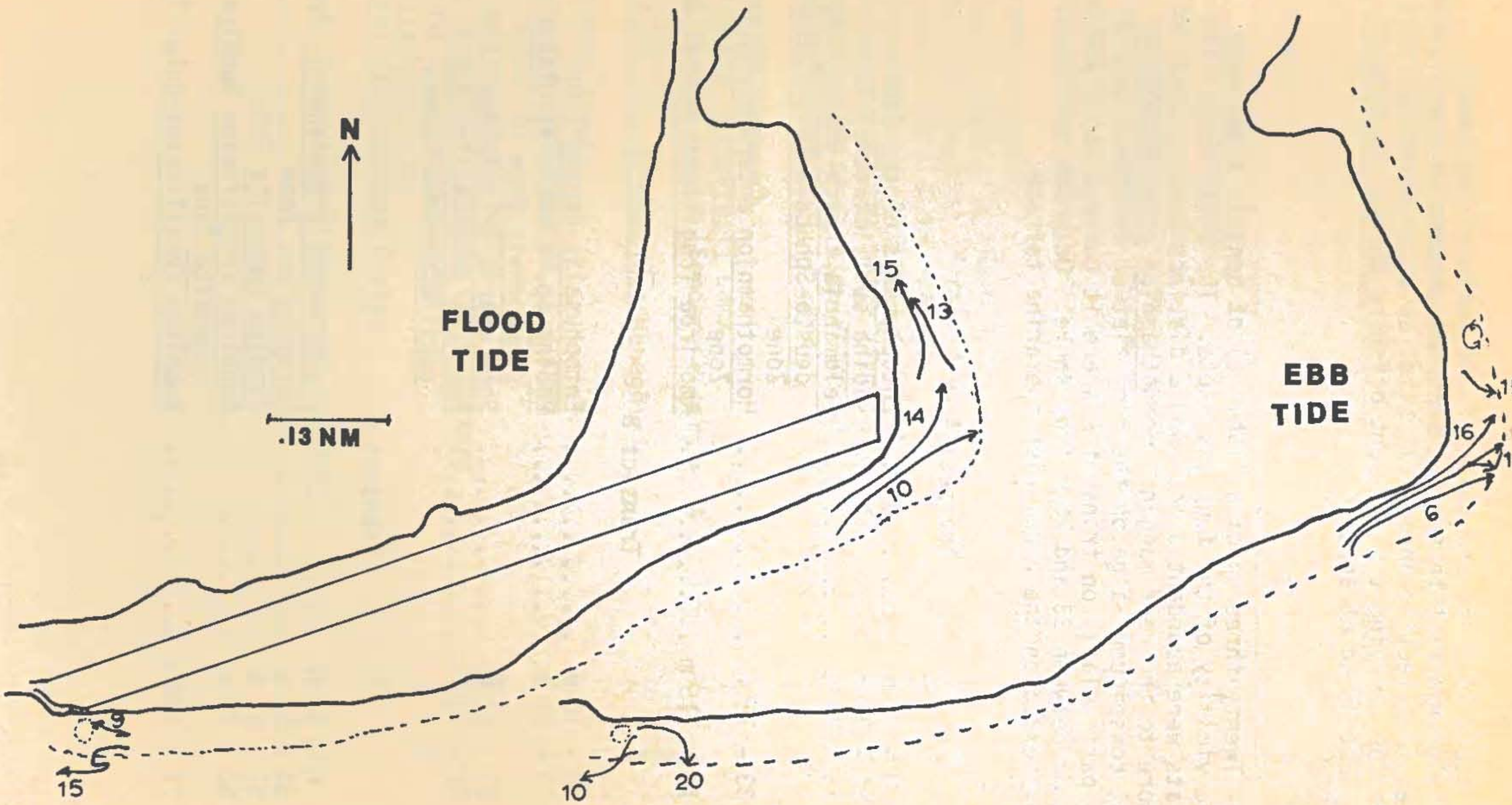


Fig. 5. Patterns of dye movement on the reef flat during ebb and flood tides. Arrows show direction and distance of dye movement and numbers indicate elapsed time in minutes.

during this study (August) and those of the Corps of Engineers (April). It is important that these seasonal changes in circulation be considered in selecting an outfall site, as water movements that are adequate for carrying the effluent offshore during one time of the year may not be so at another.

Biota

Algae - Twenty-three species (Table 4) of benthic algae were found in the vicinity of the four transects. The algae inhabiting the reef flats were abundant and showed a distinct zonation pattern from the shore to the reef margin. *Hormothamnion enteromorphoides* was the most conspicuous alga on the reef flat at the north end of the runway, particularly on transect A where it covered about 75% of the substratum between 33 and 76 m from shore. Only six species of algae were observed on the coral-rich submarine terrace.

Transect A

| | |
|---|---|
| 0 - 14 m .............. | *Entophysalis deusta* Zone |
| 14 - 25 m .............. | *Padina* sp. (immature) Zone |
| 25 - 33 m .............. | *Feldmannia indica-Entophysalis deusta-Sphacelaria tribuloides* Zone |
| 33 - 76 m .............. | *Hormothamnion enteromorphoides* Zone |
| 76 - 115 m .............. | *Amphiroa fragilissima*-Coral Zone |

Transect B

| | |
|---|---|
| 0 - 10 m .............. | *Entophysalis deusta* Zone |
| 10 - 51 m .............. | *Padina* sp. (immature)-*Cladophoropsis sundanensis* Zone |
| 51 - 82 m .............. | *Sphacelaria tribuloides* Zone |
| 82 - 130 m .............. | *Amphiroa fragilissima-Jania capillacea*-Coral Zone |

Transect C

| | |
|---|---|
| 0 - 34 m .............. | *Cladophoropsis sundanensis* Zone |
| 34 - 51 m .............. | *Ceramium* sp. Zone |
| 51 - 63 m .............. | *Boodlea composita* Zone |
| 63 - 76 m .............. | *Amphiroa fragilissima-Boodlea composita* Zone |
| 76 - 110 m .............. | *Amphiroa fragilissima*-Coral Zone |

Table 4. Checklist of algae at study sites, Majuro, August 1975.

| Species | TRANSECTS A | B | C | D |
|---|---|---|---|---|
| CYANOPHYTA (blue-greens) | | | | |
| Entophysalis deusta (Menegh.) Dr. & D. | X | X | | |
| Hormothamnion enteromorphoides B. & Fl. | X | X | | |
| Microcoleus lyngbyaceus (Kutz.) Crouan | X | | | |
| Schizothrix calcicola (Ag.) Gomont | X | | X | X |
| Schizothrix mexicana Gomont | | X | | |
| CHLOROPHYTA (greens) | | | | |
| Boodlea composita (Harv.) Brand | | | X | |
| Caulerpa racemosa (Forskal) J. Ag. | X | X | | X |
| Caulerpa urvilliana Montagne | X | X | | |
| Cladophoropsis sundanensis Reinbold | X | X | X | |
| Dictyosphaeria cavernosa (Forskal) Boerg. | X | X | | |
| Enteromorpha clathrata (Roth) Ag. | | X | | |
| Halimeda opuntia (L.) Lamx. | | | | X |
| PHAEOPHYTA (browns) | | | | |
| Dictyota bartayresii Lamx. | X | | | X |
| Feldmannia indica (Sonder) Womersley & Bailey | X | X | | |
| Padina sp. | | X | X | |
| Sphacelaria tribuloides Meneghini | X | X | | |
| RHODOPHYTA (reds) | | | | |
| Amphiroa fragilissima (L.) Lamx. | X | X | X | |
| Ceramium sp. | | | X | |
| Chondria repens Boerg. | X | | | |
| Gelidiopsis intricata (Ag.) Vickers | X | | | |
| Jania capillacea Harvey | | X | | X |
| Polysiphonia sp. | | | | X |
| Porolithon onkodes Foslie | X | | X | |
| Total Number of Species | 15 | 13 | 7 | 6 |

Corals - The reef flat at the north end of the runway contains a rich coral community (Table 5) in the outer reef flat which is depressed and rarely exposed during low tides. This community is dominated by *Acropora* and *Pocillopora* (Table 6). The inner reef flats of both transect sites, however, are devoid of coral growth within 40-50 m from shore.

Table 5. Checklist of corals found in the vicinity of the four transects on Majuro, August 1975.

| Species | TRANSECTS A | B | C | D |
|---|---|---|---|---|
| *Acropora corymbosa* (Lamarck) | | X | X | |
| *Acropora humilis* (Dana) | | X | X | |
| *Acropora nasuta* (Dana) | | X | X | X |
| *Acropora rosaria* (Dana) | | | | X |
| *Acropora surculosa* (Dana) | X | X | X | X |
| *Acropora syringodes* (Brook) | | X | X | X |
| *Acropora valida* (Dana) | | | | X |
| *Acropora variabilis* (Klunzinger) | | X | | X |
| *Favia pallida* (Dana) | X | | | |
| *Favites flexuosa* (Dana) | X | | | |
| *Heliopora coerulea* (Pallas) | | X | | X |
| *Leptastrea purpurea* (Dana) | X | X | X | |
| *Millepora platyphylla* Hemprich-Ehrenderg | | X | | X |
| *Montipora caliculata* (Dana) | | | | X |
| *Montipora ramosa* (Bernard) | X | | X | |
| *Platygyra rustica* (Dana) | X | | | |
| *Pleisiastrea verispora* (Lamarck) | X | | | |
| *Pavona (Polyastra)* sp. | | X | X | X |
| *Pavona varians* Verrill | | X | | X |
| *Pocillopora danae* Verrill | X | X | X | |
| *Pocillopora eydouxi* Milne Edwards & Haime | | | | X |
| *Pocillopora ligulata* Dana | | | | X |
| *Pocillopora setchelli* Hoffmeister | | | | X |
| *Pocillopora verrucosa* (Ellis & Solander) | | X | | |
| *Porites lutea* Milne Edwards & Haime | | X | X | X |

The reef flat off the Elementary School varies considerably from transects A and B. This area is flat, elevated, and rises slightly from shore to reef margin. The coral growth is limited to isolated, small colonies of *Leptastrea purpurea*, *Pocillopora danae* and *Favia pallida*.

Transect D on the submarine terrace supported a rich coral community dominated by various species of *Acropora* and *Pocillopora*. Any sewage discharge here would seriously alter the coral community.

Table 6. Living coral density, percent of substratum coverage, frequency of occurrence, and importance value for dominant coral species at the Majuro study area. Corals are arranged in order of their importance value.

| Species | Density/m$^2$ | Rel. Density | Percent Coverage | Rel. Percent Coverage | Freq. | Rel. Freq. | I.V. |
|---|---|---|---|---|---|---|---|
| Transect A (overall density = .079/m$^2$, overall coverage = <.01%.) | | | | | | | |
| *Acropora surculosa* | .054 | 68.75 | <.01 | 78.76 | .50 | 62.50 | 210.01 |
| *Pocillopora verrucosa* | .015 | 18.75 | <.01 | 11.58 | .20 | 25.00 | 53.40 |
| *Acropora syringodes* | .010 | 12.50 | <.01 | 9.65 | .10 | 12.50 | 36.58 |
| Transect B (overall density = .071/m$^2$, overall coverage = <.01%.) | | | | | | | |
| *Leptastrea purpurea* | .031 | 43.75 | <.01 | 60.60 | .30 | 37.50 | 141.55 |
| *Acropora surculosa* | .031 | 43.75 | <.01 | 24.24 | .30 | 37.50 | 105.49 |
| *Acropora syringodes* | .009 | 12.50 | <.01 | 15.16 | .20 | 25.00 | 52.66 |
| Transect C (overall density = .078/m$^2$, overall coverage = <.01%.) | | | | | | | |
| *Leptastrea purpurea* | .078 | 100.00 | <.01 | 100.00 | .20 | 100.00 | 300.00 |
| Transect D (overall density = 76.92/m$^2$, overall coverage = 1.04%.) | | | | | | | |
| *Acropora valida* | 29.58 | 38.46 | .54 | 52.02 | .75 | 27.27 | 117.75 |
| *Pocillopora setchelli* | 17.75 | 23.08 | .30 | 29.33 | 1.00 | 36.36 | 88.77 |
| *Acropora syringodes* | 23.67 | 30.77 | .08 | 7.40 | .75 | 27.27 | 58.34 |
| *Acropora nasuta* | 5.91 | | | | | | |

Other Macroinvertebrates - Ophiuroids were very abundant along transect B within 35 m from shore. An estimated 40 ophiuroids per $m^2$ was recorded based on 20 tosses of a 1/8 $m^2$ quadrat in this area. Echinometra mathaei was also very abundant near the reef margin on transect C. This species, however, was not observed on the reef flat at the northeast end of the runway. Soft corals were only seen on the submarine terrace and covered about 25% of the substratum.

Fishes - Surf conditions were such that transects on the reef flat (transects A, B, and C) could only be performed when the tide was low; as a result, fish counts were possible only for short distances along the transect where the water was deep enough for face mask observation.

Relatively few species of fishes were observed on the reef flat (Table 7), although their abundance was rather high considering the limited distances over which observations could be made. It may well be that during low tides, the resident fishes are concentrated in areas where the water is deepest. It is quite likely that more species occupy the reef flat when the tide is high and the effects of surf and surge are not so extreme (Hiatt and Strasburg, 1960). Many more species were observed on the deeper transect (D) beyond the reef margin. This terrace is more hospitable to fishes than the reef flat, being less subject to surge and wave action. The extensive coral cover provides much habitat for these fishes.

Plankton - In comparison with the plankton collected in the lagoon at Ebeye, the plankton on the ocean side of Majuro is less abundant (Table 8). The collections at Majuro also took notably fewer crustacean larvae, especially with the coarse mesh net. Without more detailed identifications of the organisms collected, and more systematic plankton collection both inside the lagoon and on the ocean side of the atoll, it is not possible to assess the biological role of the plankton. In view of the strong currents in this area, which are moving considerable volumes of seawater past the island, it seems most reasonable to assume that the plankton collected are open ocean species carried in the Equatorial Countercurrent. Despite their rather low abundance, the speed of the currents in which they are carried indicates that large numbers of planktonic organisms will be swept by the reef in any given period of time, providing potential forage for planktivorous species. It is not known, however, the extent to which the plankton is exploited by resident organisms.

Table 7. Fishes observed on transects at proposed sewer outfall sites, Majuro, August 1975. Distance over which fish could be observed: A - 95 m, B - 20 m, C - 20 m, D - 50 m.

| Species | TRANSECT A | B | C | D |
|---|---|---|---|---|
| Acanthuridae | | | | |
| *Acanthurus glaucopareius* Cuvier | | | | + |
| *A. lineatus* (Linnaeus) | | | | + |
| *A. mata* (Cuvier) | | | | + |
| *A. nigroris* Cuvier | | | | + |
| *A. olivaceus* Bloch & Schneider | | | | + |
| *A. triostegus* (Linnaeus) | 2 | | | 3 |
| *Naso literatus* Bloch & Schneider | | | | + |
| Balistidae | | | | |
| *Melichthys buniva* Bloch & Schneider | | | | + |
| *Rhinecanthus rectangulus* (Bloch & Schneider) | | | | + |
| Chaetodontidae | | | | |
| *Centropyge flavissimus* (Cuvier) | | | | + |
| *Chaetodon auriga* Forskal | | | | + |
| *C. falcula* Boch | | | | + |
| *C. lunula* (Lacepede) | | | | + |
| *C. reticulatus* Cuvier | | | | + |
| Cirrhitidae | | | | |
| *Paracirrhites arcatus* (Cuvier & Valenciennes) | | | | 2 |
| *Paracirrhites hemistictus* (Gunther) | | | | + |
| Labridae | | | | |
| *Halichoeres margaritaceus* (Cuvier & Valenciennes) | 14 | 5 | | |
| *Stethojulis bandanensis* (Bleeker) | | | | 1 |
| *Thalassoma lutescens* (Lay & Bennett) | | | | + |
| *T. purpureum* (Forskal) | 17 | | | |
| *T. quinquevittata* (Lay & Bennett) | | 23 | 6 | 27 |
| *Thalassoma* juveniles | | 2 | | 101 |
| Muraenidae | | | | |
| *Echidna nebulosa* (Ahl) | | 1 | | |
| Pomacentridae | | | | |
| *Abudefduf amabilis* (De Vis) | 14 | 5 | | |
| *A. dicki* (Lienard) | | | | 12 |
| *A. leucozona* (Bleeker) | 23 | | | |
| *A. leucopomus* (Lesson) | | 2 | | |
| unidentified pomacentrids | | | | 4 |

| Species | TRANSECT A | B | C | D |
|---|---|---|---|---|
| Scaridae | | | | |
| Scarus sordidus Forskal | | | | + |
| juvenile scarids | | | | + |
| unidentified scarids | | | | + |
| Serranidae | | | | |
| Cephalopholis urodelus (Bloch & Schneider) | | | | + |
| Zanclidae | | | | |
| Zanclus cornutus (Linnaeus) | | | | + |
| # individuals counted | 70 | 36 | 8 | 150 |
| # species counted | 5 | 5 | 2 | 7 |
| # species total (includes checklist) | | | | 27 |
| Total species observed = 33 | | | | |

Table 8. Relative abundance of planktonic organisms collected in oceanic waters off Majuro, August 1975.

| Planton | Coarse Net | Fine Net |
|---|---|---|
| dinoflagellates | <1% | 5% |
| diatoms | | 8% |
| foraminifera | 6% | 3% |
| radiolarians | 7% | 7% |
| tintinnids | | <1% |
| medusae | | <1% |
| siphonophores | 6% | <1% |
| mollusks | | 13% |
| polychaete larvae | | <1% |
| crustacean: | | |
| larvae | 1% | 16% |
| copepods | 41% | 42% |
| mysids | <1% | |
| amphipods | | <1% |
| unidentified | 2% | |
| chaetognaths | 9% | <1% |
| echinoderm larvae | 1% | |
| salps | 2% | |
| larvaceans | 9% | |
| fish eggs | 15% | 5% |
| fish larvae | 1% | |
| Total plankton abundance (organisms/$m^3$): | 54 | 293 |

## CONCLUSIONS

### Suitability of the Proposed Outfall Sites

Three possibilities have been proposed for sewage treatment and disposal on Majuro:

(1) secondary treatment with a shallow ocean outfall at the eastern end of the old runway on Dalap;

(2) comminution and chlorination with a deep ocean outfall at the eastern end of the old runway on Dalap; and

(3) secondary treatment with a shallow ocean outfall at the western end of the old runway, near the present elementary school, on Dalap.

A fourth possibility, an outfall inside the lagoon, was not investigated in this study, but the poor circulation on the lagoon side of the D-U-D area (Mabbett, 1972) argues against this alternative.

Secondary treatment plants produce unpleasant odors and, on this basis, alternative (1) is not favored: the site is upwind of proposed housing developments and the existing Eastern Gateway Hotel. The site at the western end of the runway, alternative (3), is downwind of the D-U-D area, but is immediately adjacent to the existing elementary school,which makes this proposal somewhat less than ideal. The raw sewage facility, alternative (2), should not produce excessive odors, and so its location at the eastern end of the runway is not objectionable from this standpoint.

Our current studies indicate strong water flow eastward along the southern coast of Dalap which swings northward along the east coast of the island. Dye studies on the reef flat indicate that this water moves slowly off the reef and presumably joins the strong current running along the outside of the reef. These studies indicate that sewage effluent entering the strong current system will be carried away by the current, and that effluent on the reef flat should eventually flow off into the strong current. However, there is evidence from the Corps of Engineers' study that seasonal changes in current flow occur, and there is a distinct possibility that, at some times of the year, the effluent may not be carried away from the island and may be carried onto the reef flat.

### Impact of Outfall Construction

It is not anticipated that the construction of the outfall across the reef flat will have any lasting deleterious effects. Strong circulation across the reef flat will carry away any silt produced. The outfall pipe itself is to be buried in a trench (U. S. Army Corps of Engineers, 1972b), and the construction of this trench will no doubt destroy certain corals, but the magnitude of the damage to the reef flat should be small. The extension of the outfall pipe to a depth of 160 feet [alternative (2)], requires that approximately 430 more feet of outfall pipe be laid. This will cross an area of rich coral growth and will have localized, though not major nor long-lasting, impact.

Impact of Effluent

Secondarily treated effluent should be low in BOD, although it will be high in nutrients. Chlorination should remove most of the potential pathogens. If carried away by offshore currents, the effluent should have little impact on the reef flat or shoreline. If seasonal changes in current flow allow the treated effluent to move onto the reef flat, the additional nutrients may affect the algal flora of the reef flats, by enhancing the growth of certain species (perhaps at the expense of other reef organisms). Chlorine may cause harm to some reef flat species. The reef terrace community beyond the reef flat may be similarly influenced by the treated effluent, but the small anticipated discharge should make these effects minimal.

The raw sewage effluent, initially high in BOD and nutrients, should be well-diluted by the time it reaches the surface waters (U. S. Army Corps of Engineers, 1972b). The environmental effects of the suspended material should be minimal unless seasonal current shifts carry it onto the reef. The settleable solids discharged by the raw sewage outfall are potentially the more damaging components of the effluent to the coral community and associated organisms. However, it appears that the strong currents in this area should be sufficient to prevent any extensive sedimentation.

## RECOMMENDATIONS

1. Additional current studies in the spring time (February - June), when the flow of the Equatorial Countercurrent is weakest, are necessary to determine whether sewage effluent is likely to move onto the reef at this time of the year.

   Fluorescein dye markers can be used to determine the direction of water movement during ebb and flood tides. Tide-related differences in water movement, such as those detected by the U. S. Army Corps of Engineers in this area, may indicate a need to schedule effluent discharge during periods of offshore flow.

2. Careful consideration of the cost and difficulty of constructing the deep ocean outfall must be taken. If it is found feasible, the optimal alternative for sewage disposal would be the deep ocean outfall discharging comminuted sewage.

3. If the deep ocean outfall is not feasible, secondary treatment would be necessary. Our current studies indicate that the effluent would be carried away by the current at either site (west end or east end of the old runway), and on the basis of potential odor nuisance, the west end may be preferable. If spring-time current studies indicate the effluent will be carried back onto the reef flat, the choice of a site for the secondary treatment plant will depend upon the evaluation of those current studies.

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PLATE I

Fig. 1. View of reef flat at transect A.

Fig. 2. View of reef flat at transect B.