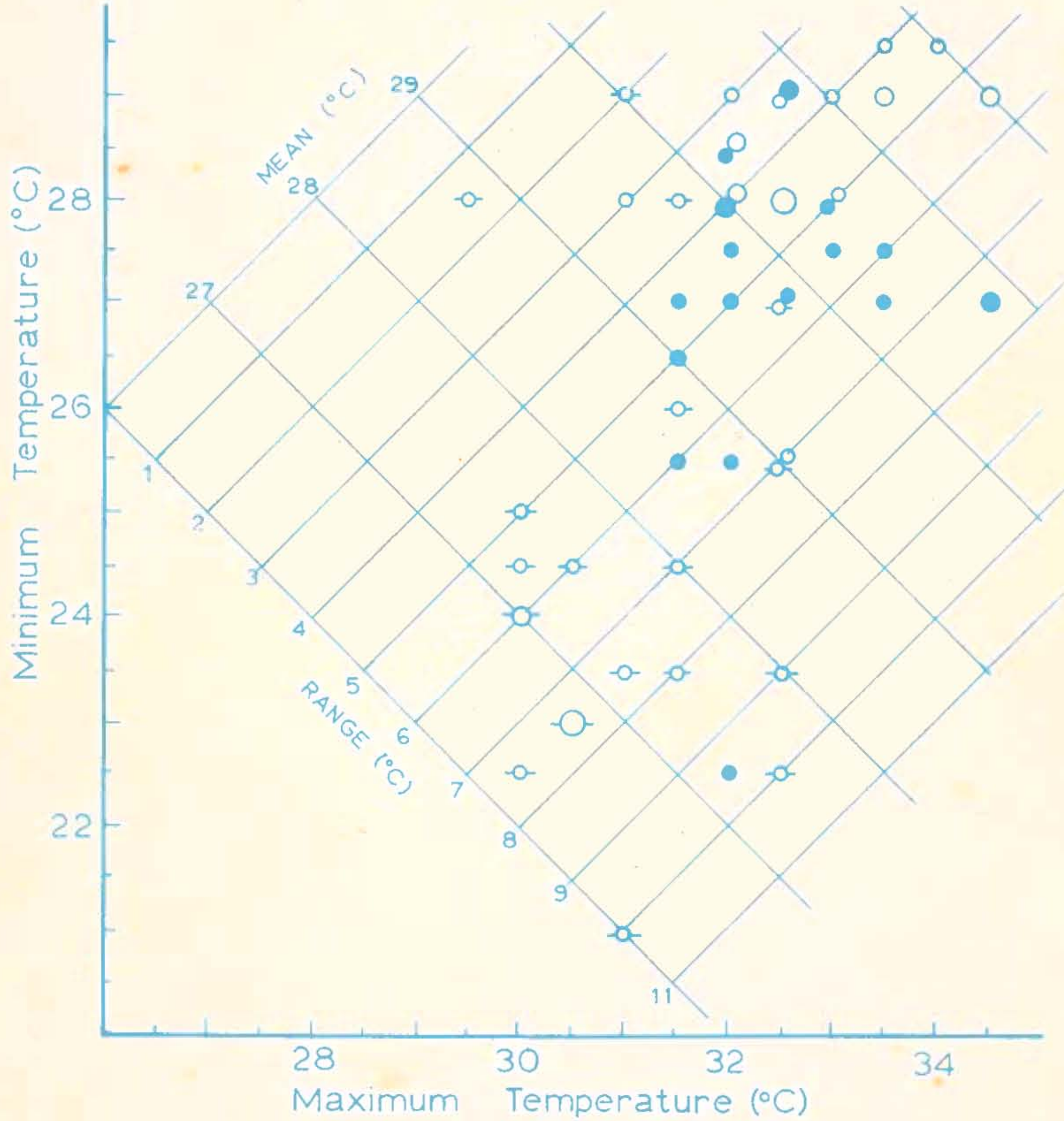
POWER PLANTS AND THE MARINE ENVIRONMENT IN PITI BAY AND PITI CHANNEL, GUAM: 1976-1977 OBSERVATIONS AND GENERAL SUMMARY

James A. Marsh, Jr., Mitchell I. Chernin, and James E. Doty



UNIVERSITY OF GUAM MARINE LABORATORY

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Maximum and minimum temperatures occurring between 26 November 1975 and 9 April 1976 on Tidal Flats B (o), C (●) and D(-o-). The size of each symbol is proportional to the number of replicate data points, (o = 1, O = 2, O = 3). Coinciding data points from differing stations are slightly offset for clarity.

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IN PITI BAY AND PITI CHANNEL, GUAM:
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By

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INTRODUCTION

This is the last report on the results of environmental studies conducted in Piti Channel, Guam, and nearby areas from January 1972 until March 1977. The main emphasis of this report is on data obtained in the study area from April 1976 to March 1977. However, data from five previous reports (Marsh and Gordon, 1972; Marsh and Gordon, 1973; Marsh and Gordon, 1974; Marsh and Doty, 1975; and Marsh and Doty, 1976) are also presented to summarize the conditions of the area before Cabras Power Plant operations (1972-1974); during the onset of Cabras Power Plant operations (August 1974); and under normal day-to-day operations of the Cabras Power Plant (1975-present).

The studies have been concerned with environmental effects of Guam Power Authority activities in Piti Bay and Piti Channel. West Piti Bay (Figure 1) was studied because sea water used to cool the condensers of both the Cabras and Piti Power Plants is drawn mainly from Tepungan Channel, located in the inner reef flat of that bay, and because it was impacted by construction activities. Piti Channel and the surrounding tidal flats (Fig. 2) were studied because this area was to be and presently is affected by power plant operations. Cooling water drawn from Tepungan Channel and Piti Canal is pumped through the power plants, with an increase in temperature, and is discharged into an outfall lagoon formed by a cul-de-sac extension of Apra Harbor. This effluent then flows approximately 1600 m westward via Piti Channel and at least two tidal flats into the Commercial Port area of the harbor.

Construction of the Cabras Power Plant began in December 1972 with the initiation of dredging in Tepungan Channel. The two arms of this channel, the north arm created by the 1972-73 dredging and an older (and shallower) south arm, which represents a natural channel that existed before the construction of the causeway, feed water under a roadway and into Piti Canal. This is a man-made canal which cuts through the Cabras Island Causeway in a northwest-southeast direction (Fig. 2) and is the common source of cooling water for both power plants.

Each of the two Cabras units has a generating capacity of 66 megawatts (MW); and the total capacity of the five units of the older Piti Power Plant, operated by the Navy Public Works Center, is approximately 74 MW (all information supplied by Guam Power Authority). The maximum pumping capacity of cooling waters through the condensers of the Cabras Plant is 9.01 cubic meters per second (120,000 gallons per minute) for both units combined. The plant was designed to have a temperature rise of 5.6-8.3° Centigrade (10-15° Fahrenheit) for cooling waters passing through the condensers. Maximum pumping capacity of

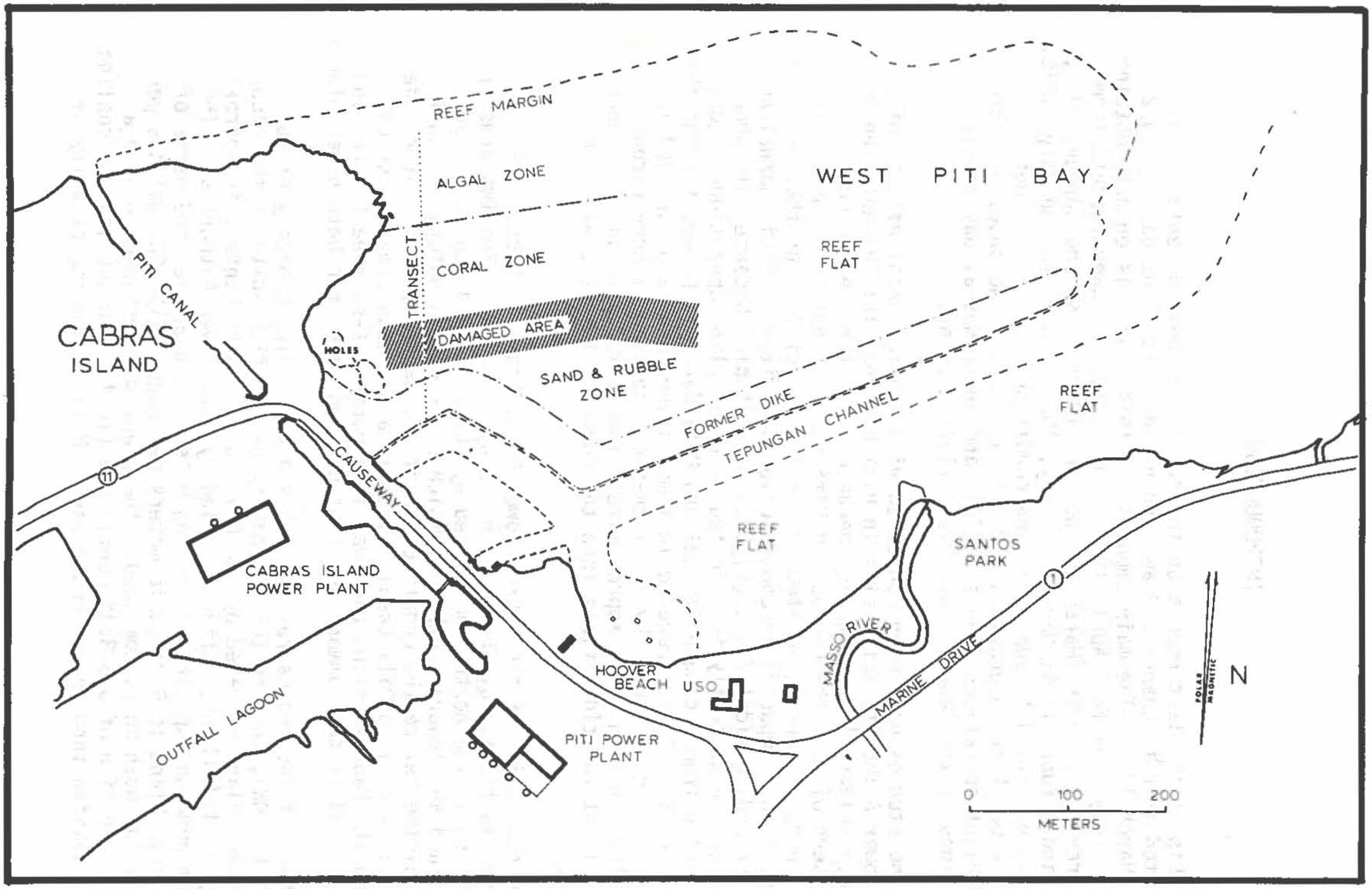

Figure 1. West Piti Bay showing the major features in the area of the Piti and Cabras Power Plants. The location of the damaged area was determined in conjunction with Guam EPA.

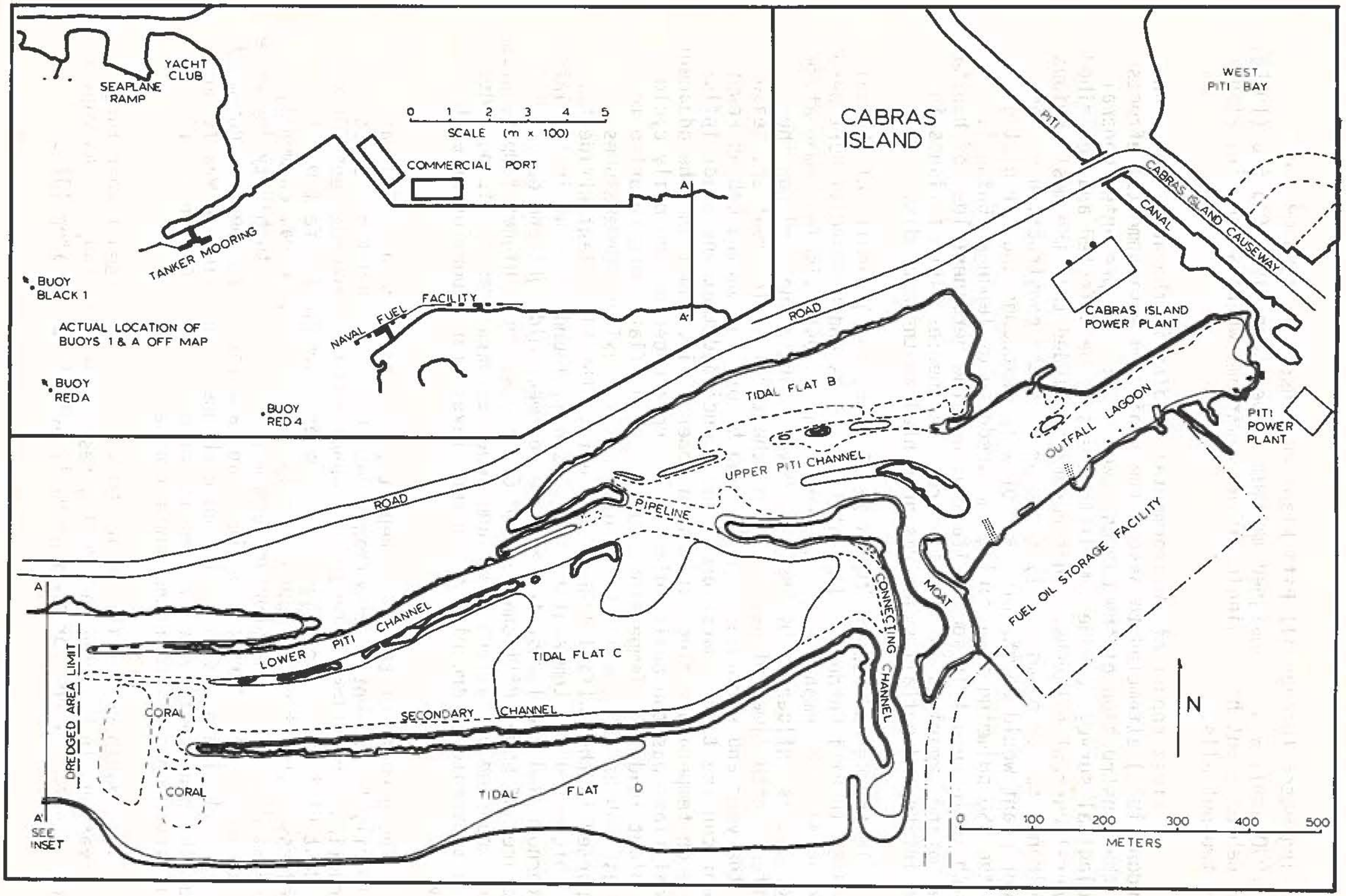

Figure 2. Major features of the area affected by the effluents of the Piti and Cabras Power Plants. Inputs of water from the power plant outfalls are indicated by arrows. Tidal Flat A was filled to provide the construction site for the Cabras Power Plant.

cooling water through all Piti Plant condensers is 4.85 $m^3 sec^{-1}$ (64,000 gpm), with a designed maximum temperature rise of 5.6°C (10°F). The Cabras Plant has a single effluent stream, whereas the Piti Plant has two outfalls.

The first report of environmental studies in the area (Marsh and Gordon, 1972) attempted to assess the projected environmental effects of the construction of the Cabras Power Plant. It presented general biological surveys of the immediate areas to be affected and described general current patterns. This report concluded that the most serious environmental problems likely to occur with the construction of the power plant would be the blockage of water exchange and circulation in the USO swimming area during the dredging of Tepungan Channel, which would result in some siltation, and the permanent loss of habitat for marine organisms in the fill area. A species list of fishes in the intake and outfall sides was presented in the appendix.

In the second report (Marsh and Gordon, 1973) results of thermal studies in Piti Channel, adjacent tidal flats and Commercial Port were discussed. The emphasis of the report was on establishing temperature regimes, as influenced by the Piti Power Plant alone, and how they differed with times of day, stage of the tidal cycle, weather, season of the year and variable plant loading before and during Cabras Power Plant construction. Marsh and Gordon concluded that the major influence on temperature fluctuations in Upper Piti Channel and the adjacent tidal flats was the daily solar cycle, reinforced by the daily cycle of plant loading. Temperatures on the tidal flats were reported to be as high as 35°C, which was equivalent to maximum temperatures reported in the outfall lagoon adjacent to the Piti Plant effluents. The highest daily temperatures were usually found to occur in the late afternoon and the lowest temperatures between midnight and dawn. In the area of Lower Piti Channel and Commercial Port, higher temperatures were reported on falling tides and lower temperatures on rising tides, with temperatures dropping to ambient levels for a portion of each day.

The purpose of the third report (Marsh and Gordon, 1974) was primarily to present information about the observed effects of construction activities in Tepungan Channel and the adjacent reef flats of West Piti Bay. The major long-term environmental effect was the needless destruction of approximately 25% of a live coral community in West Piti Bay. The shorter-term effects included turbidity increases of at least two orders of magnitude and a depauperate benthic community in the silt-laden bottom of Tepungan Channel. No evidence was found that the construction activities affected dissolved oxygen, nutrient, salinity or pH levels in the outfall area.

The fourth report (Marsh and Doty, 1975) discussed temperature observations in Piti Channel during testing and start-up of the Cabras Power Plant. Except for an abnormally hot plume of water (37°C) at the outfall, during the onset of plant operations, there was no extension of the areas enclosed by given isotherms in Piti Channel or Commercial Port beyond regions where they were found before Cabras Plant operations began. Biological observations on 16 100-m transects which ran down the axis of Piti Channel from the Piti Power Plant outfalls to the western end of the channel were presented. Three groups of organisms were distinguished, with the greatest diversity exhibited in the outfall lagoon and Lower Piti Channel. It was reported that in West Piti Bay, Tepungan Channel was permanently altered to a siltier and less biologically diverse state than it showed before dredging activities and that the bulldozed coral area showed little signs of regeneration.

The primary purpose of the fifth report (Marsh and Doty, 1976) was to present data on the temperature regimes and biological diversities in the outfall lagoon, Piti Channel, tidal flats and Commercial Port areas after the Cabras Plant was in normal operation. The Cabras outfall had an added thermal impact, with temperatures up to 37°C, to that of the Piti Plant effluents in the immediate outfall area. However, there appeared to be no increase in areas enclosed by specific isotherms for other areas in the study site. A diurnal temperature pattern for the outfall locations, tidal flats, channels, and Commercial Port area was firmly established. The effects of solar heating on the tide flats were discussed. It was also determined that the major thermal impact of the power plants on the tidal flats and Piti Channel was to impose a temperature regime which was more constantly higher than would be the case under natural conditions, but with maximum plant-induced temperatures not exceeding maximum natural temperatures. Finally, the results of 16 100-m biological transects were presented and comparisons were made between these results and those of the 1975 report. Only two distributional groups of organisms were distinguished in this report as compared with three groups in the 1975 report. The greatest biological diversity was again found in the outfall lagoon and Lower Piti Channel.

METHODS

Surface temperature measurements were made with a mercury bucket thermometer. Mercury maximum/minimum thermometers were placed at various locations in the study area over several months and read and reset periodically. Ryan thermographs were placed at sites adjacent to the maximum/minimum thermometers to obtain continuous thermal records over a 2-week period. However, because of operating difficulties with these instruments no useful data were obtained.

Qualitative and semi-quantitative biological observations were made in the field at various sites throughout the study area. Occasional specimens were collected and preserved for laboratory identification.

Determinations of dissolved oxygen were made according to the azide modification of the Winkler technique (APHA, 1971). Determinations of reactive phosphorus, nitrite and nitrate followed the procedures outlined in Strickland and Parsons (1968).

Methods used in the current studies, bathymetry and plankton tows are described in the text.

TEMPERATURES

Our temperature observations over the past five years have been of three general types. Various continuously recording instruments have been used at specific locations in an attempt to get continuous long-term records; because of problems with the instrumentation these have been only moderately successful. The instruments included Ryan thermographs, Dickson "minicorders," and a YSI multichannel telethermometer connected to a strip-chart recorder. Representative records from the minicorders were presented in the 1973 and 1974 reports, and some continuous telethermometer records were included in the 1976 report. A large number of synoptic compilations have been made from individual surface temperature measurements made at widely scattered locations throughout the study area; these compilations have been presented as isotherm plots in previous reports and are presented in the same manner here. The measurements were made with mercury thermometers or with a battery-powered telethermometer utilizing thermistor probes. More recently, we have placed a number of mercury/alcohol-column maximum/minimum recording thermometers at key locations and read and reset these at periodic intervals. The information, impressions and conclusions resulting from these three different kinds of data are similar and reinforce each other, thus giving us a high degree of confidence in those conclusions.

General Isotherm Plots

General isotherm plots of surface temperatures from 1972 to 1977 are presented in Figs. 3 - 6. The isotherm plots represent prevailing conditions before Cabras Power Plant operations began, at the onset of operations, and during normal operations of the plant. The Piti Power Plant was operational during the entire study period but worked at a reduced load after the Cabras Plant went into operation. Fig. 3A shows locations of sampling stations.

A "typical" isotherm plot before the Cabras Plant began operations was presented by Marsh and Gordon (1973) and is reproduced here as Fig. 3B. The plot is for 2 May 1972 between 1030 and 1200 hours, or approximately 2 to 3½ hr after high tide. The thermal plume from the Piti Power Plant can be seen extending westward into Piti Channel. Tidal Flats A, B, and D have temperatures of 30-31°C. The authors attributed these relatively high temperatures on Tidal Flats A and B to solar heating and plant effects. In the case of Flat D, only solar heating was responsible for the high temperatures. Morning surface temperatures recorded on 18 May 1972 were generally lower than for 2 May and afternoon temperatures were higher on the latter date. Temperatures on Tidal Flat D, unaffected by the Piti Plant, equalled or exceeded outfall temperatures.

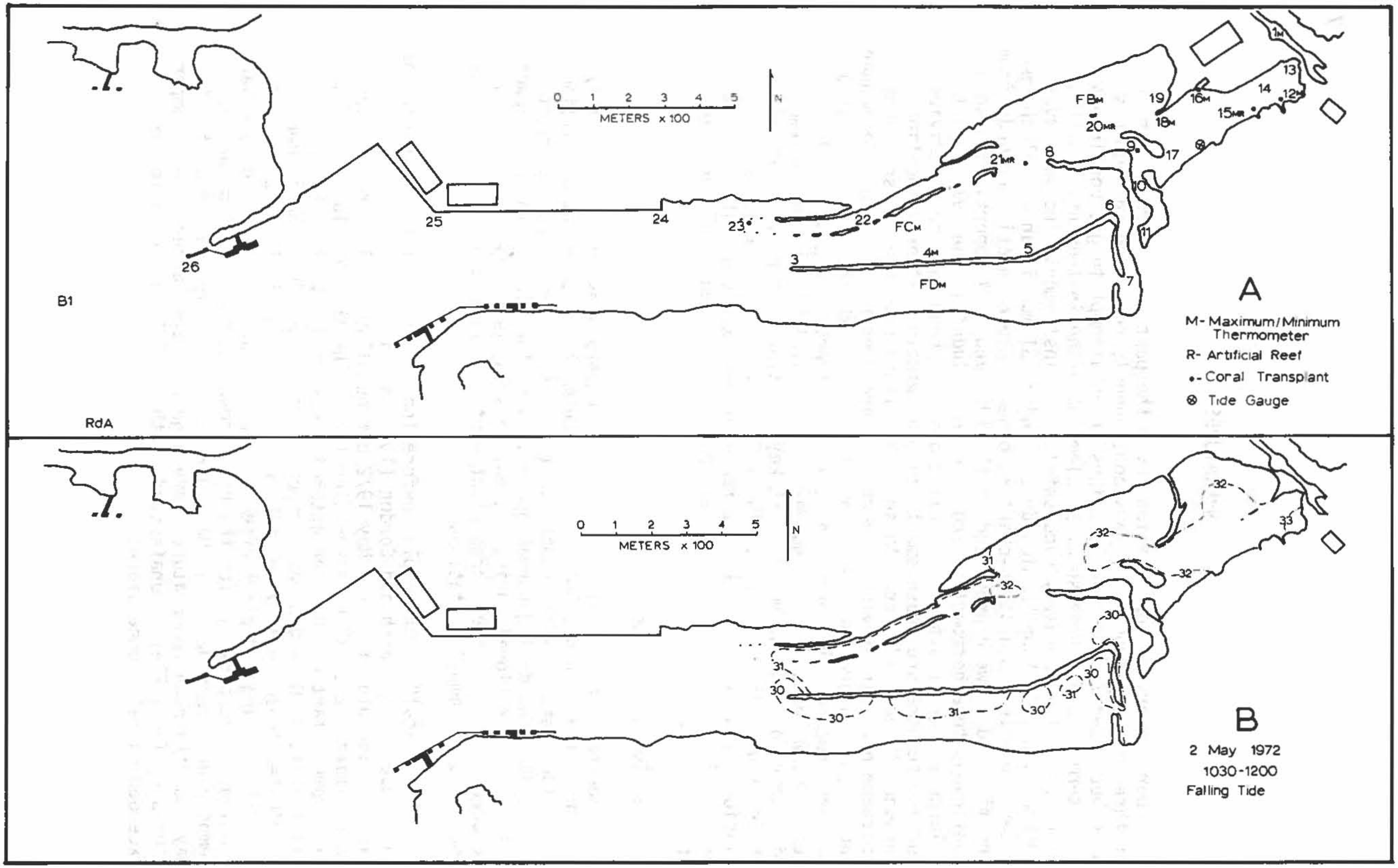

Figure 3. A. Location of sampling stations for surface temperatures in the Piti and Cabras outfall area. Numbers indicate stations referred to in Table 1; M refers to location of maximum/minimum thermometers; R refers to location of artificial reefs; • refers to coral transplant locations. B. Isotherm plot (°C) for 2 May 1972, 1030-1200 hours. A high tide of 2.0 ft occurred at 0824 hours.

The temperature data from 1973 were consistent with the earlier records discussed above. Usual temperatures ranged between 30 and 33°C at the Piti Power Plant outfalls. The temperatures on the tidal flats were still primarily influenced by solar heating.

Figure 4B shows an isotherm plot for a morning low tide on 16 July 1974 shortly before the Cabras Plant began operations (Marsh and Doty 1975). As before, the temperatures recorded represent "typical" observations. The 33°C isotherm did not extend beyond the outfall lagoon; and the 31°C isotherm was at the extreme western end of the Commercial Port area. Temperatures recorded for the afternoon high tide on 16 July 1974 (Fig. 4A) showed a 2°C decrease in the area of Commercial Port and Lower Piti Channel as a result of tidal inflow, which brings in cooler water from the outer harbor. The 33°C isotherm had moved slightly westward, outside the outfall lagoon.

The above-referenced figures and other data give a relatively consistent overview of temperature observations in Piti Channel and Commercial Port prior to the onset of Cabras Power Plant operations.

Figure 5A represents isotherm plots at the onset of Cabras Power Plant operations at low tide (Marsh and Doty 1975). At this time (15 October 1974),the Cabras Plant was not operating at peak capacity. A temperature of 37°C was recorded for the area adjacent to the Cabras Plant outfall. This is the highest temperature ever recorded for that area. (Higher temperatures have been observed on Tidal Flats C and D, which are discussed later in the report.) The 34° isotherm enclosed an area extending into Lower Piti Channel. The 31° isotherm was found in the eastern end of the Commercial Port area, well within the usual limits prior to Cabras Power Plant operations. It is apparent that the Cabras Plant was having a thermal effect above and beyond that of the Piti Plant at this time. Temperatures on Flats B and C were enclosed within the 34° isotherm, whereas temperatures on Flat D were lower but fell within the 33° C isotherm. The high temperatures on the flats were influenced by solar heating, with Flat B also influenced by the Cabras Plant and Flat C influenced by both the Piti and Cabras Power Plants. Temperatures throughout the area were 1-3° lower a few days later (18 October 1976) on a morning high tide (Marsh and Doty 1975).

Figure 5B shows plotted isotherms in the area just after a morning low tide on 5 June 1975, after both Cabras Units 1 and 2 were in operation (Marsh and Doty 1975). The Cabras outfall temperature was lower than in the earlier phases of operation (33.4° on 5 June 1975 versus 37.0°C on 15 October 1974). Specific isotherms were well within the limits of previous records before Cabras Plant operations began.

More extensive observations discussed in the 1976 report reinforced the preliminary conclusions of the 1975 report that operations of the Cabras Plant were not expanding the areas enclosed within specific isotherms beyond pre-existing conditions, when only the Piti Plant was in operation, at least for most of the area of the tidal flats and Piti Channel. However, it was clear that in the immediate vicinity of the Cabras outfall temperatures were higher than in the immediate vicinity of the Piti outfalls either before or after Cabras operations began. A "worst-case" isotherm plot after Cabras operations began (Marsh and Doty 1976) represented overall temperatures which were no higher than worst-case conditions before those operations began.

Figure 6A shows isotherm plots in the study area just after a morning low tide on 18 October 1976. On this occasion the Cabras outfall was 3.2°C warmer than the Piti outfall, and there was a distinctive Cabras plume (33° isotherm) which extended into Upper Piti Channel. The 32° isotherm extended to the far eastern end of Commercial Port.

Figure 6B shows isotherm plots just after a morning high tide on 8 November 1976. The Cabras outfall was 3.2°C warmer than the Piti outfall (as reported for 18 October 1976). The 34° isotherm was confined to the outfall lagoon with the 33°C isotherm extending into Upper Piti Channel. The temperatures recorded for the tidal flats were cooler for 8 November 1976 and 18 October 1976 (32°C versus 33° for Flat C and 31°C versus 33° for Flat D) because of overcast and rainy conditions which decreased the amount of solar heating in the area during the November observation.

The isotherm plots discussed above are sufficient to give an idea of the temperature range and usual conditions in the study area after the Cabras Plant began full operations. Additional observations are given in Table 1 rather than being presented as isotherm plots. Conclusions from the previous reports still hold, in that higher Cabras than Piti outfall temperatures are not reflected in a general expansion of areas enclosed by specific isotherms since Cabras operations began.

Maximum/Minimum Temperatures

Maximum/minimum thermometers were placed at various sites (Fig. 3A) in the study area and left in place for varying lengths of time up to 19 months. These were read and reset at periodic intervals, with readings being made to the nearest 0.5°C. The average temperature for a given time interval was calculated by adding the minimum and maximum temperatures and dividing the sum by two. Some results were reported previously (Marsh and Doty 1976), and additional results are presented in Table 2; and in Figs. 7 - 9.

The minimum temperatures for Piti Canal ranged between 26° and 28.5°C from April 1976 to February 1977. The maximum temperatures ranged between 28° and 34°C for the same time period. The mean temperature for the 10-month interval, calculated from the averages for each reading period, was 29.2°C (Standard Deviation = 0.9). Marsh and Doty (1976) reported a cooler average temperature (27.9°C; S.D. = 0.5) during the period from November 1975 to April 1976 for the same area. Fig. 7A shows an increase in average monthly temperatures for

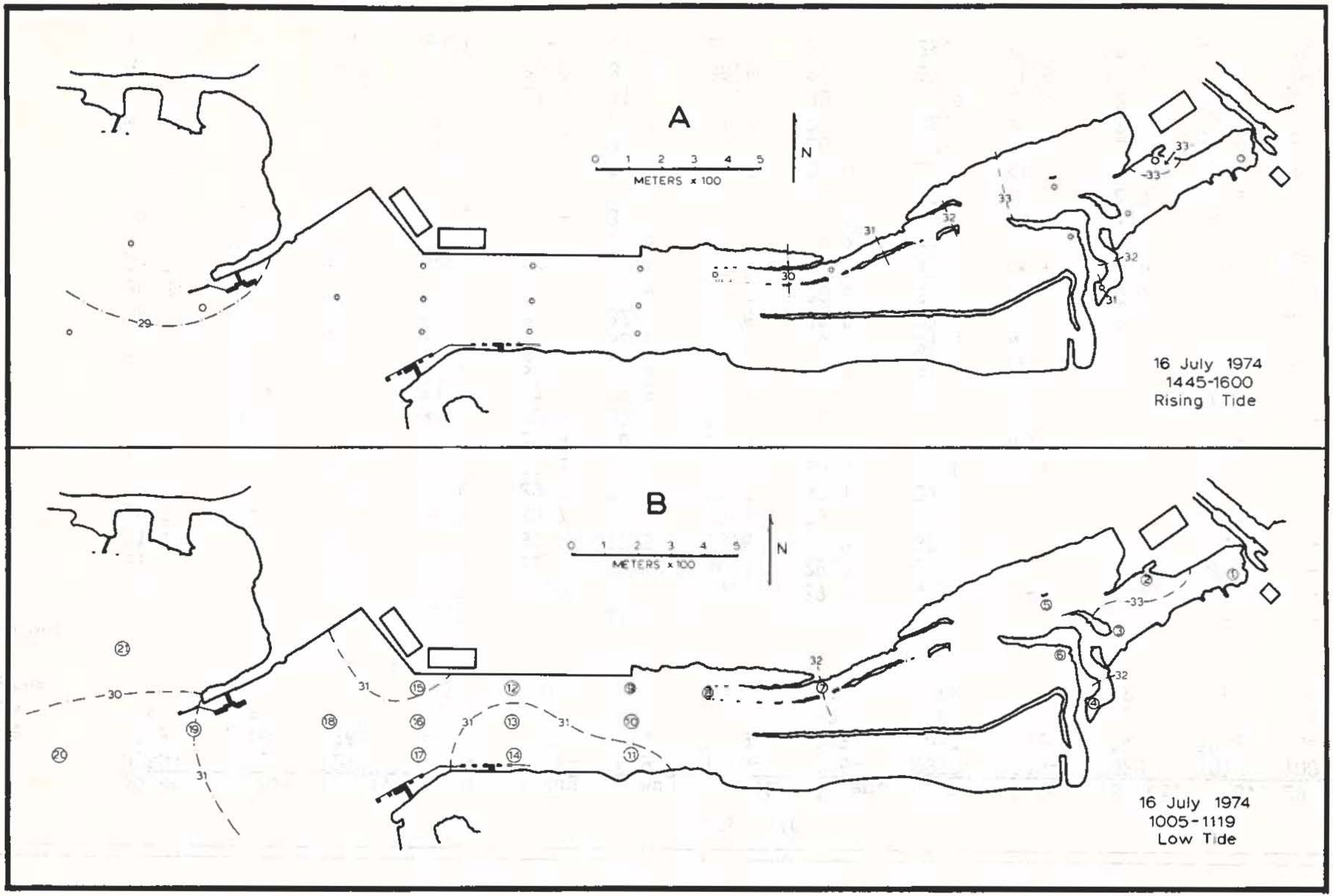

Figure 4. Isotherms (°C) for two tide levels on a single day before the Cabras Power Plant began operation. Circles indicate sampling locations.

Table 1. Surface temperatures at various stations for various dates, times of day, tides, and weather conditions. Tides: H, high; F, falling; L, low; R, rising. Weather: S, sunny; O, overcast; PC, partly cloudy; R, rainy. See Fig. 3 for station locations.

	DATE 1976												
	30 Apr.	18 May	18 May	1 Jun.	3 Aug.	10 Aug.	6 Sept.	17 Sept.	4 Oct.	11 Oct.	18 Oct.	8 Nov.	29 Nov.
Time	0950-1115	1100-1115	1215-1340	1421-1515	1005-1123	1039-1145	1225-1309	1045-1138	0950-1033	1343-1410	1020-1140	1012-1045	1009-1042
Tide	F	F	F	F	R	F	L	R	R	F	L	H	R
Weather				S	O	S	O	PC	PC		PC	R	PC
Station													
1	-	-	-	29.2	-	31.1	-	-	-	-	-	-	-
3	30.6	-	32.0	31.3	30.0	31.7	30.6	29.5	31.8	-	31.8	-	-
4	31.1	-	32.3	31.0	30.5	31.6	30.6	29.9	32.0	-	32.8	32.0	-
5	31.1	-	32.3	31.1	30.6	31.5	30.6	30.2	32.2	-	32.5	31.7	-
6	30.7	-	31.6	30.0	30.7	31.3	30.0	30.1	31.7	-	-	31.7	-
7	30.4	-	31.5	31.6	29.3	31.7	30.7	30.1	32.7	-	-	-	-
8	31.2	-	32.5	31.1	31.2	32.2	-	30.7	32.6	33.3	-	32.6	-
9	30.8	31.6	-	31.2	30.9	30.5	29.9	-	-	32.6	31.6	32.9	-
10	-	31.6	-	30.9	30.0	30.2	29.7	30.2	-	32.5	31.7	31.8	-
11	-	31.3	-	31.1	27.7	29.5	29.9	-	-	32.2	31.6	30.7	-
12	30.1	30.5	30.9	29.6	31.7	32.3	30.7	30.5	31.5	31.9	30.2	31.7	30.1
13	30.1	30.5	30.9	30.0	31.7	32.2	30.8	30.6	31.1	32.0	31.0	31.8	29.7
14	30.1	30.3	30.7	29.7	31.5	32.0	30.6	30.5	31.0	31.7	30.9	31.9	29.6
15	30.3	30.4	30.8	29.8	31.3	31.9	30.6	30.5	30.9	31.7	30.9	32.2	29.6
16	33.0	33.4	33.7	33.7	33.0	33.8	33.8	32.2	33.7	34.4	33.6	34.4	34.3
17	31.7	31.9	31.7	31.0	31.8	32.3	31.0	30.9	32.0	32.8	-	33.1	32.6
18	32.2	32.5	31.1	31.6	31.8	32.5	33.3	31.5	33.1	33.8	33.1	33.0	33.2
19	-	-	-	-	29.8	-	29.9	29.4	31.8	33.0	32.3	33.2	-
20	31.6	-	32.6	30.4	31.5	32.4	31.6	31.0	32.7	33.5	32.6	33.2	32.6
21	31.5	-	32.1	30.7	31.5	31.8	31.1	30.8	32.5	33.3	32.5	32.3	31.5
22	31.2	-	29.8	30.7	31.2	31.7	31.2	30.5	32.3	33.3	32.5	31.6	31.3
23	30.9	-	31.2	30.7	31.1	31.4	31.0	30.0	32.1	33.0	32.2	31.0	29.9
24	30.2	-	29.5	30.0	30.0	31.1	30.5	29.7	31.3	31.5	31.3	30.1	29.1
25	28.9	-	28.3	29.1	-	29.3	28.6	29.0	29.3	30.1	30.0	29.2	29.1

Table 1. (continued)

	DATE 1976												
	30 Apr.	18 May	18 May	1 Jun.	3 Aug.	10 Aug.	6 Sept.	17 Sept.	4 Oct.	11 Oct.	18 Oct.	8 Nov.	29. Nov.
Time	0950-1115	1100-1115	1215-1340	1421-1515	1005-1123	1039-1145	1225-1309	1045-1138	0950-1033	1343-1410	1020-1140	1012-1045	1009-1042
Tide	F	F	F	F	R	F	L	R	R	F	L	H	R
Weather				S	O	S	O	PC	PC		PC	R	PC
Station													
26	28.4	-	28.4	-	28.2	29.2	-	28.5	29.3	29.6	29.9	29.1	29.1
RdA	28.2	-	28.2	-	28.3	28.5	-	28.4	29.0	29.4	29.5	29.0	28.9
B1	28.1	-	28.2	28.4	28.3	29.0	-	28.3	28.2	29.3	29.3	29.1	29.1
FB	30.9	-	32.0	-	31.1	32.5	-	-	-	-	-	-	-
FC	31.1	-	-	-	29.7	32.3	-	-	-	-	33.3	-	-
FD	30.6	-	31.1	-	-	32.4	-	-	-	-	33.6	-	-

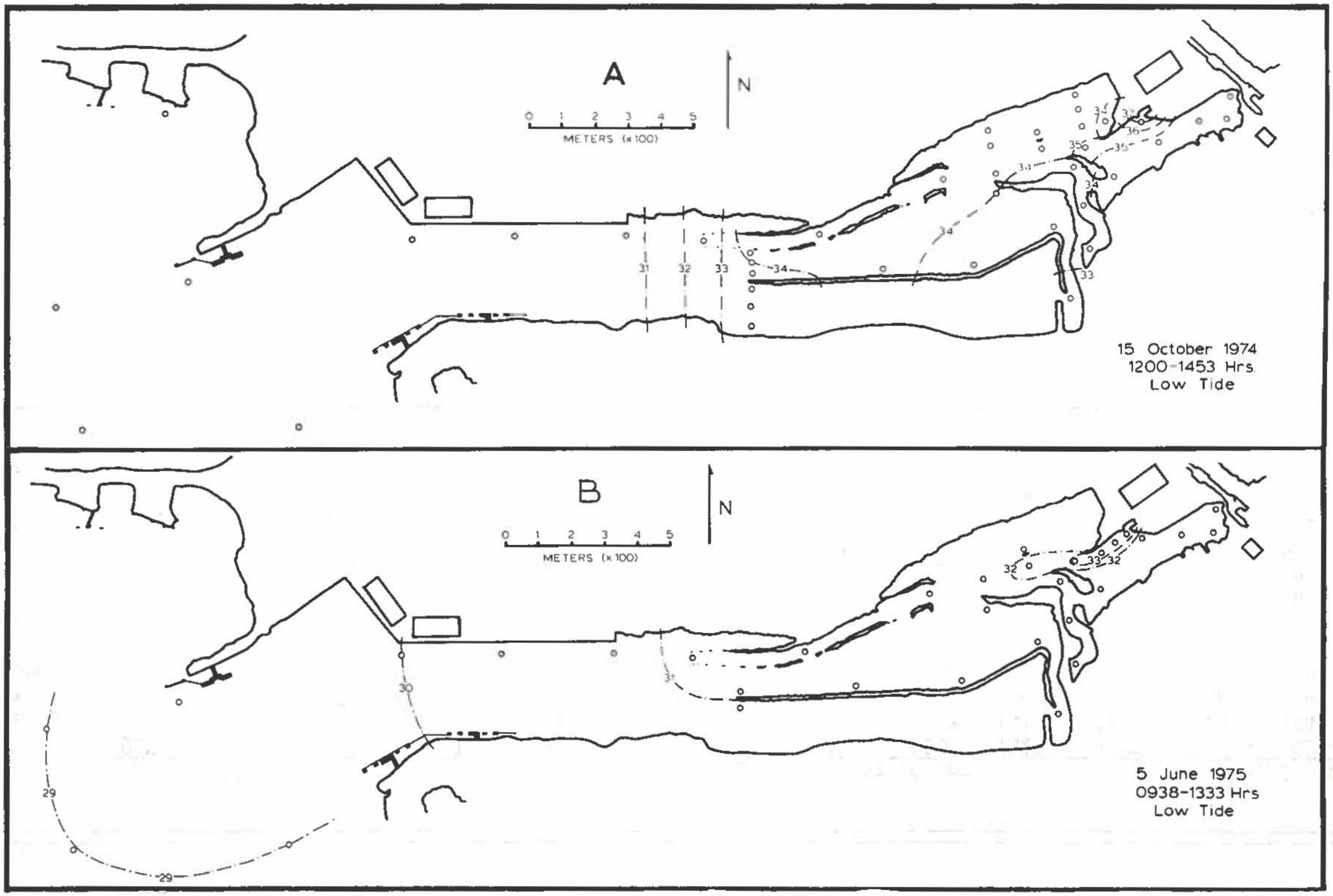

Figure 5. A. Isotherm plot (°C) at low tide at the onset of Cabras Power Plant operations.
B. Isotherm pattern during normal operation of the Cabras Power Plant on 5 June 1975.

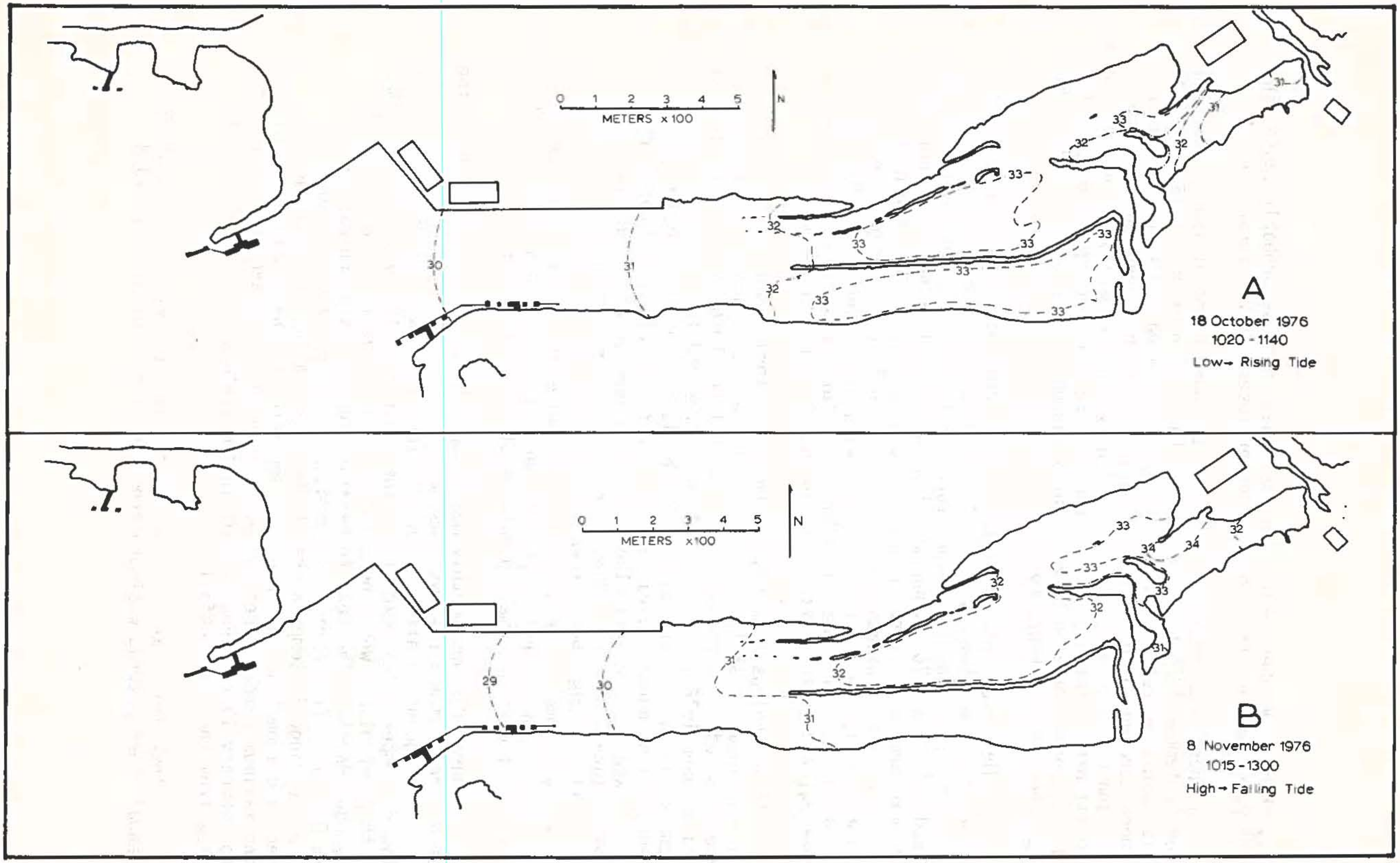

Figure 6. "Typical" surface temperatures (°C) for two tide levels during normal operations of the Piti and Cabras Power Plants.

July through October 1976. This seasonal increase probably causes the difference between the two mean temperatures (29.2°C versus 27.9°C).

Temperatures recorded for the Piti Power Plant effluent (Sta. 12) from September 1976 to February 1977 had a mean of 30.8°C (S.D. = 0.9). This mean temperature was lower than anticipated. A slightly higher temperature would be expected if observations had been made between July and October 1976, when consistently high temperatures were recorded for all other stations. The minimum temperatures ranged from 27°C to 30.5°C, and the maximum temperatures ranged between 30°C and 34°C from September 1976 to February 1977.

An instrument placed in the outfall channel at the Cabras Plant recorded minimum temperatures of 26.5-31.5°C from April 1976 through February 1977. The low temperature (26.5°C) was recorded after Typhoon Pamela (22 May 1976), when normal plant operations had been shut down. The maximum temperatures ranged between 32°C and 36°C. Marsh and Doty (1976) reported maximum temperatures of 34-37°C from August through October 1975, the period of peak loading of the Cabras and Piti Power Plants and also the period of highest intake temperatures. The mean temperature for the outfall station was 32.0°C (S.D. = 0.9).

It is obvious from Fig. 7A that the Cabras Plant has more of a thermal impact than the Piti Plant when areas adjacent to the outfalls are compared. The peaks in July and October 1976 for the Cabras Plant and October 1976 for the Piti Plant correspond to a seasonal rise in temperature at the intake. On the basis of monthly averages, the Cabras Plant generally raised the temperature of the intake water by 2.8°C, whereas the Piti Plant showed an average rise over the intake temperature of 1.6°C. (These monthly averages, of course, are not indicative of the temperature rise of water passing through the plants at a given time.) The difference in temperature between the Cabras and Piti Plants is not surprising because of a decreased load at the Piti Plant during normal operations of the Cabras Plant.

Figure 7B shows monthly mean temperatures at four stations in the study area and again shows seasonal patterns. Sta. 15, located in the outfall lagoon and affected only by the Piti Plant effluent, showed the lowest temperatures, except for the month of July 1976. At this time both power plants were operating at reduced loading as a result of Typhoon Pamela. The mean temperature for this station was 30.3°C (S.D. = 1.1) from April 1976 through February 1977. The lowest average range in temperature of the four stations (2.8°C) was also recorded from Sta. 15. Minimum temperatures ranged between 27 and 31°C, and maximum temperatures ranged between 29.5 and 34°C from April 1976 to February 1977. These trends in temperature closely paralleled data from the Piti outfall.

A thermometer at Sta. 18, located at the downstream end of the seawall that extends westward from the Cabras outfall, recorded temperatures slightly lower than the temperatures at the Cabras outfall location. The mean temperature of 31.5°C (S.D. = 0.9) was 0.5 degrees lower than the Cabras outfall temperature from April 1976 to January 1977. The minimum and maximum temperatures ranged between 25 and 30.5°C and 32 and 36°C respectively.

Sta. 20, in Upper Piti Channel, is influenced by the effluents of both power plants. It had a mean temperature of 31.4°C (S.D. = 0.8) and an average range in temperature of 3.9°C from April 1976 to February 1977. Minimum temperatures were 26.3-31°C and maximum temperatures ranged between 31 and 35°C for the same time period.

Sta. 21, located in Lower Piti Channel, is subjected to both warm water from the power plants and cooler incoming harbor water on rising tides. It appears that the power plants exert the greater influence since the station had a mean temperature of 30.8°C (S.D. = 0.9) from April 1976 to February 1977. Except for the tide flats, this station had the highest average range in temperature (4.5°C). This is to be expected from the opposing influences previously mentioned. Minimum and maximum temperatures for this station were 25.5-30.5°C and 31-35.5°C, respectively.

A thermometer on Tidal Flat B (Fig. 2) showed minimum temperatures ranging between 25.5 and 31°C from April 1976 to February 1977. The lowest temperature was recorded shortly after Typhoon Pamela. Maximum temperatures at this site ranged from 31.5 to 36.5°C for the same time period. Marsh and Doty (1976) reported a range in maximum temperatures between 32 and 34.5°C from September 1975 to April 1976. Their data are comparable with data recorded this year.

Tidal Flat C (Fig. 2) showed minimum temperatures which ranged from 25.5 to 31°C and maximum temperatures between 31.5 and 40°C from April 1976 to February 1977. The highest temperature ever recorded from this flat (40°C) resulted from solar heating at low tide coinciding with the resumption of normal operations of the Cabras Plant after Typhoon Pamela.

The minimum temperatures on Tidal Flat D (Fig. 2) ranged between 23 and 29.5°C from April 1976 to February 1977. Maximum temperatures ranged from 31 to 42.5°C. Minimum temperatures below 25°C were recorded six times for this flat. Presumably these temperatures resulted from subaerial exposure during nighttime low tides or lowered water temperatures due to heavy rainfall, as reported by Marsh and Doty (1976). The high temperature of 42.5°C occurred on the same day as the high temperature on Flat C, again reflecting the influence of solar heating.

Fig. 7C shows the monthly mean temperatures for the three tidal flats. It can be seen from the data that the temperatures are relatively comparable, and there are clear seasonal patterns. The

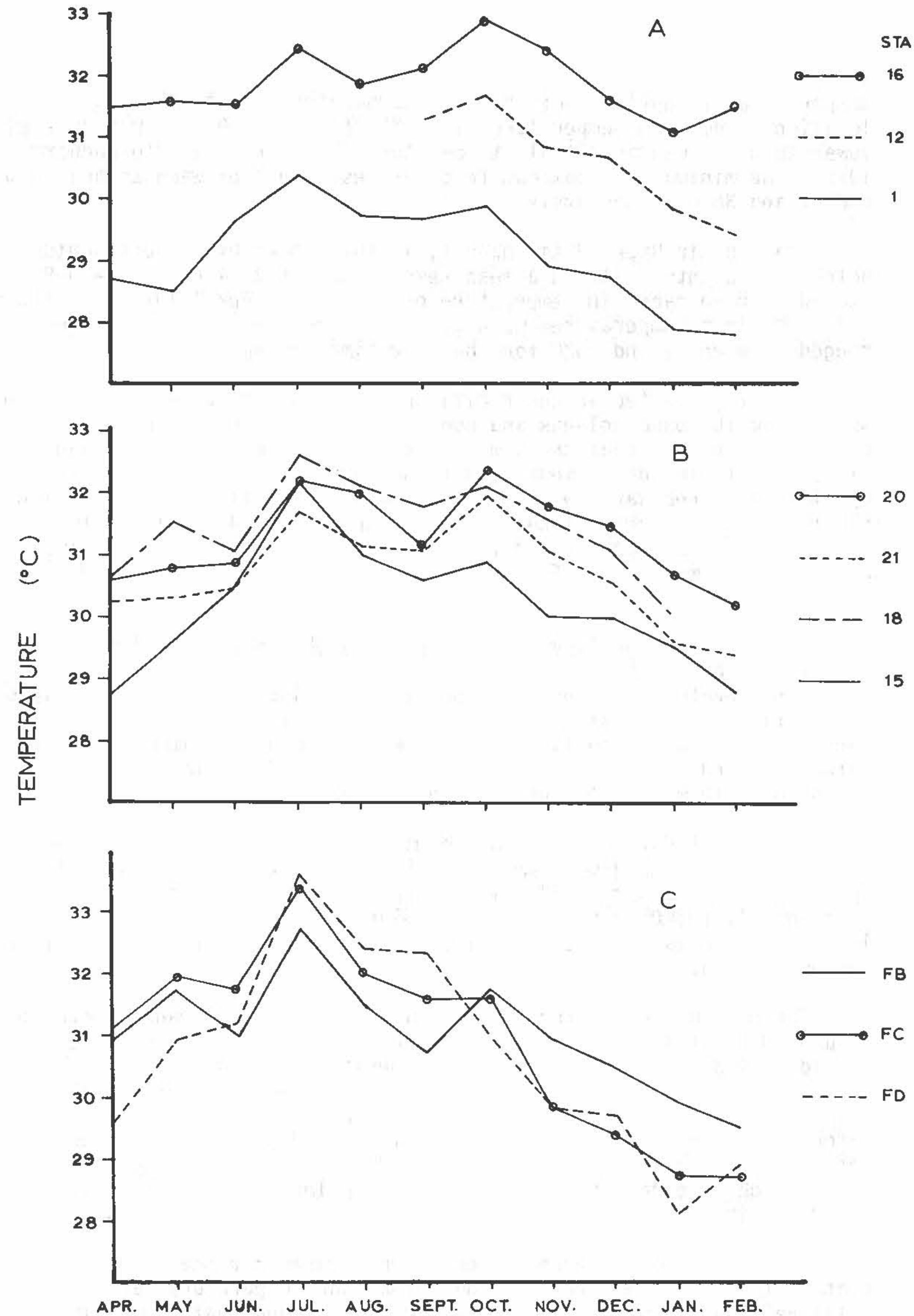

Figure 7. Comparison of monthly maximum/minimum mean temperatures (°C) at selected sites in the outfall area. A. Sta. 16, Sta. 12, and Sta. 1. B. Sta. 15, Sta. 20, Sta. 21 and Sta. 18. C. Tidal Flats B, C and D. See Fig. 3A for station locations.

overall mean temperatures on Flats B, C and D were 31.1, 31.0 and 30.8°C respectively, from April 1976 to February 1977. This orderly decrease in mean temperatures is in agreement with the ranked order for minimum temperatures recorded by Marsh and Doty (1976) but shows less separation between the three flats. The reverse ranking exists when comparing the average ranges in temperature for the three flats, again in agreement with previous results. Flat D had an average range of 9.3°C; Flat C, 7.0°C; and Flat B, 4.6°C.

Figs. 8-9 present the maximum-minimum data according to a format designed by James E. Doty. In these figures each reading is plotted on a set of axes with minimum and maximum values as x and y coordinates respectively. A second pair of axes, depicting the range and mean temperature, is oriented at 45° angles to the x and y coordinates. Points with equal ranges (i.e., maximum minus minimum temperature) fall along a line with a slope of 1 on the x-y coordinates. Points with equal average temperatures (i.e., the average between maximum and minimum temperatures) fall along a line with a slope of -1 on the x-y coordinates. Hence, each point or cluster of points representing the temperature regime of a given location can be compared in four ways: minimum, maximum and mean temperatures and temperature range.

Fig. 8 shows generally higher maximum and minimum temperatures at the Cabras outfall than at the Piti outfall, as expected from the discussion above. Again as discussed above, mean temperatures at the Cabras outfall generally exceed those at the Piti outfall, which exceed those at the intake station. The overall temperature range for all points is smaller for the Piti outfall than for the intake station, which in turn is slightly smaller than for the Cabras outfall. The cluster of points representing the intake station shows a clear-cut separation from the cluster of points representing the Cabras outfall, with the cluster of points representing the Piti outfall overlapping the other two clusters.

Fig. 9 shows data for the tidal flats. There is a reasonably clear separation between the cluster of points for Flat B and that for Flat D. Extensive overlap of points occurs between Flats B and C and between Flats C and D for maximum, minimum and mean temperatures and for the overall range. The higher maximum temperatures reported for Flat D represent a change from last year (Marsh and Doty 1976), when a greater separation between Flats B and D was apparent. The 1976 data showed Flat D to have both lower maximum and minimum temperatures than Flat B. This year's data are heavily weighted by the midday low spring tides, whereas last year's data were more heavily weighted by nighttime low spring tides. This leads to an apparent, but artificial warming trend in this year's data for Flat D (which is not generally affected by power plant operations). Hence, a seasonal effect rather than a permanent change is the likely explanation for the differences between this report and last year's report. The previous conclusion still holds, that the major thermal impact of the power plants is to impose a greater temperature constancy on Flats B and C

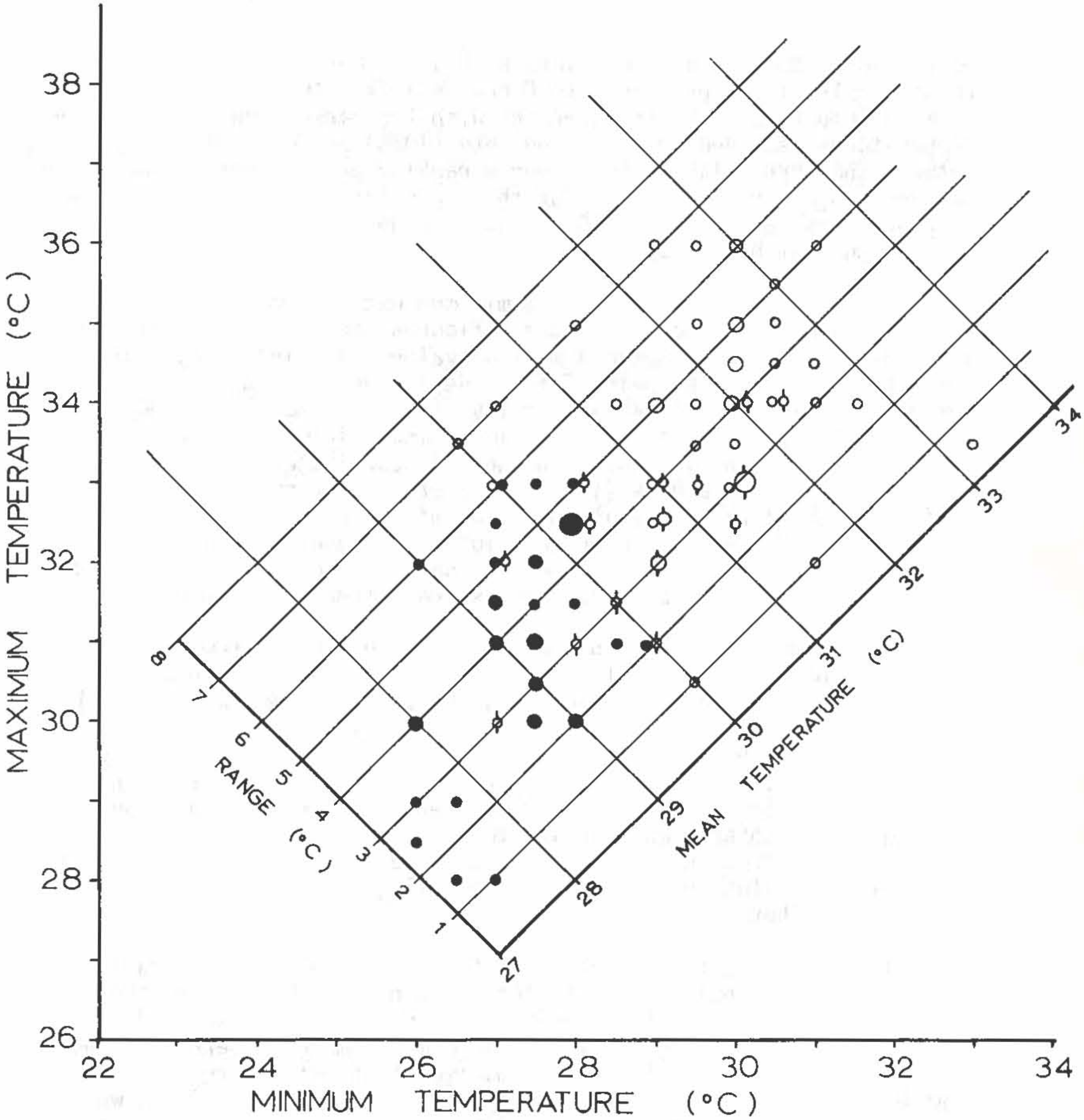

Figure 8. Maximum and minimum temperatures occurring between 9 April 1976 and 14 February 1977 at the Cabras intake (●), Cabras outfall (○), and Piti outfall (ϕ). The size of each symbol is proportional to the number of replicate data points, (∘ = 1, o = 2, ◯ = 3). Coinciding data points from differing stations are slightly offset for clarity. The actual values are given in Table 2.

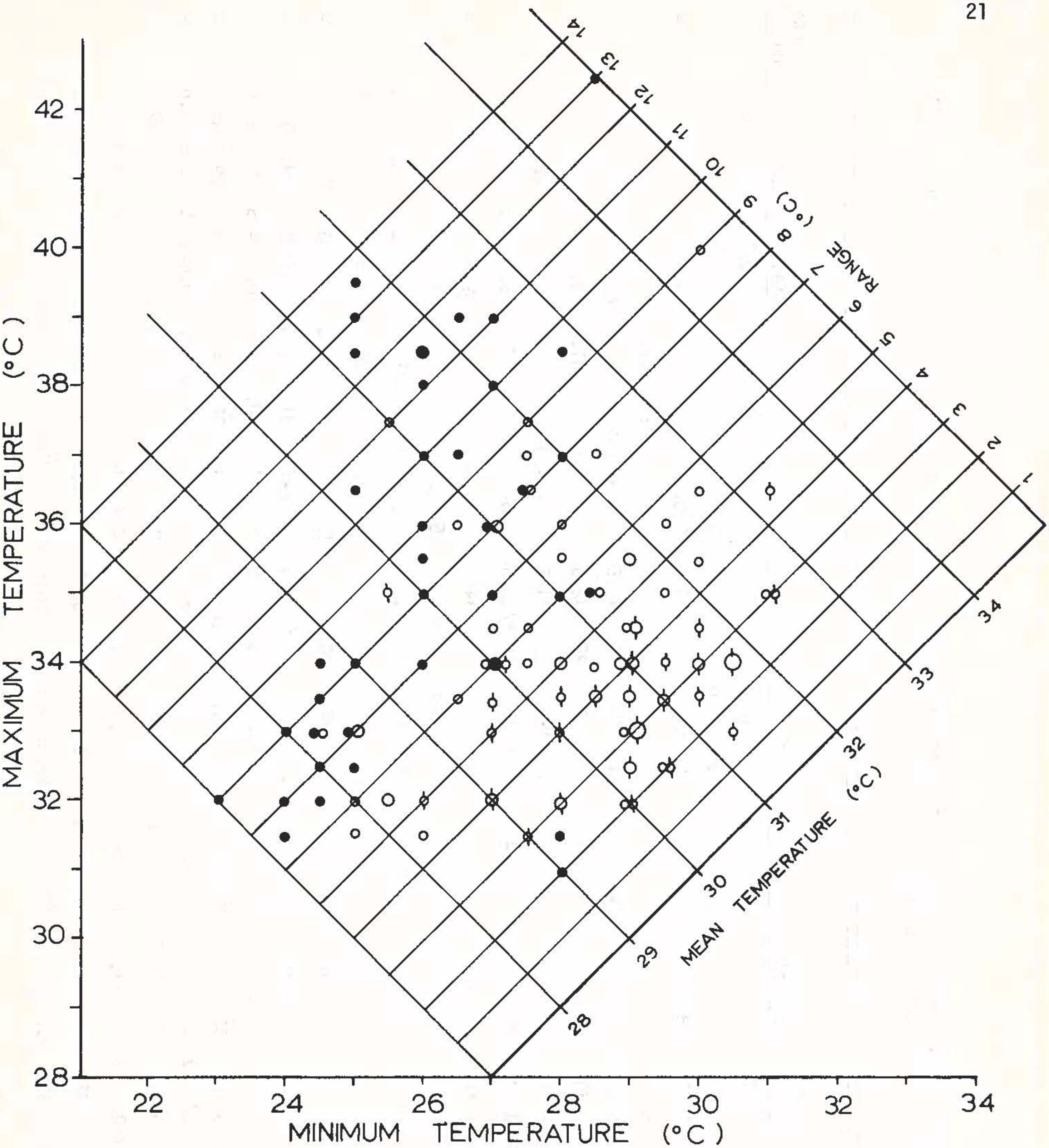

Figure 9. Maximum and minimum temperatures occurring between 9 April 1976 and 14 February 1977 on Tidal Flats B (ϕ), C (○) and D (●). The size of each symbol is proportional to the number of replicate data points, (○ = 1, ○ = 2, ◯ = 3). Coinciding data points from differing stations are slightly offset for clarity. The actual values are given in Table 2.

Table 2. Minimum/maximum temperatures (°C) at selected sites in the study area from April 1976 to February 1977. See Fig. 3 for station locations.

Observation Interval	Cabras Intake	Cabras Outfall	Sta. 18	Tidal Flat B	Tidal Flat C	Tidal Flat D	Sta. 15	Sta. 20	Sta. 21	Piti Outfall
2-9 April 76	27.5/30.0	-	27.0/33.0	28.0/32.0	29.0/32.0	28.0/31.0	27.0/29.0	28.0/32.0	28.0/32.0	-
9-23 April	27.0/31.0	-	28.5/34.5	29.0/34.0	28.5/34.0	25.0/32.5	29.0/31.5	29.0/33.0	28.0/33.0	-
23-30 April	27.0/31.5	28.0/35.0	28.5/32.0	29.0/34.5	28.5/35.0	28.0/35.0	-	29.0/34.0	28.0/34.0	-
29 Apr-7 May	-	-	-	-	-	-	28.0/32.0	-	-	-
30 Apr-7 May	26.5/28.0	30.0/35.0	29.5/35.0	31.0/35.0	31.0/35.5	27.0/36.0	-	29.0/34.0	29.0/34.0	-
7-11 May	27.5/30.5	29.5/33.5	29.5/34.0	30.0/33.5	29.5/32.5	28.0/31.5	29.0/31.0	29.5/33.0	29.0/32.0	-
11-18 May	27.5/32.0	30.0/35.0	29.5/35.0	30.5/33.0	29.0/34.5	27.0/34.0	29.5/31.5	29.0/34.0	28.0/33.0	-
18 May-1 June	26.0/30.0	26.5/33.5	25.0/34.0	25.5/35.0	25.5/37.5	25.0/39.0	25.5/30.5	26.5/31.5	25.5/32.0	-
1-8 June	27.5/31.5	28.5/34.0	28.0/32.0	29.0/32.0	29.0/34.0	28.5/35.0	28.5/30.5	29.0/31.0	28.0/32.0	-
8-15 June	27.5/33.0	29.5/34.0	28.5/34.0	29.0/33.0	29.5/35.0	26.0/36.0	29.0/33.0	29.5/33.5	28.0/33.0	-
15-22 June	27.0/31.0	30.0/34.5	29.0/34.0	29.5/32.5	29.0/33.0	27.0/34.0	29.0/31.5	29.5/33.5	28.0/33.0	-
22-29 June	26.0/32.0	27.0/34.0	29.0/34.0	29.0/34.0	28.0/36.0	27.0/36.0	28.0/34.0	28.5/33.0	28.5/33.5	-
29 Jun-6 July	28.0/32.5	29.0/32.5	30.0/34.5	30.5/34.0	30.0/36.5	29.5/36.5	31.0/33.5	29.5/33.5	29.0/34.0	-
6-13 July	28.0/32.5	30.0/36.0	30.5/36.0	31.0/36.5	30.0/40.0	28.5/42.5	31.0/33.5	30.0/35.0	29.0/35.0	-
13-20 July	28.5/31.0	30.5/35.0	30.0/35.0	30.0/34.5	30.0/35.5	28.0/37.0	30.5/34.0	30.0/34.5	28.5/35.0	-
20-27 July	28.0/34.0	30.0/36.0	30.0/35.0	30.5/34.0	29.5/36.0	27.5/39.0	30.0/34.0	30.5/34.5	29.0/34.0	-
27 Jul-3 Aug	27.5/31.0	29.5/36.0	30.0/34.5	30.0/34.0	28.5/37.0	26.5/37.5	31.0/32.0	30.0/34.0	29.0/34.0	-
3-10 Aug	27.0/31.5	30.0/34.0	28.5/34.5	27.0/34.0	27.0/34.5	25.0/38.5	29.5/32.0	29.0/34.0	29.0/32.5	-
10-17 Aug	27.0/32.5	29.5/30.5	30.0/35.0	29.0/34.5	29.0/35.5	27.0/38.0	29.5/33.5	30.0/34.0	29.0/33.0	-
17-24 Aug	27.0/33.0	29.0/36.0	29.0/35.0	29.5/33.5	28.0/35.5	26.0/38.5	29.0/32.0	30.0/34.0	29.0/33.0	-
24-30 Aug	28.0/32.5	30.0/34.5	29.5/35.0	29.5/34.0	29.0/35.5	28.0/38.5	30.0/32.0	31.0/34.0	29.0/34.0	-

Observation Interval	Cabras Intake	Cabras Outfall	Sta. 18	Tidal Flat B	Tidal Flat C	Tidal Flat D	Sta. 15	Sta. 20	Sta. 21	Piti Outfall
30 Aug-6 Sept	28.0/33.0	29.5/35.0	29.0/34.5	28.0/33.5	27.0/36.0	26.5/39.0	29.5/32.0	29.0/33.0	28.5/33.0	-
6-13 Sept	28.0/31.0	30.0/34.5	29.5/34.0	29.0/32.5	29.0/34.0	27.5/36.5	30.0/32.0	30.0/33.5	29.5/33.0	30.0/33.0
13-20 Sept	28.0/30.5	31.0/32.0	30.5/33.0	27.0/33.5	27.0/36.0	25.0/39.5	29.0/31.5	30.0/32.0	29.0/32.5	30.0/32.5
20-27 Sept	27.5/31.0	30.5/34.5	29.5/34.5	28.5/33.5	27.5/36.5	26.0/38.5	30.0/30.5	29.5/32.5	30.5/32.5	29.5/32.5
27 Sept-4 Oct	29.0/31.0	31.0/34.0	30.0/34.0	30.0/34.0	27.5/37.5	26.5/37.0	29.5/31.5	30.5/33.0	30.0/34.0	30.0/33.0
4-11 Oct	28.0/33.0	30.5/35.5	30.0/35.5	30.5/34.0	27.5/37.0	26.0/37.0	30.0/33.0	31.0/35.0	28.5/35.5	30.0/34.0
11-18 Oct	28.0/31.5	31.5/34.0	30.0/34.5	29.0/33.5	28.0/34.0	26.0/35.5	29.5/31.5	30.5/34.0	30.5/34.5	30.5/34.0
18-25 Oct	27.0/32.0	31.0/36.0	30.0/35.0	29.0/34.0	26.5/36.0	25.0/36.5	30.5/32.0	30.0/35.0	29.0/34.5	30.0/33.0
25 Oct-1 Nov	27.5/32.0	31.0/34.5	30.0/32.0	29.5/33.5	27.5/34.0	26.0/35.0	30.0/32.0	30.5/34.0	29.5/34.0	30.0/33.0
1-8 Nov	27.5/31.0	30.0/35.0	29.0/34.5	-	27.5/34.5	27.0/35.0	29.5/31.0	29.0/34.0	29.0/33.5	29.5/33.0
1-15 Nov	-	-	-	29.0/33.5	-	-	-	-	-	-
8-15 Nov	28.0/30.0	33.0/33.5	29.0/34.5	-	28.0/34.0	25.0/34.0	29.0/32.0	30.0/34.0	29.0/34.0	29.5/33.5
15-22 Nov	27.0/30.5	30.0/34.0	29.0/34.0	28.5/33.5	27.0/34.0	26.0/34.0	28.5/31.0	30.0/34.0	28.5/33.0	29.0/32.0
22-29 Nov	27.0/30.0	30.0/34.0	29.0/34.0	28.0/33.0	24.5/33.0	24.5/33.5	28.5/30.0	30.0/33.5	28.5/33.0	29.0/32.0
29 Nov-6 Dec	28.0/30.5	29.0/34.0	30.0/34.0	29.0/33.0	26.5/33.5	26.0/38.0	28.0/32.0	30.0/33.5	29.0/33.0	29.0/32.0
6-13 Dec	27.0/30.0	30.0/33.0	28.5/33.5	29.0/33.0	26.0/33.0	24.5/33.0	28.0/32.0	30.0/33.5	28.5/33.0	29.0/33.0
13-27 Dec	27.0/29.5	30.0/33.5	28.0/33.0	27.0/32.0	25.5/32.0	24.5/32.0	29.0/32.5	28.5/32.0	28.5/32.0	29.0/32.5
27 Dec-3 Jan	27.5/30.0	29.0/33.0	28.0/32.5	28.0/32.0	25.5/32.0	24.0/32.5	28.5/31.0	29.0/32.0	27.0/31.5	29.0/31.0
3-10 Jan	-	30.5/34.0	28.5/32.5	27.5/31.5	25.0/32.0	24.0/32.0	28.5/32.0	30.0/32.0	28.0/31.0	28.5/31.5
3-17 Jan	26.0/29.0	-	-	-	-	-	-	-	-	-
10-17 Jan	-	27.0/33.0	28.0/32.5	28.0/31.5	26.0/31.5	24.0/31.5	27.0/32.0	29.0/32.0	27.5/31.5	28.0/31.0
17-24 Jan	26.0/28.5	-	27.0/32.0	27.0/32.0	25.0/31.5	23.0/32.0	27.0/30.0	28.5/32.0	28.0/31.0	27.0/32.0
24-31 Jan	26.5/29.0	-	-	29.0/32.5	27.0/33.0	25.0/33.0	27.0/32.0	29.0/33.0	28.0/32.5	28.0/33.0
31 Jan-7 Feb	26.0/30.0	29.0/34.0	-	27.0/33.0	25.0/33.0	24.5/34.0	27.5/31.0	28.0/33.0	27.0/32.0	28.0/32.5
7-14 Feb	27.0/28.0	29.0/34.0	-	26.0/32.0	25.5/31.5	24.0/33.0	27.0/29.5	28.0/32.0	27.0/31.5	27.0/30.0

than would be the case without the power plants, with this more constant level being in the upper part of the natural temperature range.

A comparison between temperature data obtained from the maximum/minimum thermometers and data from individual surface temperature measurements for six stations is shown in Table 3. It may be seen that the means for the two kinds of data are similar. This further strengthens any conclusions based on one kind of data alone.

Table 3. Comparison of mean maximum/minimum and mean individual surface temperatures at six stations in the study area. Values in parentheses represent standard deviations from the mean. See Fig. 3 for station locations.

STATION NO.	$\bar{x}$ SURFACE TEMPERATURE	$\bar{x}$ MAXIMUM/MINIMUM TEMPERATURE
12	30.4 (1.0)	30.8 (0.9)
15	30.4 (0.9)	30.3 (1.1)
16	32.9 (1.0)	32.0 (0.9)
18	32.1 (1.0)	31.5 (0.9)
20	31.6 (1.0)	31.4 (0.8)
21	31.2 (1.1)	30.8 (0.9)

Surface Temperatures: Before-and-After Observations

Figs. 10-12 present data for selected stations where a large number of individual surface-temperature measurements were made before and after the Cabras Plant began operation. Fig.10 shows an upward shift in the temperature regime at Sta. 16 (the site of the Cabras outfall) after the new plant began operations and a downward shift at the Piti outfall (Sta. 12). A definite seasonality can be seen for measurements made after the Cabras Plant began operations at both locations, with a shift toward higher temperatures for July through October and a shift toward lower temperatures for November through June. This generally coincides with the seasonality in the time of day when low spring tides occur on Guam. Curiously, such seasonal shifts in temperature did not occur before the Cabras Plant began operations.

Fig.11 shows a downward temperature shift at Sta. 15 after Cabras operations began, but not at Sta. 20. Since Sta. 15 is affected only by the Piti Plant and not by the Cabras Plant, it is not surprising that the downward shift there coincided with the downward shift at the

Piti outfall. The fact that there was no significant upward shift at Sta. 20, located downstream of the Cabras outfall, suggests that the thermal impact of the new plant does not extend any great distance. There is again a seasonal temperature shift at both stations after Cabras operations began but not before.

Before-and-after data for Stas. 21 and 23, even further downstream in Piti Channel, are presented in Fig. 12. As for Sta. 20, these stations show no general shift in the thermal regime after Cabras operations began, and there is again evidence for a seasonal shift after that time but not before.

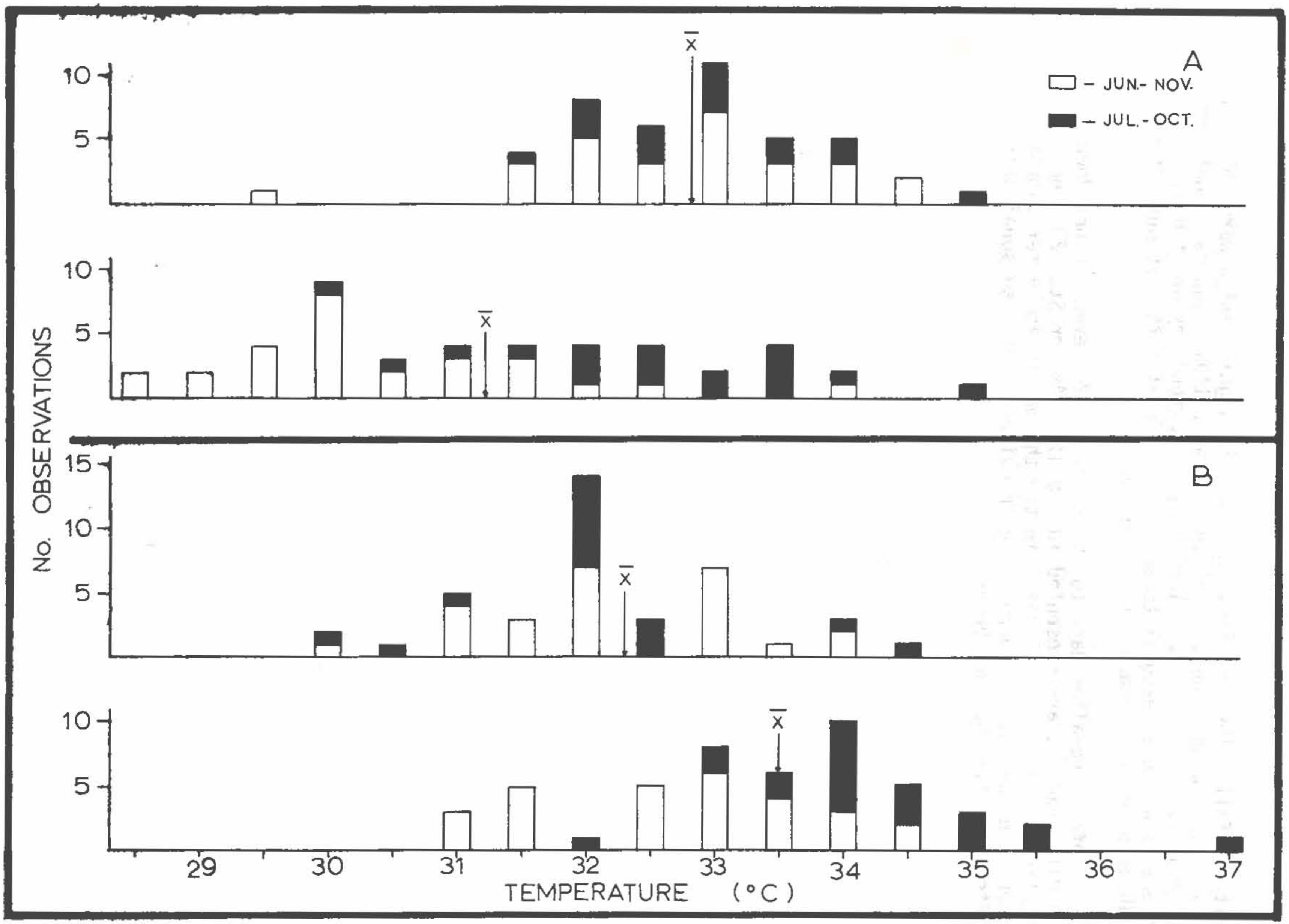

Figure 10. Comparison of surface temperatures before and after Cabras Power Plant operations began. A. Sta. 12 (Piti outfall); top graph indicates temperatures before Cabras Plant operation, bottom graph indicates temperatures after Cabras Plant operation. B. Sta. 16 (Cabras outfall); top graph indicates temperatures before Cabras Plant operation, bottom graph indicates temperatures after Cabras Plant operation. $\overline{X}$ = mean surface temperature.

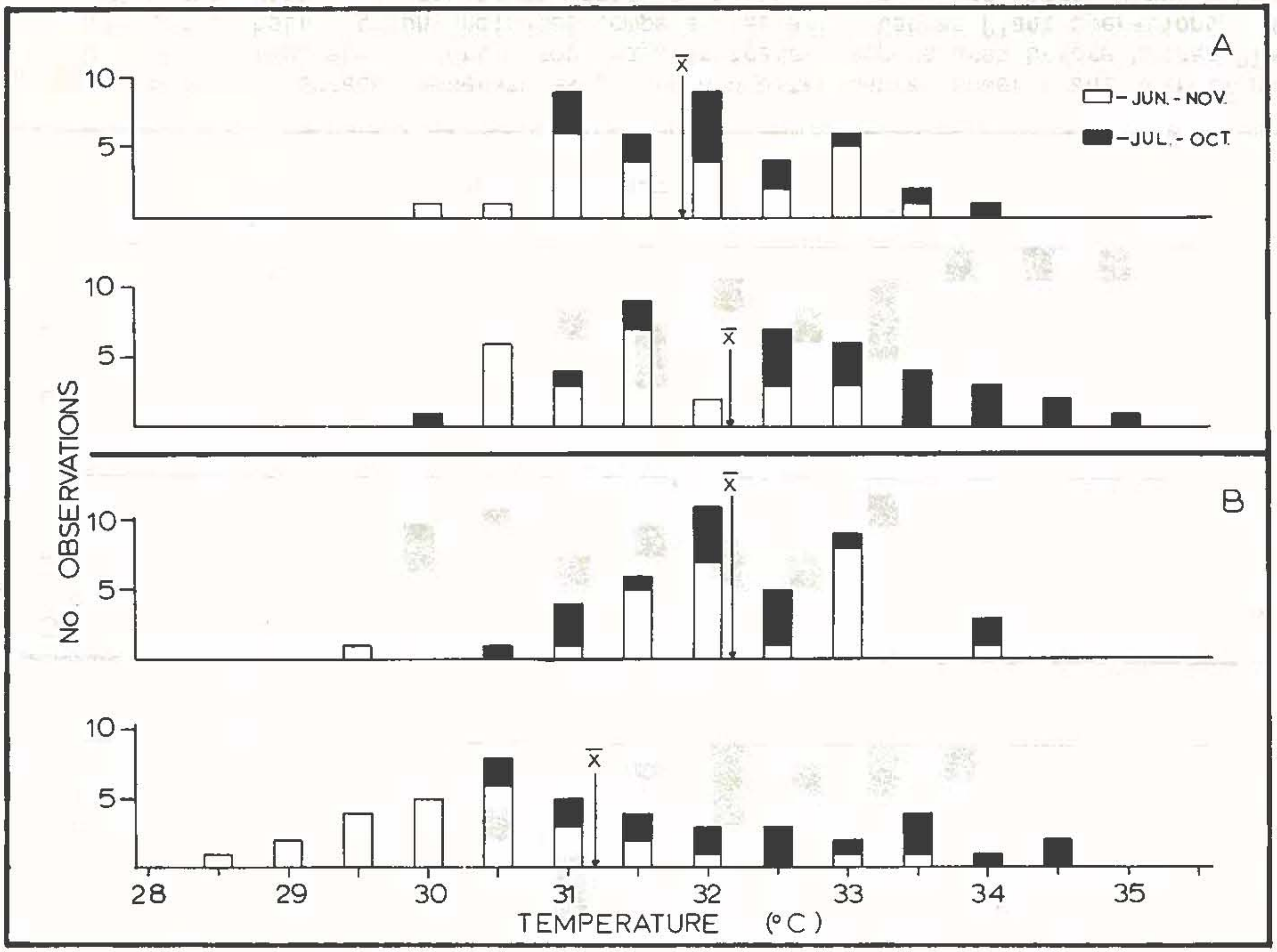

Figure 11. Comparison of surface temperatures before and after Cabras Power Plant operations began. A. Sta. 20 (Artificial Reef II); top graph indicates temperatures before Cabras Plant operations, bottom gragh indicates temperatures after Cabras Plant operations. B. Sta. 15 (Artificial Reef I); top graph indicates temperatures before Cabras Plant operations, bottom graph indicates temperatures after Cabras Plant operations. $\overline{X}$ = mean surface temperature.

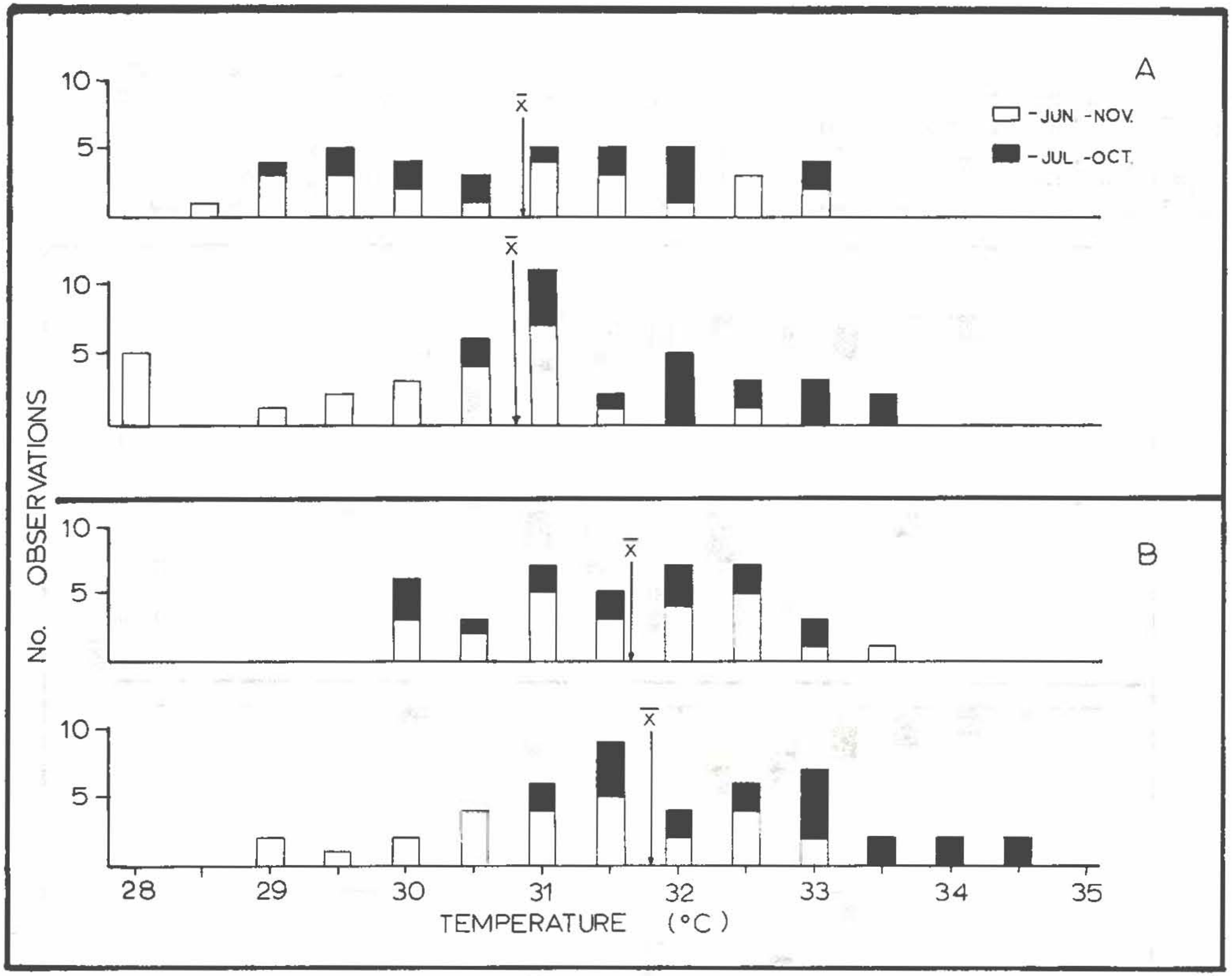

Figure 12. Comparison of surface temperatures before and after Cabras Power Plant operations began. A. Sta. 23 (Commercial Port); top graph indicates temperatures before Cabras Plant operations, bottom graph indicates temperatures after Cabras Plant operations. B. Sta. 21 (Artificial Reef III); top graph indicates temperatures before Cabras Plant operations, bottom graph indicates temperatures after Cabras Plant operations. $\overline{X}$ = mean surface temperature.

BATHYMETRY

Five areas were selected for detailed profiles of the bottom topography. The transect location in each of the study sites is shown in Fig. 13. The profiles are shown in Figs. 14-25.

The elevation in relation to mean lower low water (MLLW) was determined using a permanent bench mark on the south wall of the outfall lagoon and standard surveying techniques. A Belfort Instruments Recording Tide Gauge was used to record tidal fluctuations. The corrected elevation was determined by recording the water depth at 5- or 10-m intervals along the transects and subtracting this measured water depth from the tidal influence for that particular time period.

The profile of Tidal Flat B (Fig. 14) shows the substrate elevation to be below MLLW at all points. This is the deepest tide flat and we have never observed any exposure of this flat during extreme low tides. No cross-sectional transects were done, but from previous observations we believe that the flat has a fairly consistent topography from northeast to southwest. The southeastern edge of the flat is bordered by a small channel which connects with Upper Piti Channel.

An approximate 100-m stretch of Tidal Flat C (Fig. 15) does become exposed during low tides. The area most affected is southwest of the peninsula separating Lower Piti Channel and Flat C. This area was probably raised by the dredge material deposited there when the GORCO pipeline was constructed across Piti Channel. The eastern end of Flat C quickly drops off at the Connecting Channel and the western end of the flat drops off into a coral bed before meeting the dredged area of Commercial Port. The southern limit of Flat C drops off into the Secondary Channel, which runs along the entire length of the flat and eventually meets the Connecting Channel at the western end. The northern edge of Flat C is separated from Lower Piti Channel by a series of small islands. Even though breaks (transects 9. Figs. 16; 10 and 12, Fig. 17) do occur along the boundary, little water is exchanged between the two areas. These breaks are above the MLLW line and are frequently exposed at low tides. A cross-sectional view (Fig. 17 A & D; Fig. 18 A & B; and Fig. 19 B) shows the deepest area of Flat C to be approximately 10 m from the northern edge in the eastern end of the flat. Toward the western end of Flat C, this deep cut moves slightly southward.

Flat D (Fig. 20) has the highest elevation and the eastern 600 m is exposed during low tides. The northern boundary of Flat D is separated from Flat C by a peninsula which runs the entire length of the flats to the coral bed at the western end. The eastern end of Flat D is partially bordered by the peninsula, which curves around the upper area of the flat, and also connects with Flat C via the Connecting Channel. A cross-sectional view (Fig. 21 A, B, C, & D) shows a slight depression along the northern edge midway along the flat. The western end of the flat shows a depression along the southern boundary, as was found with Flat C.

The Secondary Channel (Fig. 22 B) is approximately 10 m wide and runs along the entire southern boundary of Flat C. The depth is fairly consistent along its entire length and ranges between 1.5 and 2.3 m below MLLW. The depth increases rapidly at the coral zone along the western boundary.

Piti Channel (Fig. 22 A) ranges between 1.1 and 2.8 m below MLLW. It is the area most affected by the effluents of the Cabras and Piti Power Plants. It is also utilized by boat owners who moor their boats in the lagoon area behind the power plants, especially during storms.

A detailed profile of the Piti Channel area around the GORCO pipeline (UGML 1977) is shown in Figs. 23 and 24 . Transect B skirted the edge of a shallow sand bar for about 80 m. It crossed the upper pipeline at 15-28 m from the peninsula and skirted the edge of a steep drop-off between 40 and 80 m. Transect A ran directly along one of the parallel pipelines, which was exposed for the first 90 m and buried from 90 to 160 m. Transect C ran south of the pipeline and is considered to be the boundary between Flat C and Lower Piti Channel. It crossed the northern edges of a shallow sand bar on Flat C between 40 and 65 m.

The topographic features seen in all the profiles probably strongly influence observed current patterns and in turn are shapped by the currents. Current flows are discussed in the next section.

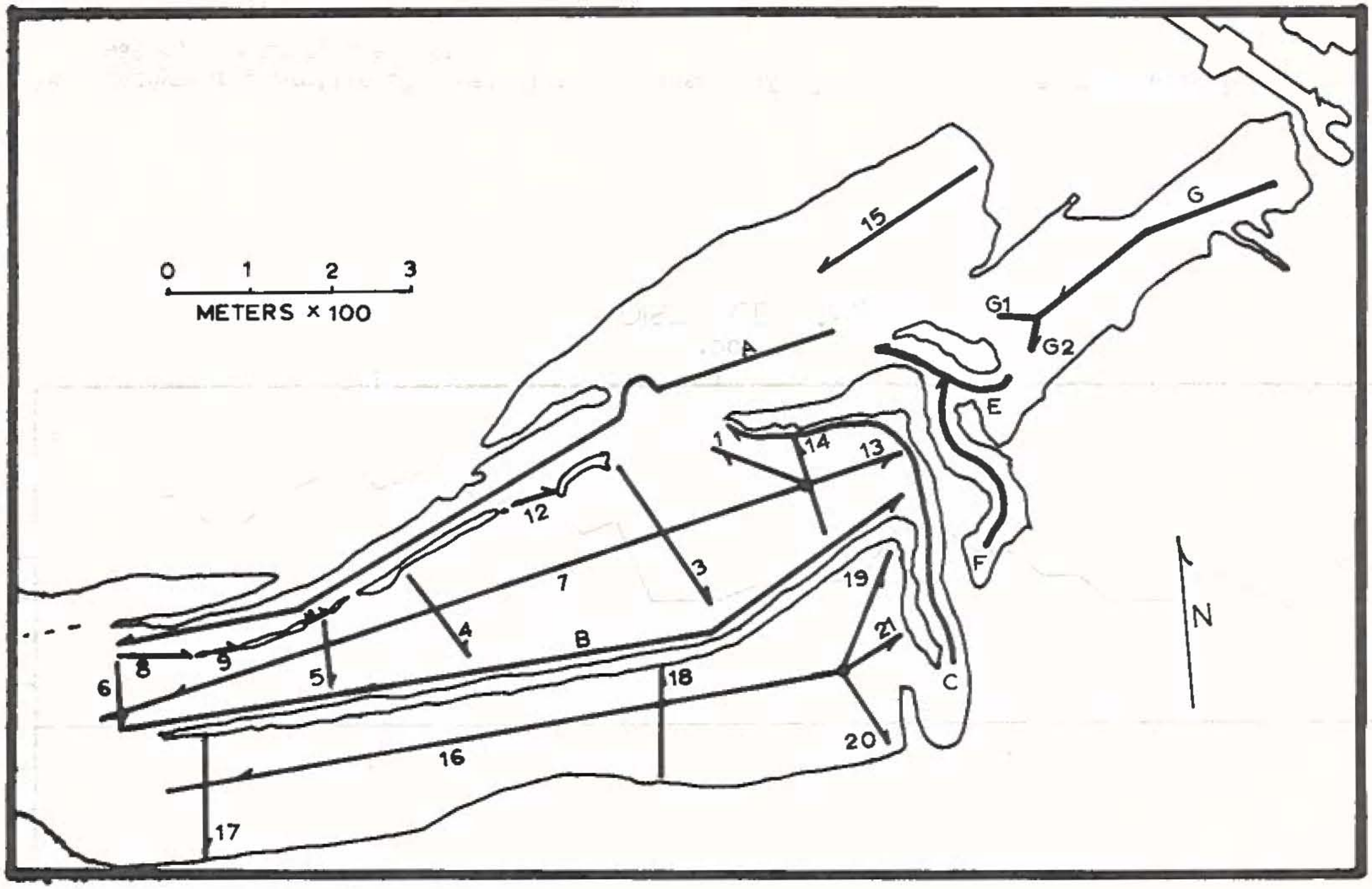

Figure 13. Location of bathymetric transects. Numbers indicate transects on tide flats; letters indicate transects in channels.

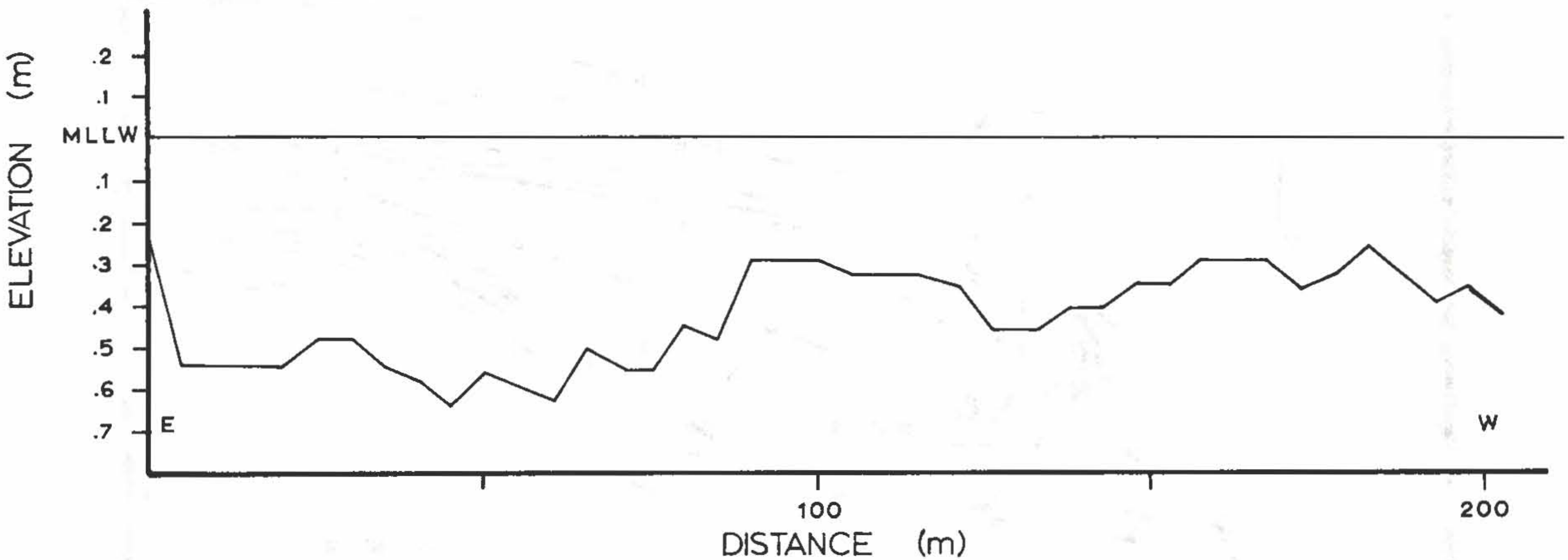

Figure 14. Bathymetric profile of Tidal Flat B, transect 15 (Fig. 13). MLLW = mean lower low water; E = east; W = west.

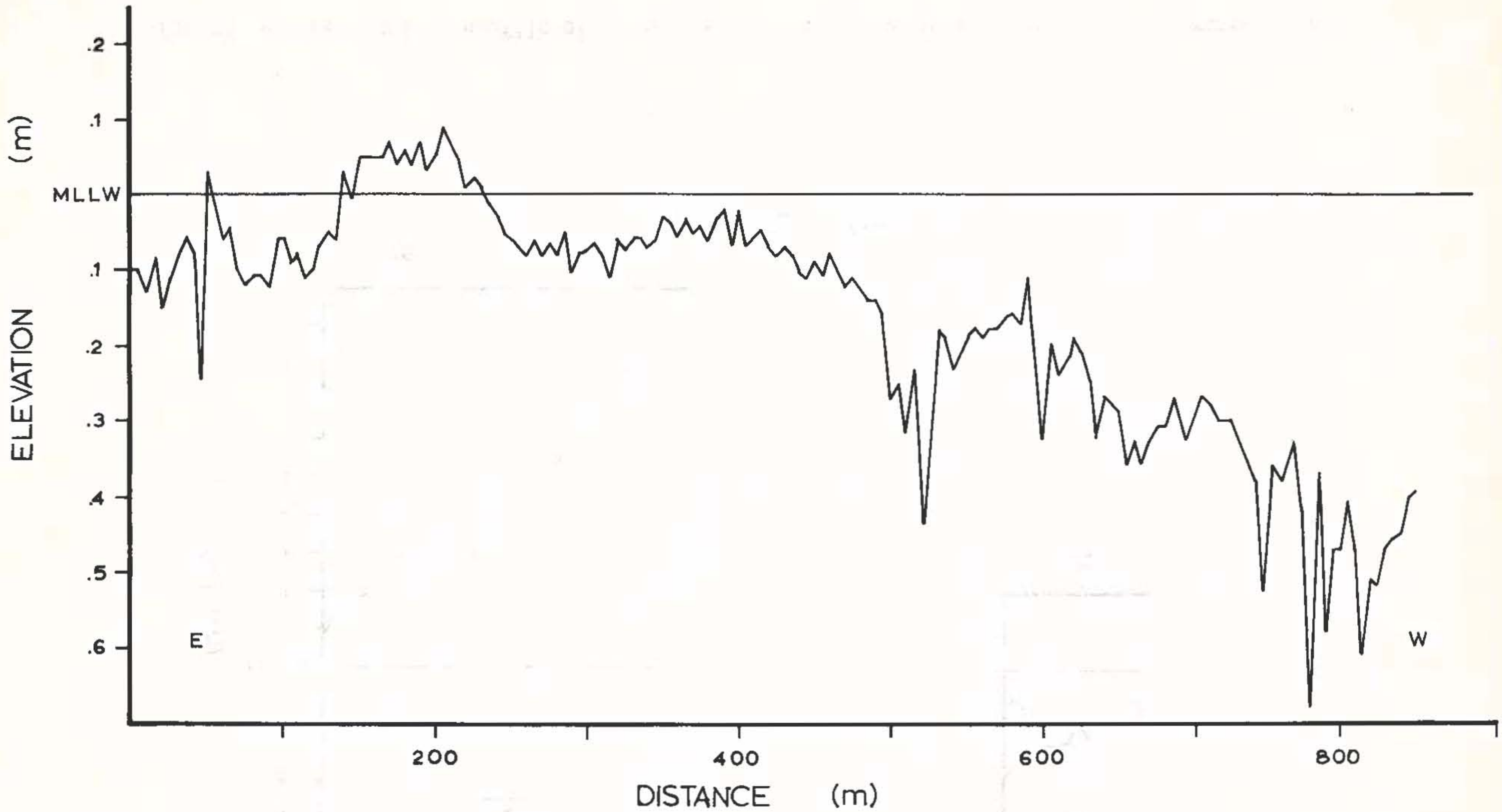

Figure 15. Bathymetric profile of Tidal Flat C, transect 7 (Fig. 13).

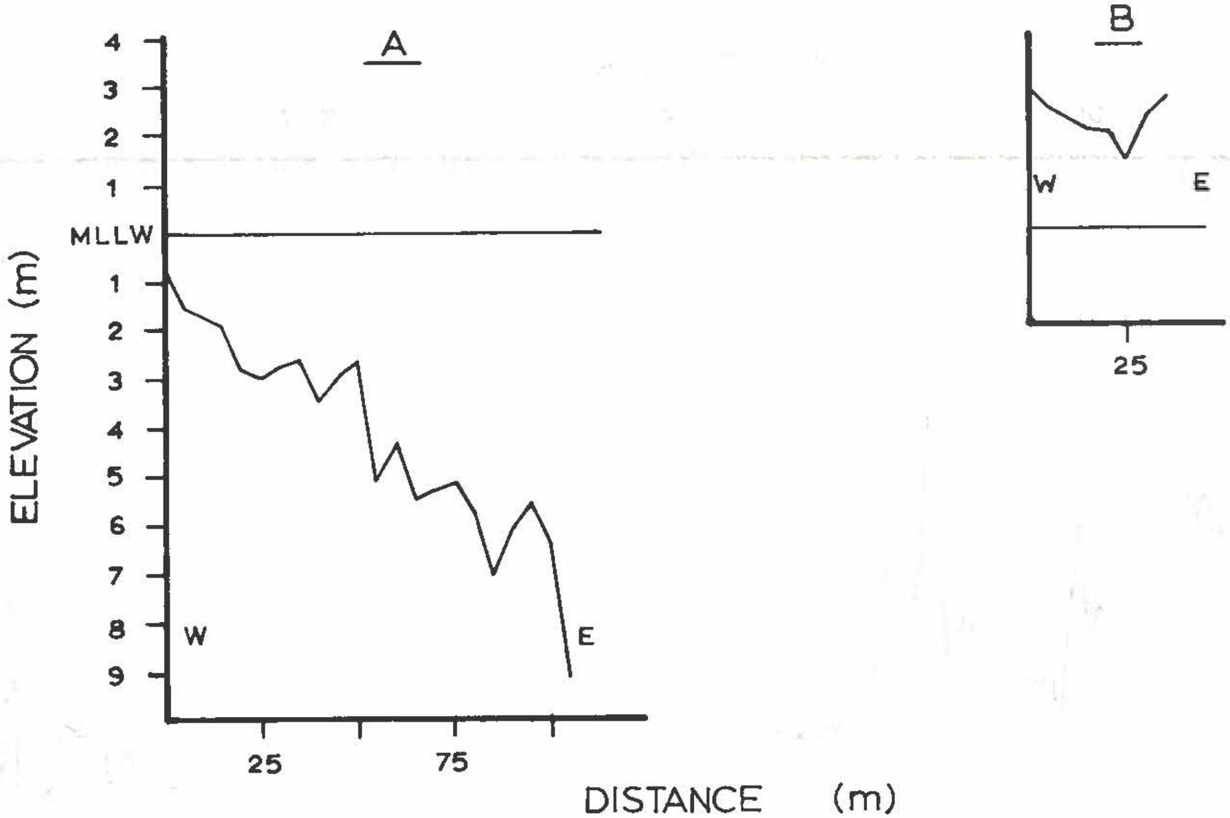

Figure 16. Bathymetric profile of Tidal Flat C. A. Transect 13 (Fig. 13). B. Transect 9.

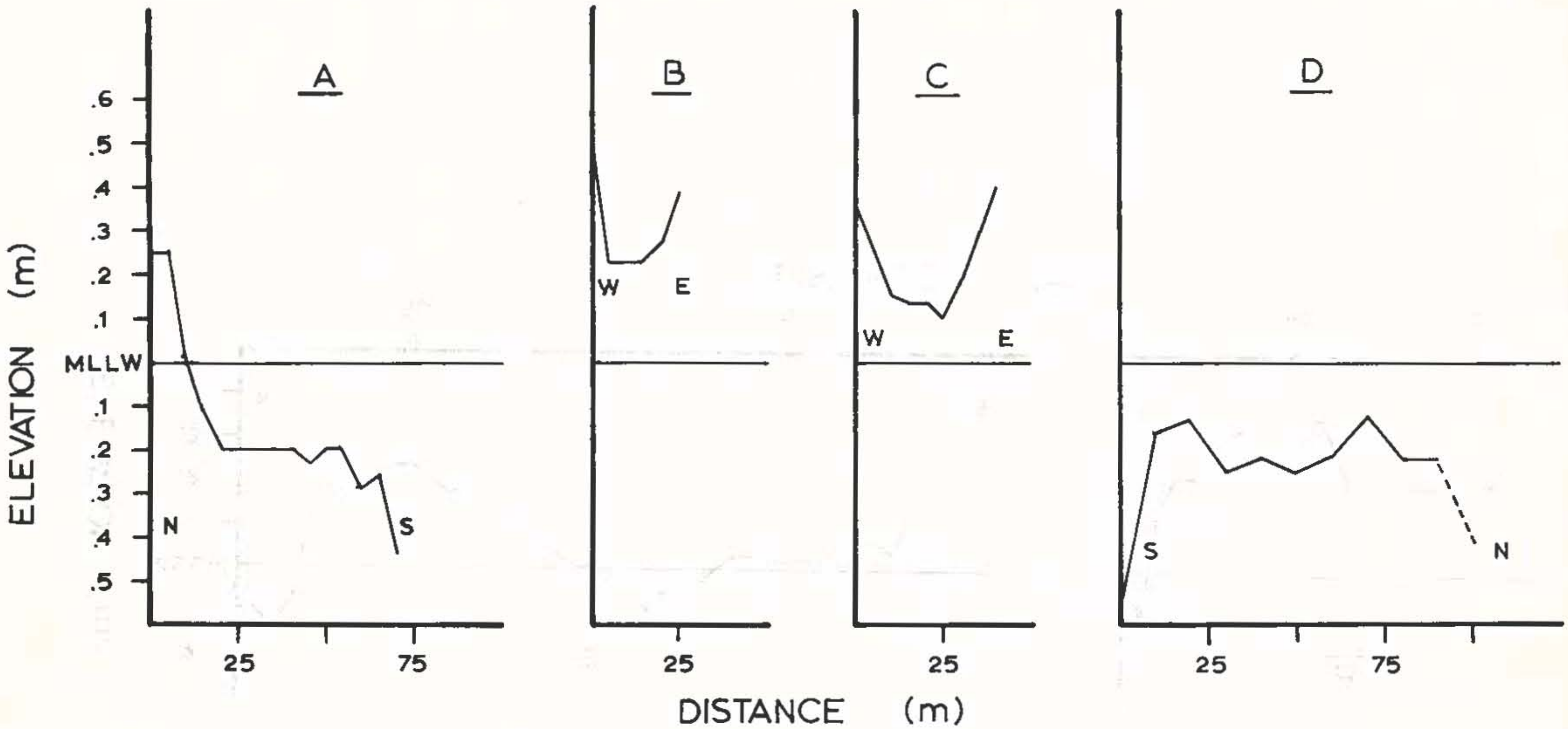

Figure 17. Bathymetric profile of Tidal Flat C. A. Transect 5 (Fig. 13). B. Transect 10. C. Transect 12. D. Transect 14. N = north; S = south.

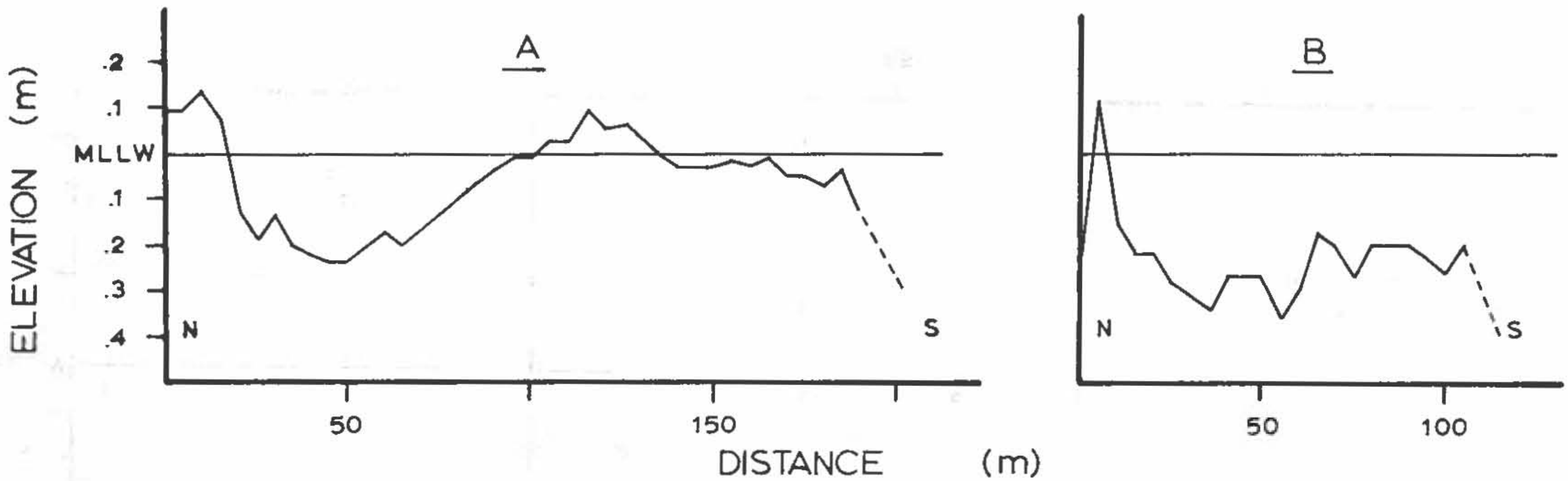

Figure 18. Bathymetric profile of Tidal Flat C. A. Transect 3 (Fig. 13). B. Transect 4.

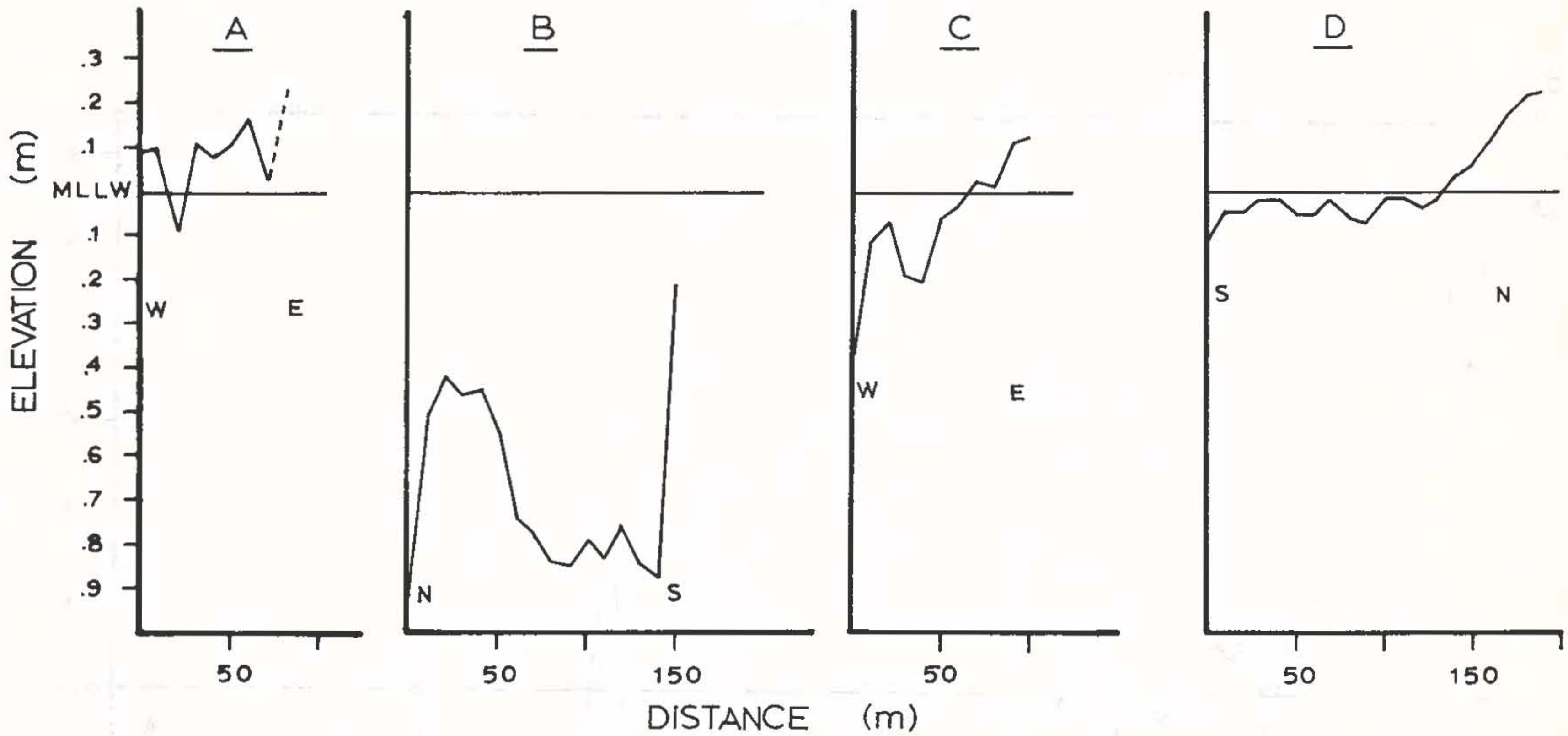

Figure 19. Bathymetric profile of Tidal Flats C and D. A. Transect 21 (Fig. 13). B. Transect 6. C. Transect 8. D. Transect 1.

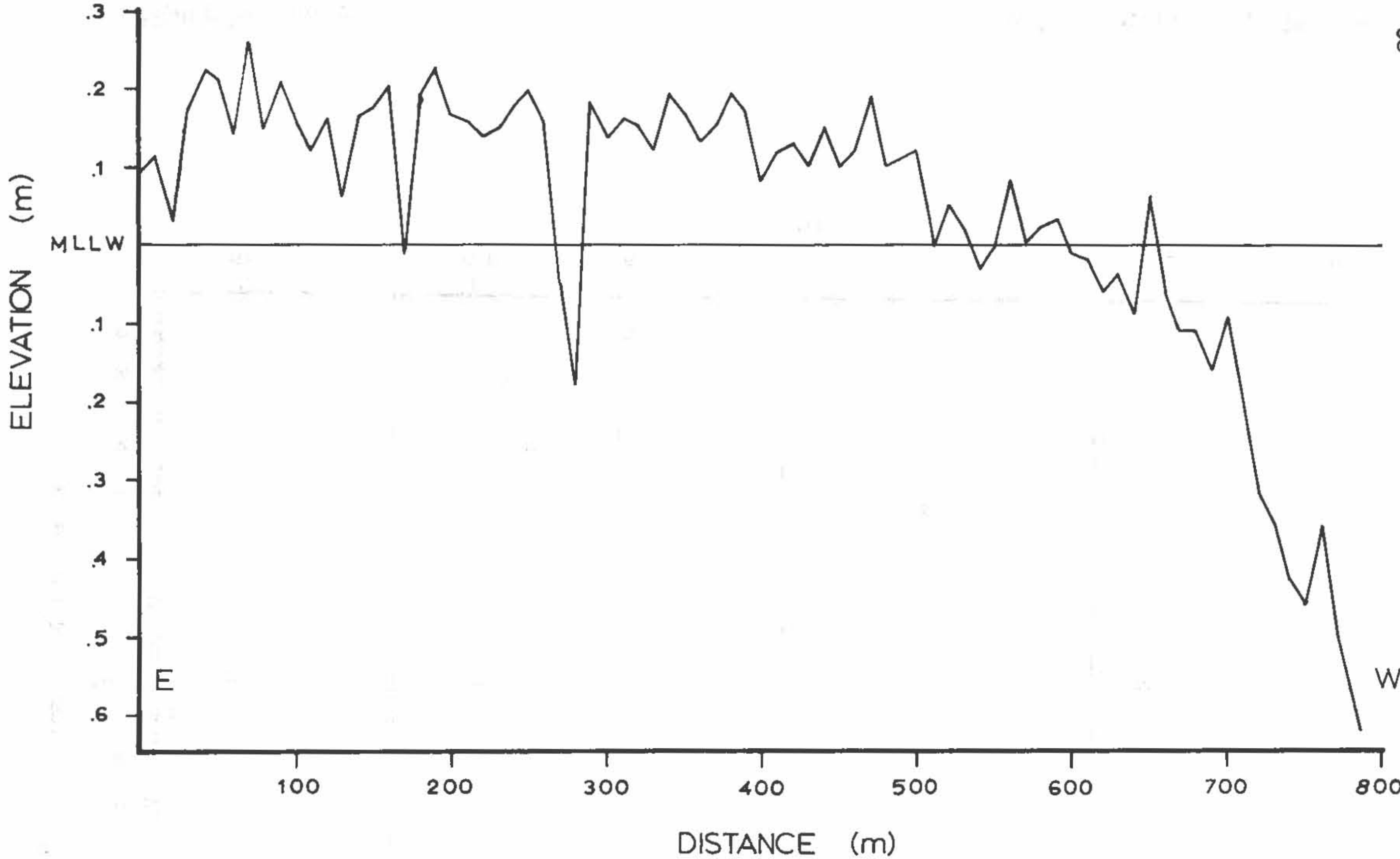

Figure 20. Bathymetric profile of Tidal Flat D, transect 16 (Fig. 13).

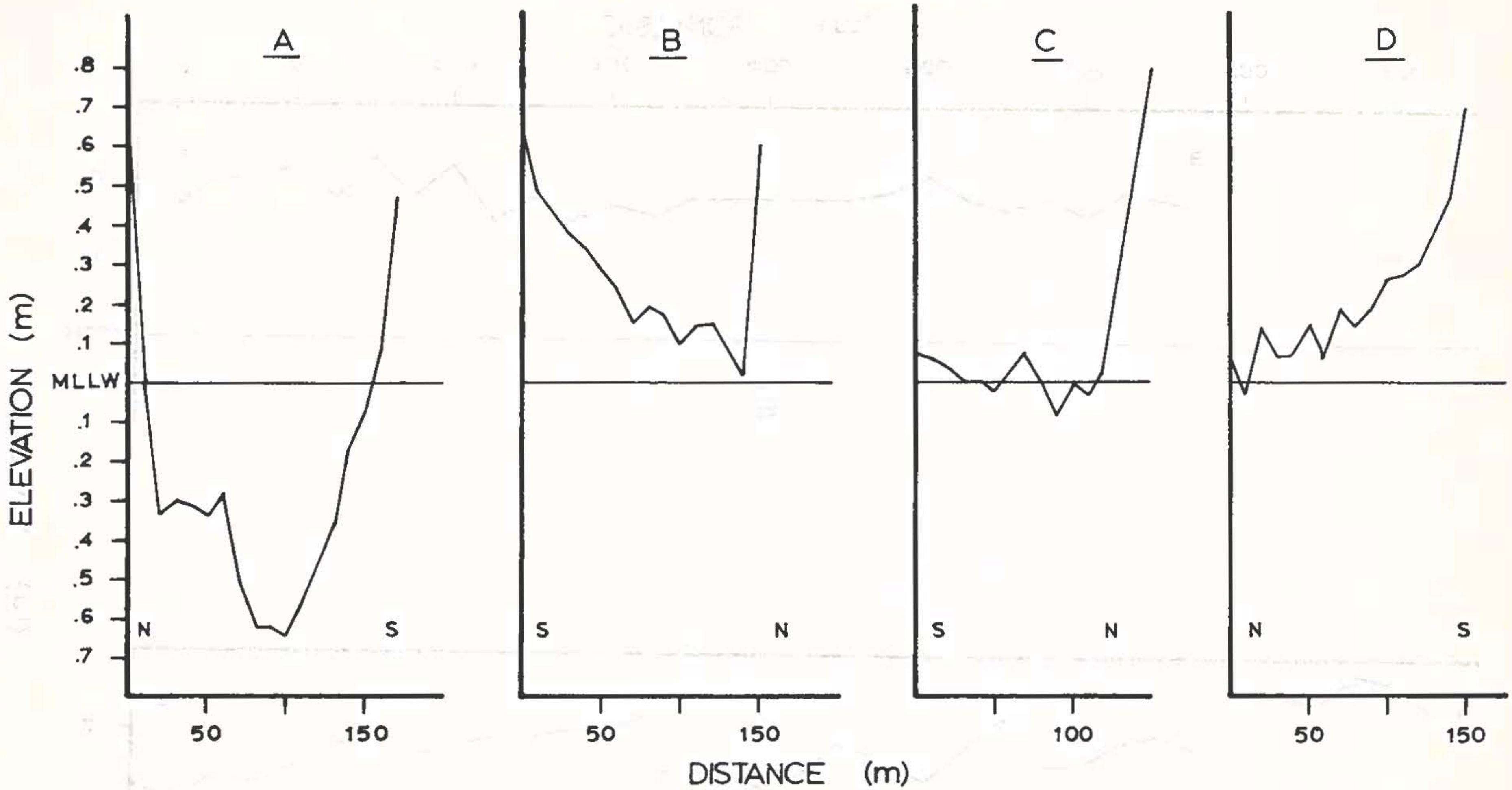

Figure 21. Bathymetric profile of Tidal Flat D. A. Transect 17 (Fig. 13). B. Transect 18. C. Transect 19. D. Transect 20.

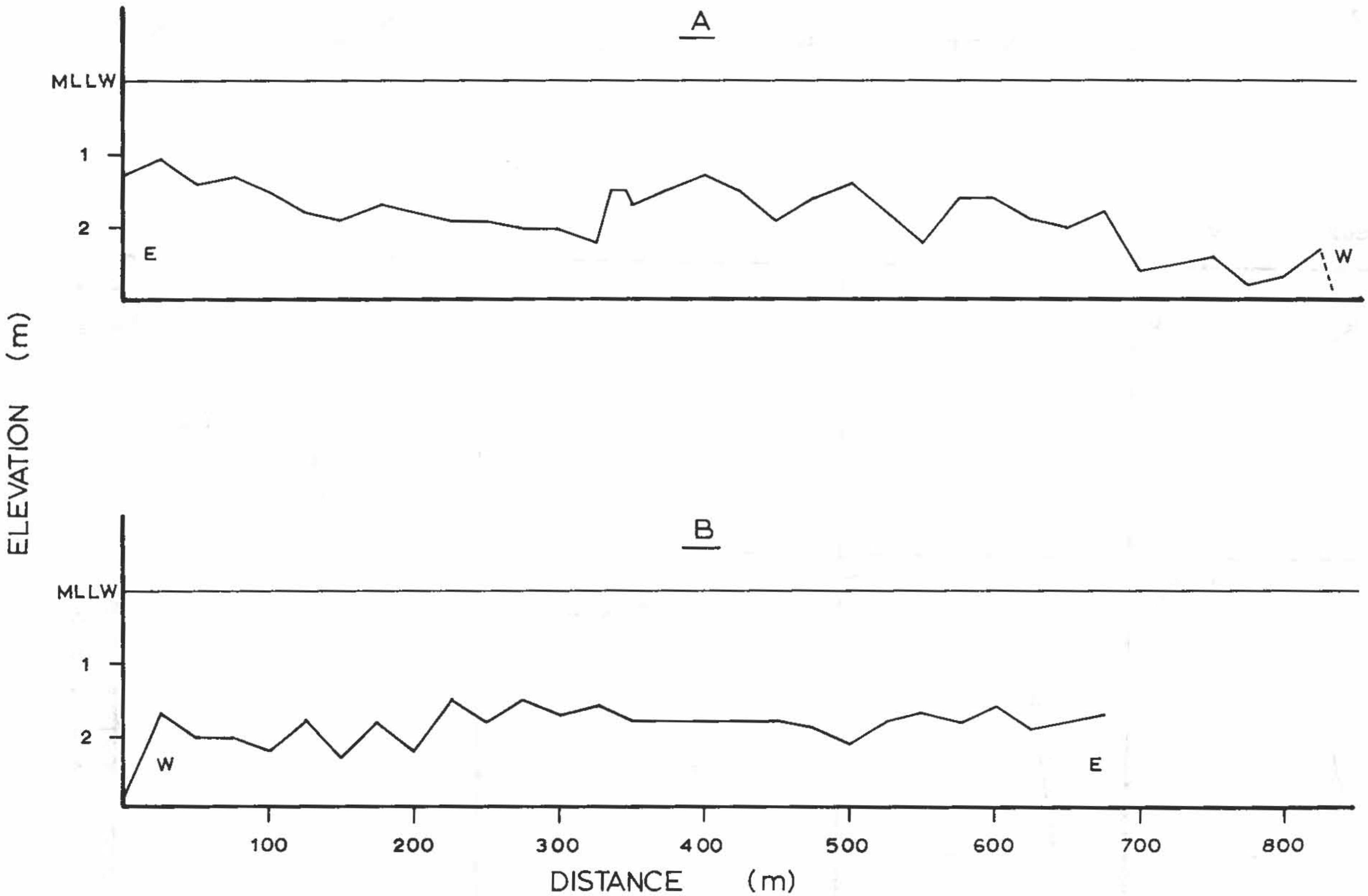

Figure 22. A. Bathymetric profile of Piti Channel, transect A (Fig. 13). B. Profile of Secondary Channel, transect B.

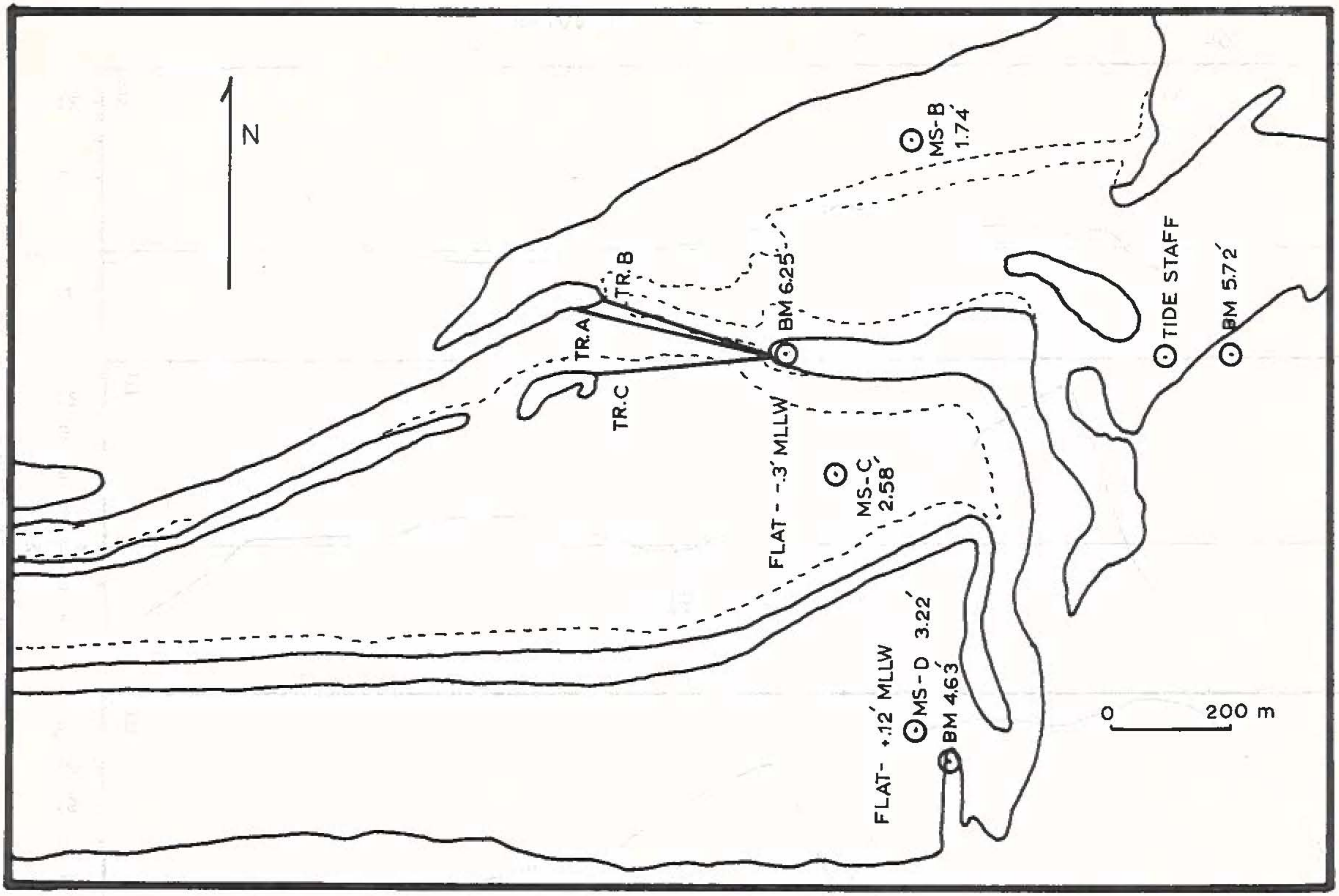

Figure 23. GORCO pipeline transects for 12 February, 1977. BM = bench mark; MS = reef flat bench marks.

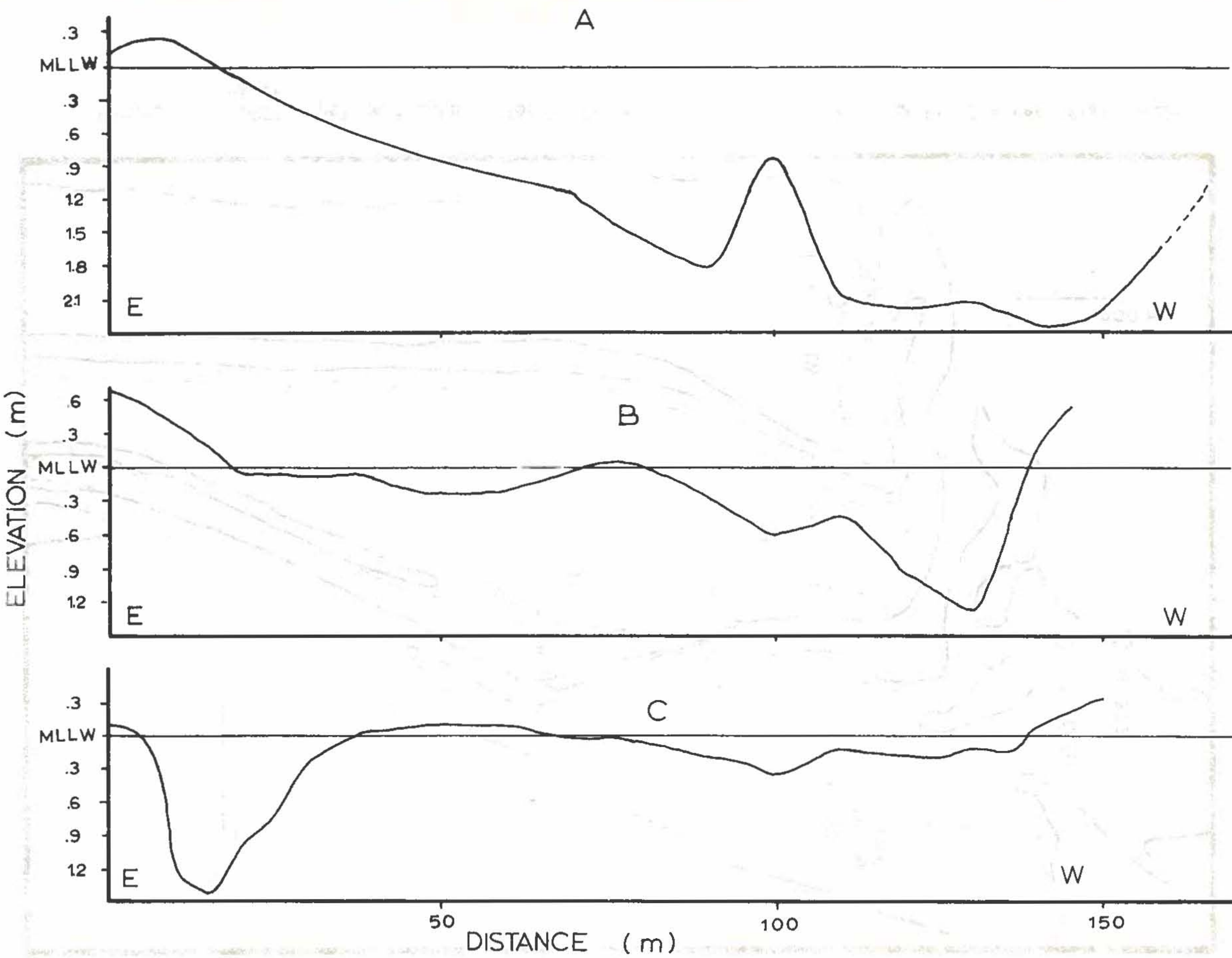

Figure 24. Profiles of GORCO pipeline transects. See Fig. 23 for transect locations.

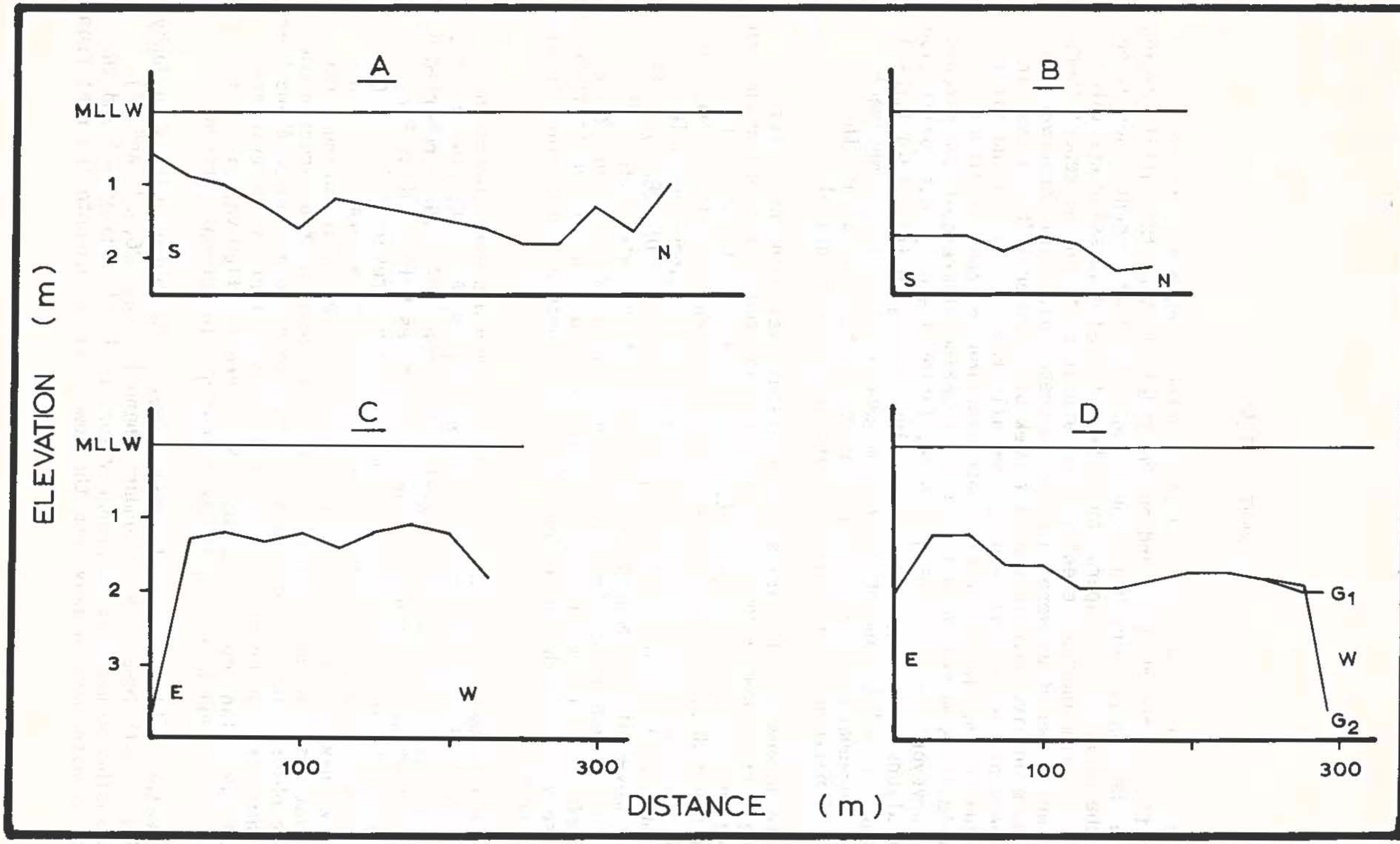

Figure 25. Bathymetric profiles of secondary channels in the study area. A. Transect C (Fig. 13). B. Transect F. C. Transect E. D. Transect G, G1 and G2.

CURRENT PATTERNS

Marsh and Gordon (1973, 1974) reported on current patterns and velocities in the channels and on the tidal flats of the outfall region before the Cabras Plant began operations. Here we present observations with the plant in full operation. The data and discussion are taken primarily from another recent Marine Laboratory technical report (UGML, 1977) which two of us were involved in preparing. Field observations were made on five days in the last week of December 1976 and the first two weeks of January 1977 and covered all stages of rising and falling neap and spring tides. Precise determinations of current directions and velocities were made primarily by tracking fluorescein dye patches with surveyor's transits (Figs. 26-34, Tables 4 and 5), but qualitative observations were also made by releasing large quantities (2-4 liters) of concentrated dye and observing the general direction of movement. While the general trend for major current patterns is clear, the detailed pattern at individual locales is probably variable.

In agreement with earlier observations, water in Upper Piti Channel still shows a continuous outward flow toward the harbor on both rising and falling tides (Fig. 26, Tracks G, H; Fig. 27, A', G; Fig. 28, F). Water moves down the channel from the power plants and divides near the GORCO pipeline, with major flow into Lower Piti Channel and a lesser flow onto Flat C (Fig. 26, G, H; Fig. 27, A', G, C; Fig. 28, F). This latter movement is enhanced by wind. Some of the water leaving Piti Channel also enters the Connecting Channel (Fig. 26, A'; Fig. 27, B'; Fig. 28, E). This occurs continuously, with no tidal change in direction, as observed by Marsh and Gordon (1973, 1974) before Cabras Plant operations began.

Surface waters in Lower Piti Channel move westward toward the harbor on both falling and rising tides (Fig. 29, A, B, C; Fig. 30, A', B'; Fig. 31, V; Fig. 27, E). Marsh and Gordon (1973, 1974) reported a slight reversal on strongly rising spring tides before Cabras Plant operations began. The failure to observe such a reversal in the observations reported here is probably not indicative of a permanent change, since we have occasionally noticed a reverse flow while making other observations. We would expect to find a reversal with a larger number of dye observations. The flow velocities reported in Tables 4 and 5 are in the same range as previously reported. Hence, there is no evidence that Cabras Plant operations have led to greater flow velocities in Lower Piti Channel or to qualitative changes in current patterns.

Water on Flat C generally moves toward the harbor, with a tendency to drift south toward the Secondary Channel (Figs. 26, 27, and 28). This southward movement is probably the result of wind effect and the force of water moving away from the power plants and onto the flat from

Upper Piti Channel. There is no evidence for a tidal effect on current direction or velocity on the eastern half of the flat. At the western end of Flat C there is a tendency for westward flow velocity to decrease on rising tides (Figs. 29, 30, and 31), but only Path G (Fig. 29) showed a reversal. Water movement directly westward of the peninsula separating Flats C and D showed a further tendency toward southward drift on its way to the harbor.

Water moving southward across Flat C and entering the Secondary Channel shows a tendency to divide into two flows, with part of the surface water moving westward toward the harbor and part flowing eastward in the channel (Figs. 26, 27, and 28). In addition, Path C in Fig.32 showed a depth pattern rather clearly. At this point a large quantity of dye was released near the surface and about 2 m below the surface. The surface patch moved westward, while the subsurface patch moved eastward. As in Lower Piti Channel, a thermal gradient between surface and deeper water is often obvious to a snorkeler in the Secondary Channel. Marsh and Gordon (1973, 1974) reported a slight surface flow reversal in this channel on strongly rising tides.

Eastward moving water in the Secondary Channel joins southward moving water in the Connecting Channel, and the combined water mass moves slowly southward in the extension of the Connecting Channel toward Flat D (Figs. 26, 27, and 28). On at least some tidal states this water moves around the bend onto Flat D, spreads out, and moves westward (Figs. 33 and 34). Marsh and Gordon (1973) reported the reverse movement of water draining off Flat D to the eastward on a strongly falling tide. At the western end of the flat the westward flow continues on a falling tide but reverses on a rising tide (Fig. 29, H, L; Fig. 30, H'; Fig. 31, S, T). There is a suggestion that on an ebb tide flow velocity is approximately four times greater on Flat C than on Flat D (Paths K and L, Fig. 29). This phenomenon probably reflects a greater movement of effluent water from the power plants across Flat C than across Flat D. Probably very little water from the plants moves onto Flat D, as indicated by the temperature data.

In summary, there is a dominant westward outflow of water in the area on both ebb and flood tides. The only tidal reversal occurs on the western half of Flat D. Warm water from the power plants moves down Piti Channel, across Flat C and into the Secondary Channel, introducing a warm surface layer on top of a cooler subsurface layer in the channels. There is a southward wind drift on Flat C. Water pumped from the power plants helps flood the area during rising tides. However, there must be another source of flooding water also, and this source is apparently a subsurface inflow in Piti Channel and the Secondary Channel on strongly rising tides.

As discussed in UGML (1977), surface water in the Commercial Port area moves westward at all tidal states and is strongly influenced by the prevailing wind. There is some westward movement of deeper water on falling tides and some evidence of eastward movement on rising tides.

Deeper waters are probably affected by complex eddies, particularly when there is ship traffic, and the waters of the port are probably well mixed vertically.

Table 4. Dye patch directions and velocities in Lower Piti Channel, Flats C and D. See Figs. 29-31 for locations. The tide change was calculated from the tide curve for runs longer than 15 minutes; for shorter runs a falling tide is indicated by (-) and a rising tide by (+).

Date	Start Time	Fig.	Dye Patch	Time (min.)	Dist.	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel. (knots)	Tide Change
12/28/76	1400	29	A	2.40	25	.16	270°	60°	10-12	-
	1410		A	2.50	25	.15	270°	60°	10-12	-
	1415		B	2.10	25	.19	270°	60°	10-12	-
	1420		B	2.15	25	.19	270°	60°	10-12	-
	1405		C	1.00	25	.42	270°	60°	10-12	-
	1425		C	1.10	25	.36	270°	60°	10-12	-
	1030		F	75.00	113	.03	252°	90°	10	+.36
	0900		G	21.40	100	.08	117°-270°	90°	10	+.1
	0900		H	23.30	44	.03	87°	90°	10	+.1
	1600		I	30.00	56	.03	209°	60°-90°	8-12	-.1
	1650		J	20.00	28	.02	280°	60°-90°	8-12	-.09
	1418		K	10.00	161	.27	265°	60°	10-14	-
	1400		L	8.30	37	.07	270°	60°	10-14	-
1/04/77	1200	30	A'	4.30	25	.09	270°	90°	5-13	-
	1600		A'	5.30	30	.09	270°	90°	9-13	+
	1211		B'	3.00	25	.14	270°	90°	5-13	+
	1610		B'	4.30	25	.09	270°	90°	9-13	+
	1130		C'	17.00	50	.05	270°	90°	5-13	-.05
12/29/76	0945		D	12.00	75	.10	270°	90°	10-18	+
	1154		D	9.00	50	.09	270°	90°	15-18	+
1/04/77	0928		E	17.00	37	.04	240°	90°	5-10	-.05
12/29/76	1020		F'	17.00	75	.07	254°	90°	10-18	+.09
	1255		F'	10.00	25	.04	254°	90°	12-16	+
	0915		H'	16.00	25	.03	86°	90°	10-14	+.09
	1120		H'	17.00	25	.02	86°	90°	10-18	+.09
1/04/77	1102		I'	10.00	50	.08	244°	90°	5-13	-
1/11/77	1518	31	C"	1.15	25	.33	270°	50°	6-10	-
	1522		C"	1.55	25	.22	270°	50°	6-10	-
	1526		C"	2.15	25	.19	270°	50°	6-10	-
	1457		F"	2.15	25	.19	222°	50°	6-10	-
	1505		I"	7.20	50	.08	255°	50°	6-10	-
	1504		M	3.00	50	.28	272°	50°	6-10	-

Table 4. (continued)

Date	Start Time	Fig.	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel. (knots)	Tide Change
1/11/77	1500	31	N	1.30	25	.28	270°	50°	6-10	-
	1422		O	8.15	75	.15	263°	50°	5-8	-
	1355		P	8.30	25	.05	270°	50°	8-10	-
	1422		Q	5.15	25	.56	276°	50°	6-10	-
	1513		R	3.15	25	.13	245°	50°	6-10	-
	1351		S	12.15	25	.03	269°	50°	8-10	-
	1408		S	5.10	25	.08	269°	50°	8-10	-
	1057		T	28.08	25	.07	94°	50°	5-8	+.04
	1520		U	3.25	25	.12	270°	50°	6-10	-
12/27/76	1515		V	1.45	25	.24	267°	50°	4-6	-
	1520		V	2.00	25	.21	267°	50°	4-6	-
	1525		V	2.03	25	.20	267°	50°	4-6	-

Table 5. Dye patch directions and velocities in Upper Piti and Secondary Channels, Flats C and D. See Figs. 26-28, 33-34 for locations. The tide change was calculated from the tide curve for runs longer than 15 minutes; for shorter runs a falling tide is indicated by (-) and a rising tide by (+).

Date	Start Time	Fig.	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel. (knots)	Tide Change
1/10/77	1200	26	A	6.15	20	.05	270°	30°	9-12	-
	1700		A'	3.00	10	.06	91°	50°	4-8	-
	1222		B	5.30	20	.06	209°	30°	9-12	-
	1710		B'	6.00	20	.05	90°	50°	4-8	-
	1240		C	5.00	20	.07	208°	30°	9-12	-
	1730		C'	6.00	10	.03	270°	50°	4-8	+
	1300		D	7.30	10	.02	105°	30°	9-12	-
	1740		D'	3.15	10	.05	63°	50°	4-8	+
	1753		E	4.00	15	.06	62°	50°	4-8	+
	1800		F	5.00	20	.07	90°	50°	4-8	+
12/27/76	1100		G	5.00	20	.067	90°	30°	4-6	+
	1110		H	5.00	20	.067	248°	30°	4-6	+
1/10/77	1600	27	A	5.30	20	.06	271°	30°	4-8	-
1/04/77	1223		A'	6.00	30	.08	257°	90°	5-13	-
	1626		A'	5.00	25	.08	257°	90°	9-13	+
1/10/77	1620		B	4.00	20	.08	233°	50°	4-8	-
1/04/77	1315		B'	5.00	5	.02	97°	90°	5-13	+
	1655		B'	10.00	10	.02	97°	90°	9-13	+
1/10/77	1631		C	2.00	20	.17	242°	50°	4-8	-
	1641		D	2.00	20	.17	253°	50°	4-8	-
12/27/76	1540		E	2.02	25	.20	252°	50°	4-6	-
	1545		E	1.55	25	.22	252°	50°	4-6	-
	1625		F	6.15	25	.07	61°	50°	4-6	-
	1635		F	6.35	25	.07	61°	50°	4-6	-
1/10/77	1056		G	6.00	31	.08	243°	30°	4-6	+
	1143		H	6.00	20	.056	90°	30°	4-6	-

Table 5. (continued)

								Wind		
Date	Start Time	Fig.	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Dir.	Vel. (knots)	Tide Change
12/27/77	0900	28	A	70.00	165	.04	235°	30°	4-6	+.25
	0900		B	105.00	210	.03	238°	30°	4-6	+.38
	1100		C	30.00	80	.04	160°	30°	4-8	+.12
	1200		D	30.00	55	.03	266°	60°	2-6	+.10
	1300		E	45.00	120	.04	90°	60°	2-6	+.0
	1530		F	15.00	155	.17	209°	50°	4-6	-.03
	0715	33	D	84.00	200	.04	253°	30°	4-6	+.31
	0907		E	53.10	100	.03	290°	30°	4-6	+.28
	1043		F	10.00	25	.042	256°	30°	4-6	+
	1140		A'	45.00	100	.037	283°	60°	2-6	+.10
	1230		B'	37.00	60	.027	105°	60°	2-6	+.10
	1021		C'	53.00	160	.05	174°	30°	4-6	+
	1442		D'	29.00	100	.057	288°	50°	4-6	-.10
	1518		E'	15.00	50	.056	259°	50°	4-6	-.05
	1550		F'	5.45	50	.145	304°	50°	4-6	-
1/10/77	1452	34	A'	8.00	20	.042	190°	50°	9-12	-
	1600		B'	21.00	100	.079	269°	50°	4-8	-.10
	1225		C	19.00	100	.088	305°	30°	9-12	-.10
	1631		C'	44.00	125	.047	275°	50°	4-8	-.15
	1320		D	4.00	25	.104	260°	30°	9-12	-
	1326		D	4.00	25	.104	260°	30°	9-12	-
	1719		D'	13.00	25	.032	266°	50°	4-8	-
	1311		E	4.00	25	.104	263°	30°	9-12	-
	1339		F	10.00	25	.042	262°	30°	9-12	-
	1355		F	4.00	25	.104	262°	30°	9-12	-
	1405		F	3.00	25	.139	262°	30°	9-12	-

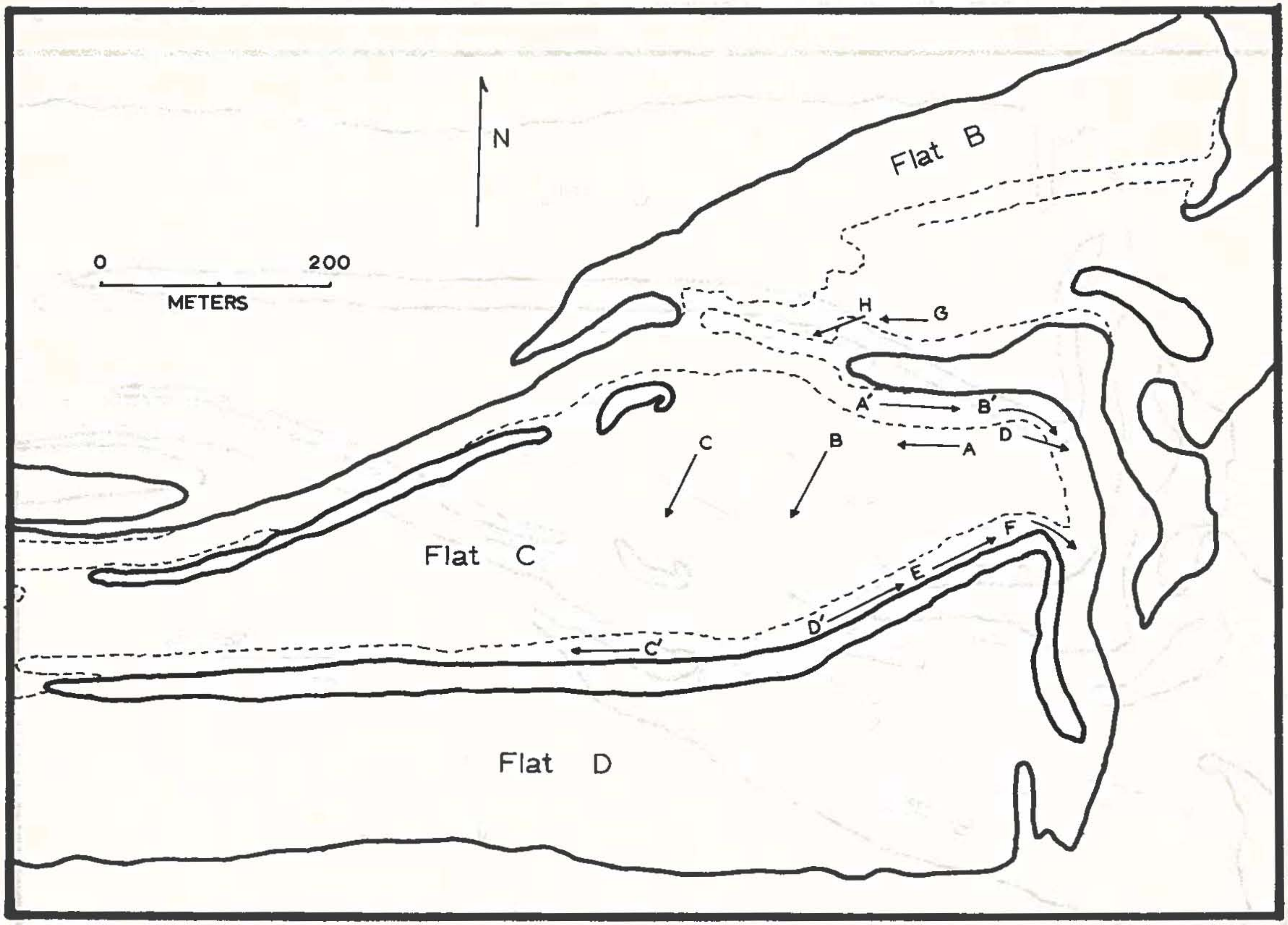

Figure 26. Dye paths of Upper Piti and Secondary Channels and Flat C. See Table 5 for detailed information.

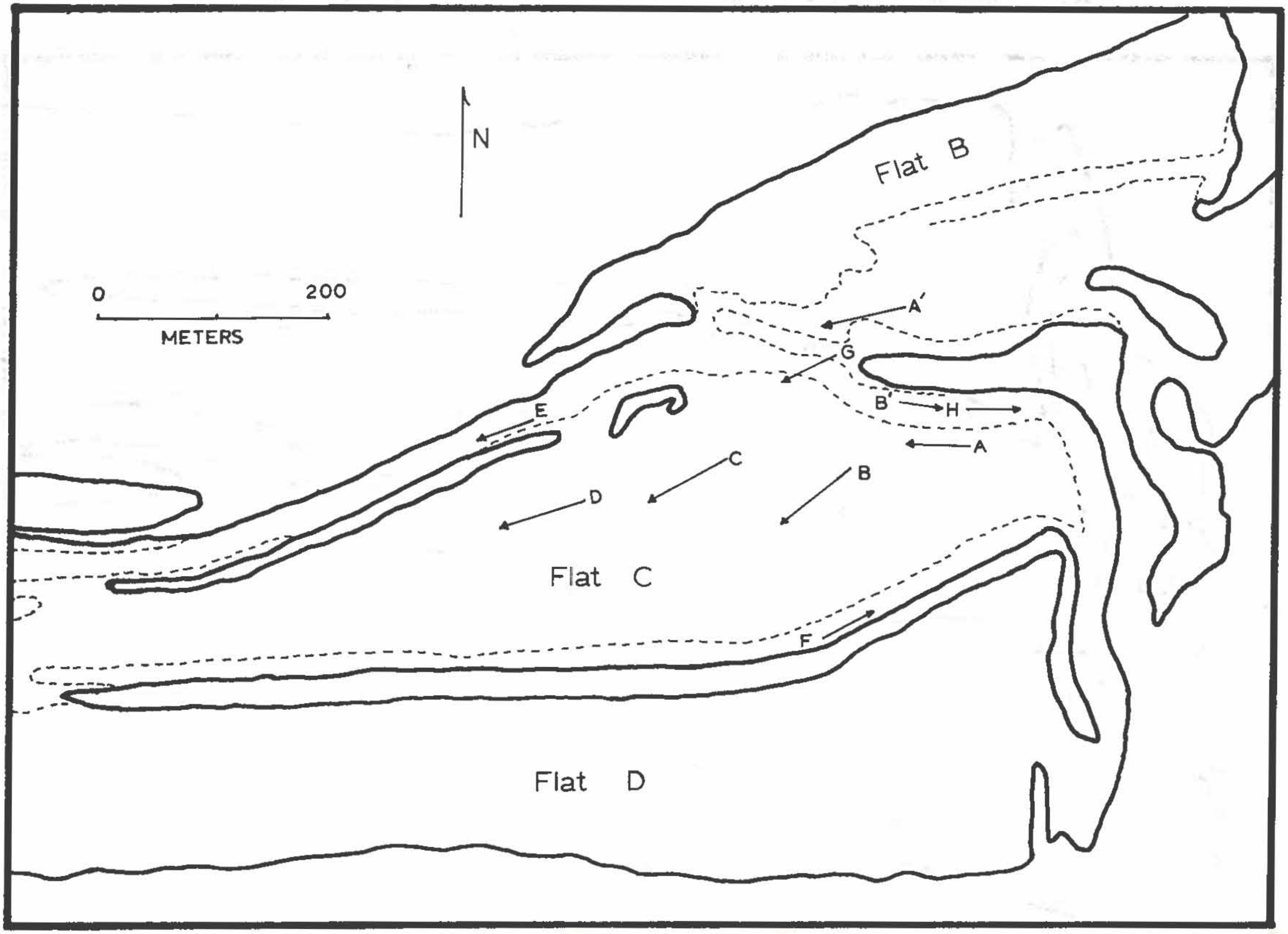

Figure 27. Dye paths of Upper Piti and Secondary Channels and Flat C. See Table 5 for detailed information.

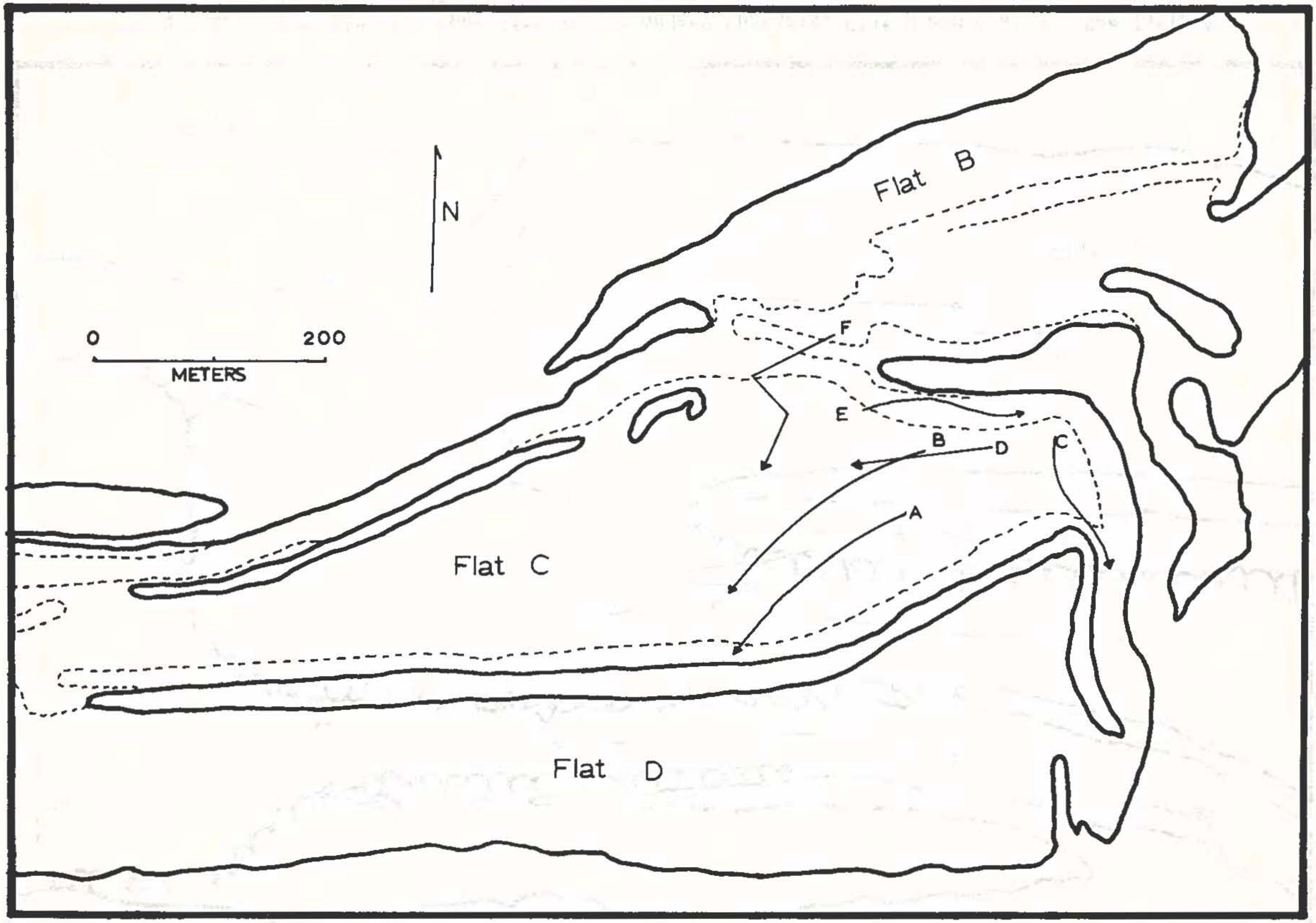

Figure 28. Dye paths of Upper Piti and Secondary Channels and Flat C. See Table 5 for detailed information.

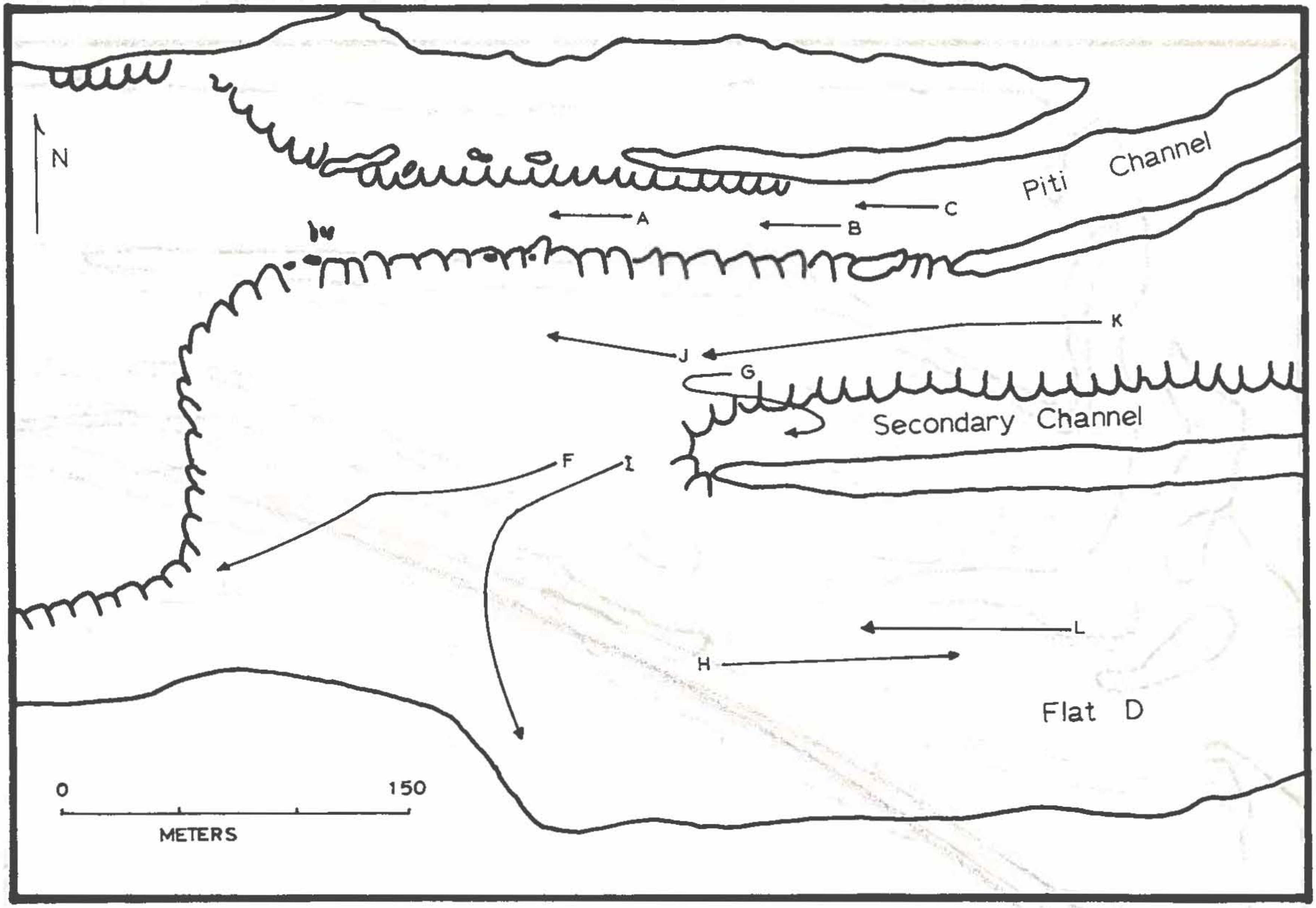

Figure 29. Dye paths in Lower Piti and Secondary Channels, Flat C and Flat D. See Table 4 for detailed information.

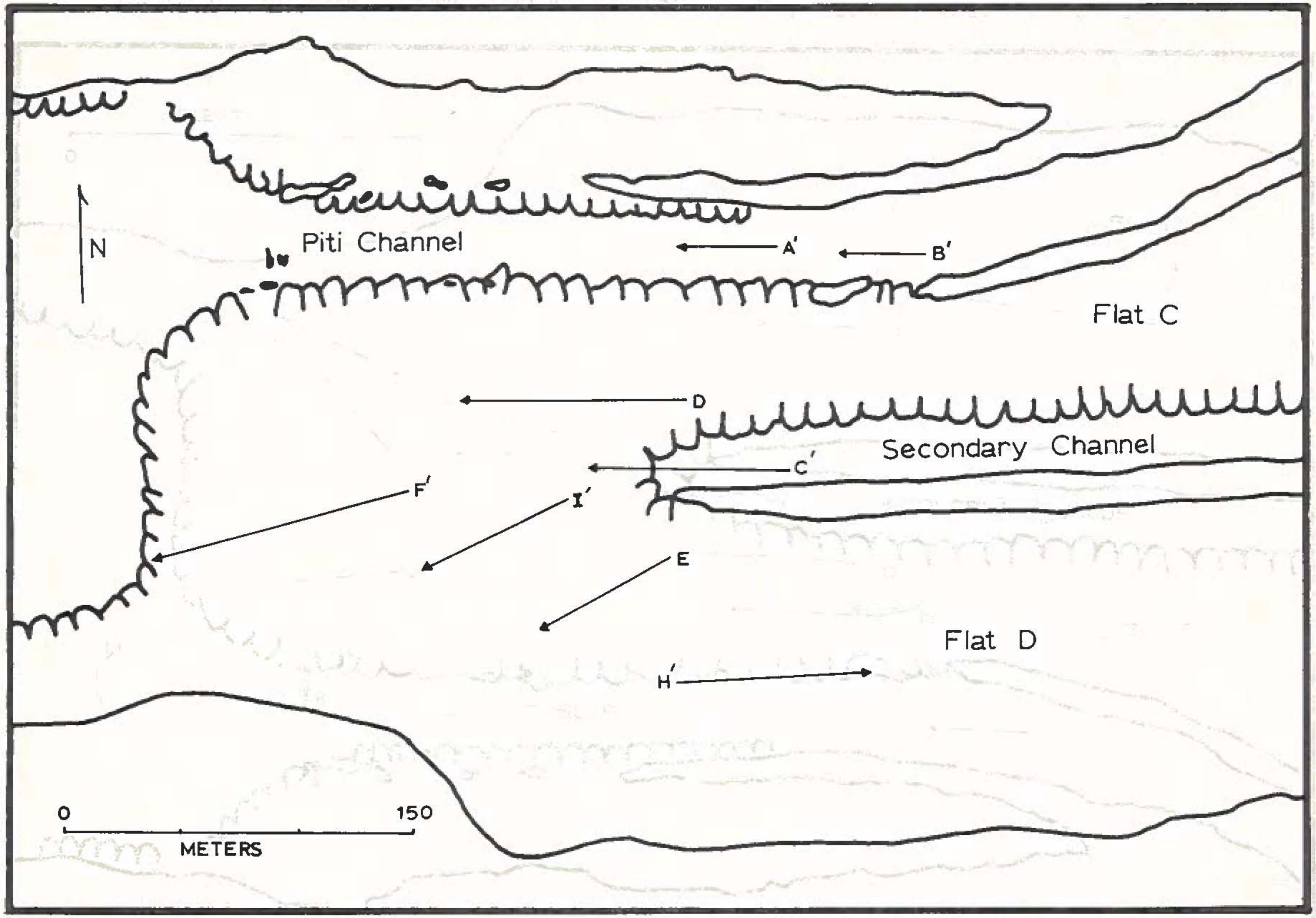

Figure 30. Dye paths in Lower Piti and Secondary Channels, Flat C and Flat D. See Table 4 for detailed information.

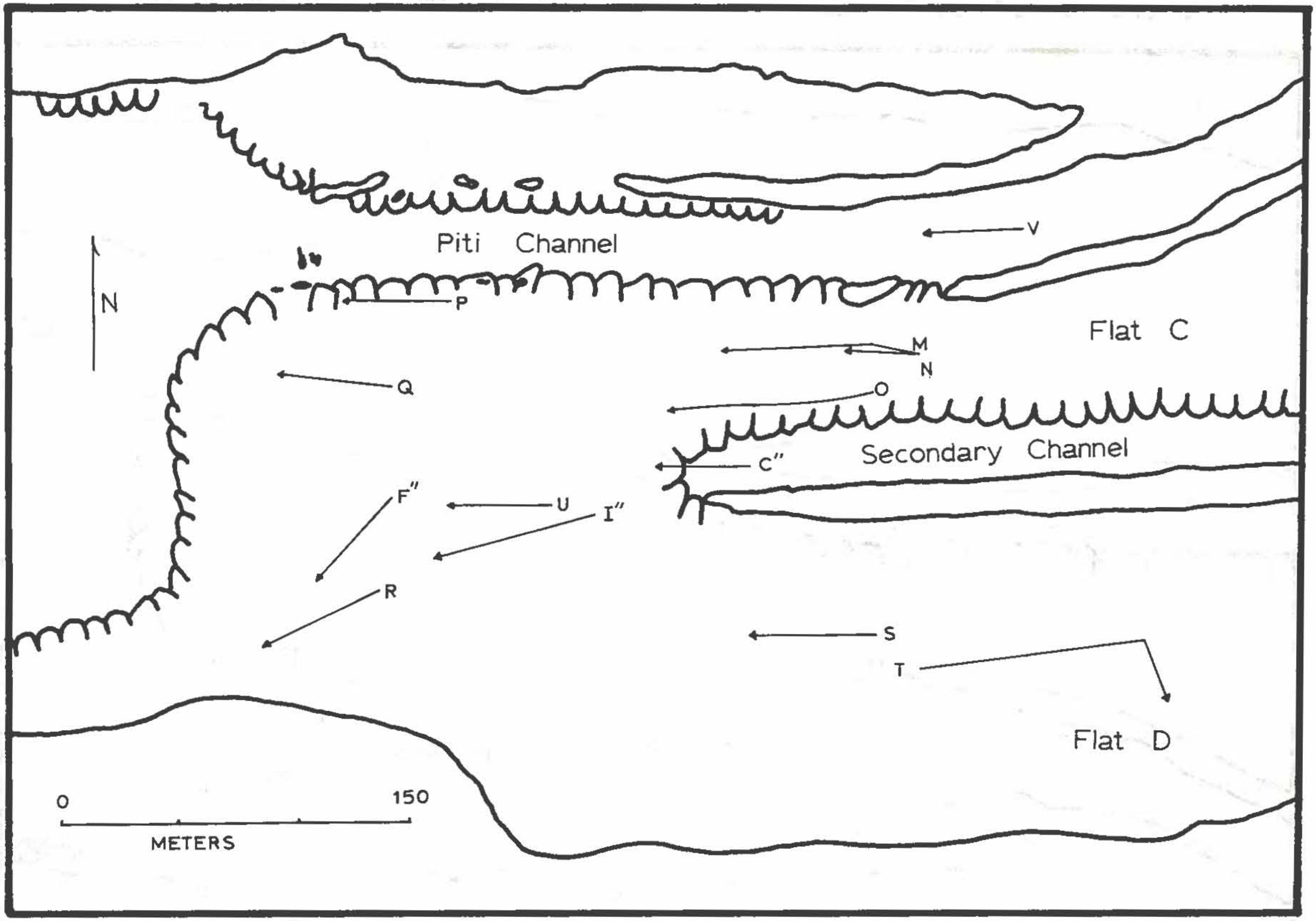

Figure 31. Dye paths in Lower Piti and Secondary Channels, Flat C and Flat D. See Table 4 for detailed information.

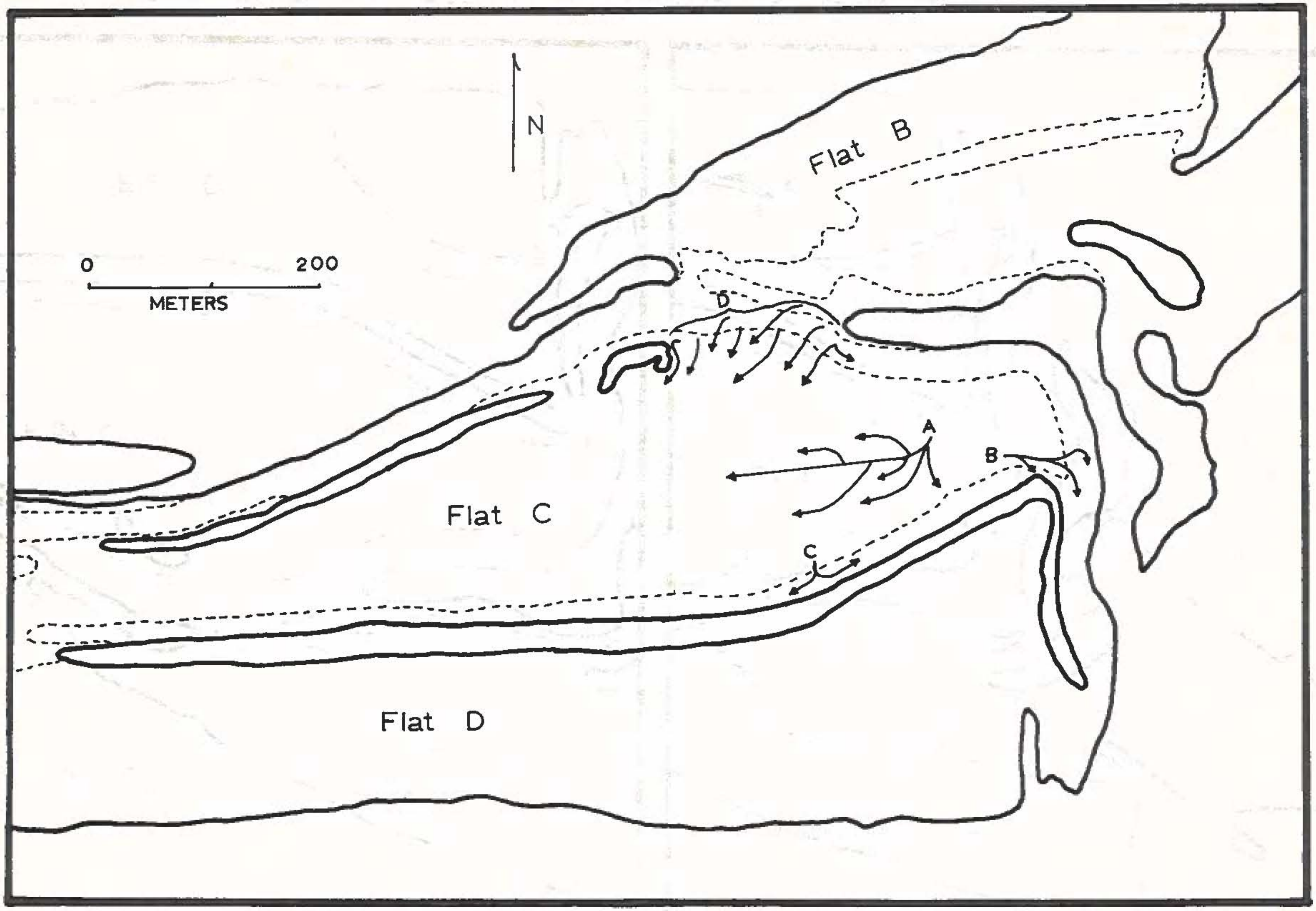

Figure 32. Qualitative study of dye patch movement for Flat C and Upper Secondary Channel.

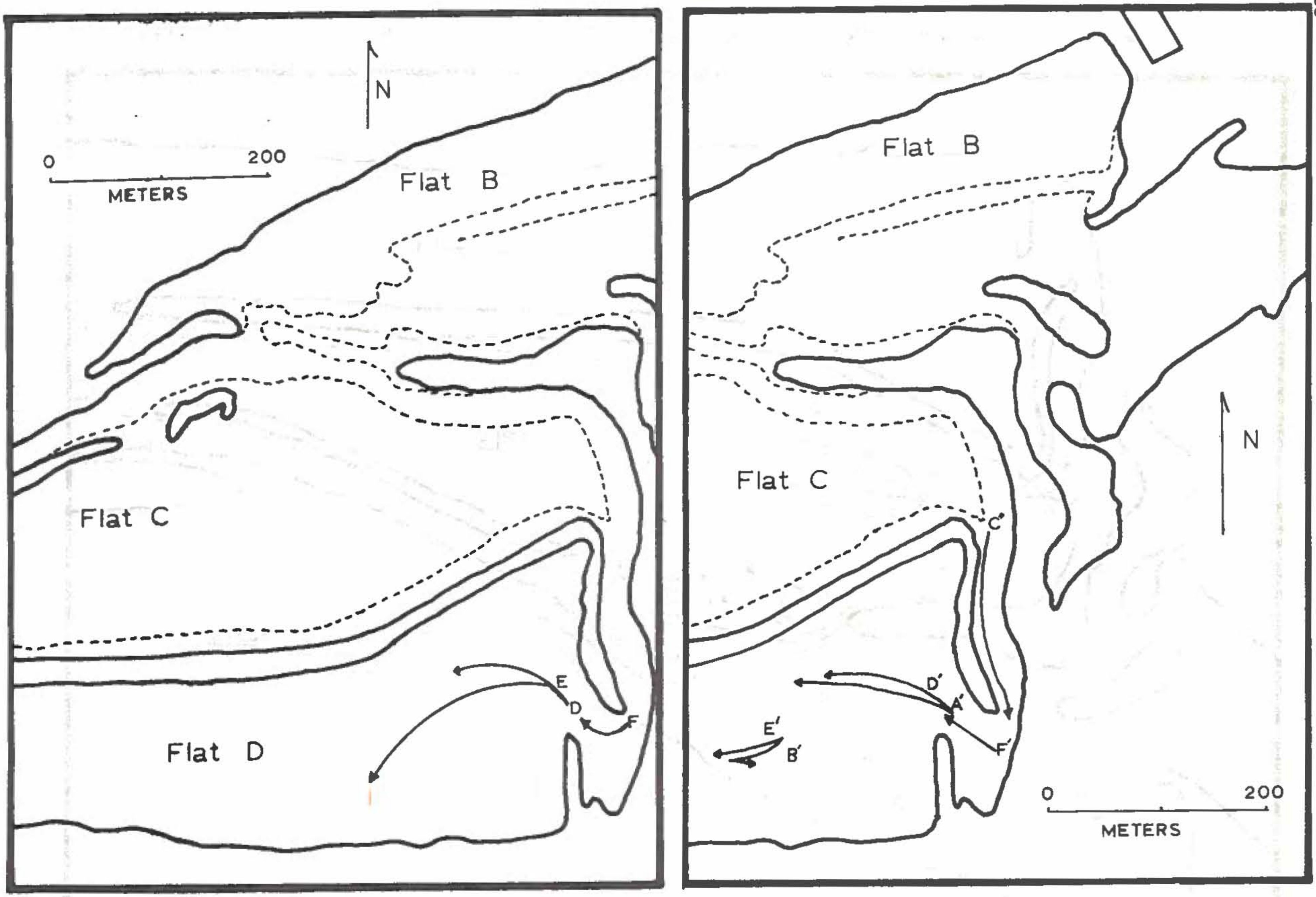

Figure 33. Dye paths of Flat D. See Table 5 for detailed information.

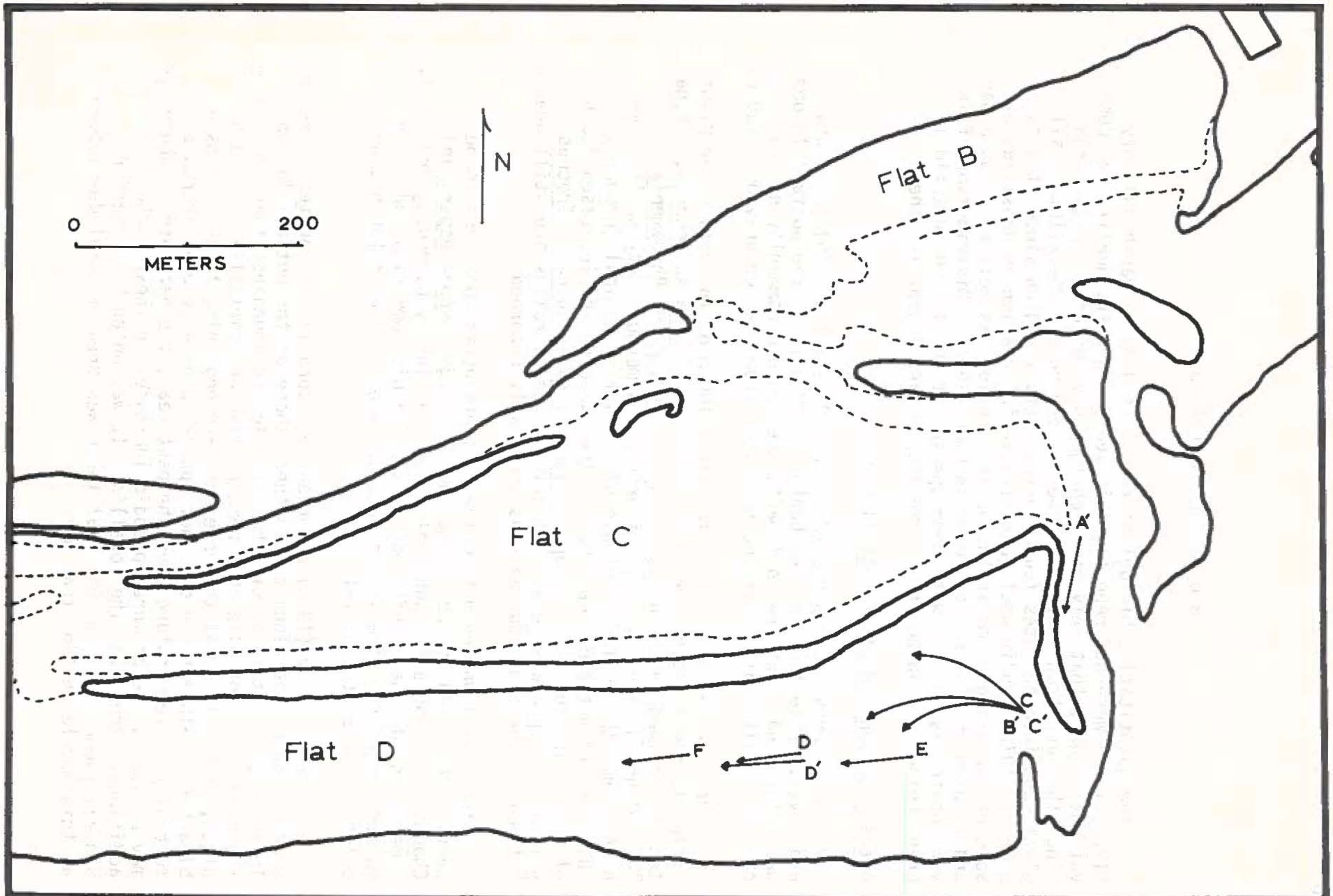

Figure 34. Dye paths of Flat D. See Table 5 for detailed information.

BIOLOGICAL OBSERVATIONS

The quantitative biological transects done by Marsh and Doty (1975, 1976) were not repeated this year. However, qualitative observations suggest that only minor changes have occurred in the area since the last transect. The Appendix presents a checklist of all plants and invertebrates found in the outfall region since studies began in 1972. Additional quantitative information on densities of some of these organisms in the outfall region, as well as in Sasa Bay and at Jade Shoals, may be found in UGML (1977). Distribution of invertebrates is patchy, with some species of snails and intertidal crabs being very abundant in some locales and absent in others.

Outfall Lagoon and Other Outfall Areas

In two previous reports (Marsh and Doty 1975, 1976) the flora and invertebrate fauna of the benthic community in the outfall lagoon were discussed. For the most part, the benthic community has not changed significantly over the past year from the two previous studies.

The rock surfaces within the first 100 m of the Piti Power Plant effluents remain covered with the algae *Gracilaria salicornia*, *Padina tenuis*, *Halimeda opuntia*, *Sargassum polycystum* and *Rhodymenia* sp. The molluscan fauna is still diverse but numerous empty shells have been seen. The periodic release of a caustic chemical (probably chlorine) from the effluent may be the cause of the increased deaths of these invertebrates. *Drupa ricina*, *Planaxis sulcata*, *Trochus niloticus*, *Cypraea moneta*, *C. tigris* and *Conus rattus* are still present but not in the same abundance as previously recorded.

The area downstream from the Piti effluents continues to be heavily colonized by the filamentous red algae *Hypnea esperi* and *Champia* sp. The sandy substrate, kept in flux by burrowing organisms, remains the dominant influence on the benthic community and is in marked contrast to the stable rock surfaces available for biological colonization at the outfalls.

Marsh and Doty (1976) reported live corallia of *Porites lutea* in a deep dredge area along the southern shore of the outfall lagoon. These corallia still persist but in a lesser abundance than previously reported. The corallia that remain alive are partially covered by algae, particularly at the base, and are beginning to show signs of bleaching. Since there does not appear to be a general increase in turbidity or temperature over the past year, the decrease in abundance may be due to one or more episodic increases in these factors causing additional stress for the corallia. It was noted by Richard H. Randall (UGML, 1977, p. 28) that there was greater coral development at this locale in 1967 than now.

The effluent canal of the Cabras Power Plant has remained relatively unchanged over the past year. The alga Padina tenuis still grows in a thick turf on the smooth concrete facings, and the numerous species of molluscs noted last year (Drupa ricina, Pincta martensii, Strombus mutabilis, Cypraea erosa, C. emarginata, Cymatium nicobaricum, and Trochus niloticus) are still present.

The area west of the Cabras Power Plant effluent is primarily sand and rubble. Some scattered patches of Padina tenuis and the seagrass Halophila minor persist and are frequently inhabited by the pomacentrid fish Dascyllus aruanus. The highest constant water temperatures (35-37° C) are recorded from this area and may be the cause of exculsion of other species.

The substrate on the three tidal flats (B, C and D; Fig. 2) is composed primarily of sand and coral rubble. Flat D appears to have finer sand and less rubble than the other two flats. Flats B and C are similar biologically while Flat D is noticeably different. Flat D has a greater abundance of the red alga Gracilaria salicornia and the seagrass Enhalus acoroides than Flats B and C. These latter flats have a greater abundance of the sponge Spirastrella vagabunda. Padina tenuis is common throughout the flats as are burrowing organisms, particularly snails and worms. Other organisms seen on the tidal flats include the algae Halimeda opuntia and Champia sp.; the seagrass Halophila minor; the crabs Carpilius maculatus, Calappa hepatica, Clibanarius striolatus and at least two species of portunids; and numerous species of molluscs.

All three tide flats contain the blue-green alga Schizothrix calcicola. This alga usually grows on the substrate, but for a 3-month period (September 1976-November 1976) large mats of it were seen floating and being carried by the current into the Commercial Port area.

There are three peripheral channels in the effluent area: the Secondary Channel, the Connecting Channel and the Moat (Fig. 2). These areas were discussed by Marsh and Doty (1976), and no major changes in the biota have been observed since their last report. However, R. H. Randall recently noted the presence of scattered colonies of Porites lutea and Pocillopora damicornis along the edges of the Secondary Channel and at the western end of Flat D; and the snail Nerita reticulata (a species which is usually rare) was found at one point along the edge of the Secondary Channel near its western end (UGML, 1977).

At the western end of Flat C is a coral community consisting of a number of mounds and patch reefs. Randall identified 11 species from this area, including the dominant Pavona frondifera which has not been recorded anywhere else on Guam (UGML, 1977). This is the most unique biological feature of the entire outfall region.

West Piti Bay

As discussed extensively in two previous reports (Marsh and Gordon, 1974; Marsh and Doty, 1975) and in a letter to Guam Power Authority on 12 April 1973, the most serious environmental impact resulting from the dredging of Tepungan Channel during construction of the Cabras Power Plant was the unnecessary bulldozing of a 3000-m^2 portion of the coral community on the reef flat seaward of the channel and temporary access dike (Fig. 1). A three-dimensional community was flattened and reduced to an area of rubble, sand, and broken-up coral remains; there was extensive destruction of biota and habitat. We have continued our qualitative observations in the area since the initial destruction in April 1973. There has not been any marked regeneration of the coral community in the four succeeding years. The area has gradually come to resemble the adjacent non-coral portion of the inner reef flat and may be characterized as a sand-rubble community with algae and echinoderms as the predominant biological components. Field recognition of the affected area is now possible only with prior knowledge of the swath of the bulldozer. Various blue-greens (Hormothamnion, Schizothrix) and browns (Padina, Dictyota, and Hydroclathrus) are the dominant algae. The dominant echinoderms are the urchins Diadema and Echinothrix; a heavy settlement of the juveniles of these organisms in 1973 was noted in previous reports. This natural sporadic occurrence resulted eventually in an increase in the number of adult urchins on the Piti reef flat and other similar areas, and many of these have persisted to the present time.

Numerous broken fragments (mostly less than 25 cm diameter) of larger massive heads of Porites corals which were left in the bulldozed area still survive there and appear to be healthy. If these are growing they are doing so very slowly, however, and will take a long time to regenerate heads as large as those in the area before the bulldozing. There has been little growth of the staghorn coral Acropora, which was formerly represented in the area by standing dead thickets (killed by extreme low tides) with regenerating basal portions. In contrast, nearby areas with standing dead thickets which were not crushed by the bulldozer are showing extensive regrowth at the bases and up to the level of low-tide exposure. Especially noteworthy was the settlement of many new colonies of Pocillopora damicornis on the Piti reef flat during the summer of 1976. This was a general phenomenon seen in other areas of Guam, including Piti Canal and even the outfall lagoon of the power plants (discussed elsewhere in this report). While many of these colonies died, many of them also survived and presently appear healthy. The key factor was probably whether they settled on pieces of rubble or areas of solid substratum large enough to provide stability without allowing the colonies to be smothered by sediment. The living colonies now range in size from approximately 2 to 6 cm in diameter. This heavy set of Pocillopora was a natural sporadic occurrence which may prove significant in rehabilitation of the bulldozed area if the colonies survive in large numbers.

The 1974 report noted that the sea cucumber Synapta became much more noticeable in the bulldozed area within about two months after the damage than it had been previously. By 1975 this organism was not nearly so visually obvious in the damaged area; and a quantitative transect indicated that it was no more abundant in that zone than in other reef zones. While no recent quantitative transect has been made qualitative observations indicate that the organism is presently not particularly abundant in the bulldozed area.

Two other observations are of interest relative to the damaged area. Schools of juvenile rabbitfish (siganids), which are common on Guam reef flats in May and June, have commonly been seen in the damaged area as well as other areas on the Piti reef flat. It appears that these herbivorous fish are grazing extensively on fine algal filaments in the damaged area and that it is just as good a habitat for them as are other reef areas. Marsh (1974) studied the productivity of the Piti reef flat before the bulldozer damage took place and reported an average net community productivity value of .32 grams carbon per m^2 per hr, a gross productivity value of .58 g C $m^{-2}hr^{-1}$, and a 24-hr gross production-to-respiration ratio of 1.1. The study was repeated on the same transect (Fig. 1) in April 1977 by the Biology 512 class of the University of Guam, which found similar values of .38 g C $m^{-2}hr^{-1}$ for Net P, .72 g C $m^{-2}hr^{-1}$ for Gross P, and a P:R ratio of 1.1. Only about 50 m of the 275-m study transect fell across the damaged area, so the similarity in before-and-after metabolic rates may be due more to the undamaged portion of the transect than to the damaged portion.

The area formerly covered by the temporary access dike (Fig. 1) is generally indistinguishable from the remainder of the inner reef flat on the basis of visual inspection and consists of an algae-echinoderm community with the same species as noted above for the bulldozed area. The western portion of the dike area, adjacent to the new (north) arm of Tepungan Channel, has a slightly higher elevation than the remainder of the dike area and adjoining reef flat and is somewhat more barren because of low-tide exposure to the air.

Biological colonization in Tepungan Channel has been slow. The sloping sides of the channel have now lost much of the loose sediment which was present immediately after the dredging, rock outcrops and rubble provide a relatively stable substratum which appears suitable for the settlement of benthic organisms. However, there has not yet been much settlement. The most common organism is the coral Pocillopora damicornis, which has settled on the upper slopes of the channel as well as on the reef flats discussed above. There are numerous small colonies (2-6 cm in diameter) and occasional larger colonies, up to 10-12 cm in diameter. One area of the long arm of the channel near its fork into the two shorter arms, has scattered colonies of the staghorn coral Acropora on the upper portions of the seaward sloping side. These colonies are approximately 20 cm across and probably originated from pieces of live rubble swept into the channel from upstream portions of the reef flat. Numerous damsel fish, Dascyllus aruanus, are associated with these coral colonies. Algal coverage is not particularly striking on the slopes of the channel. Associated with various nooks and crevices are several species of chaetodontids (butterflyfish), pomacentrids (damsel fish), and acanthurids (surgeon fish); these are not present in very large numbers. There are also scattered tubeworms along the edges of the channel. The most abundant organisms are the sea urchins Diadema and Echinothrix, which are generally associated with rubble or other hard substrate. In general, the seaward sloping side of the channel supports many more organisms than the landward sloping side.

The bottom of Tepungan Channel is still silt-covered for the most part and provides a substrate too unstable for the settlement of most organisms. The presence of a burrowing shrimp-goby association was noted in the 1975 report. Qualitative observations suggest that these organisms may not be as dense now as was previously the case. The stony corals noted on the sides of the channel are not found on the bottom. One colony of soft coral has been seen. It now appears that any further biological development of the channel bottom is likely to be very slow.

Underwater visibility in Tepungan Channel is rather poor, and there is a considerable amount of suspended material in the water most of the time. It is not usually possible to see the bottom of the channel (about 5 m deep) from the surface. However, water clarity is noticeably better now than it was in the period following the dredging. Often there is a layer of murky, warmer water (ranging from a few centimeters to a meter thick) on the surface, with noticeably cooler and clearer water occupyiny most of the volume of the channel. This surface water flows into the channel area from the reef flats.

Fishermen are commonly seen fishing Tepungan Channel, particularly at the western ends of the two shorter arms where these pass under the causeway. It is not uncommon to see at least half a dozen fishermen at a given time, particularly on the weekends. Sometimes pole-and-line fishermen also wade onto the reef flat to gain access to other parts of the channel. Jacks are apparently the most common fish taken, but other species are no doubt caught as well.

Coral Transplants

In October 1975 small colonies of Porites lutea were collected from Lower Piti Channel near Sta. 23 and transplanted to five sites (Fig. 3A). As reported previously (Marsh and Doty, 1976), the corals at the Cabras outfall site were dead within a month; but corals at all other sites were still alive in April 1976. The corals were not attached to the substrate but were set upright on available surfaces and were thus subject to being overturned and buried by sediments if they were disturbed by currents or fish. One transplant site was a submerged wooden platform near Sta. 14, and the corals at this site are still growing successfully and becoming attached to the substrate by basal growth. Corals at the other sites can no longer be found and have apparently been rolled over and buried in sediment. Several transplanted colonies at the Piti outfall site were still alive as recently as July 1976.

Additional transplants from the coral patch at the end of Flat C were done in December 1975. Artificial reefs were created by piling stones (up to .5 m diameter) on the sandy bottom, and coral colonies were wedged in among the stones but not attached to them. The locations of the three artificial reefs are shown in Fig. 3A. Marsh and Doty (1976) reported that the transplanted corals were still alive in April 1976. By May and June 1976 Pocillopora damicornis at Artificial Reefs II and III began to show signs of stress. In July 1976 this coral was dead at Reefs II and III and was bleached at Reef I. The remaining coral colonies of Porites lutea, Porites cocosensis, Pavona frondifera, Pavona obtusata and Lobophyllia corymbosa were still alive. By August 1976 all the Pocillopora damicornis was dead and the Pavona frondifera was partially bleached at all three reefs. In September 1976 colonies of Acropora formosa were transplanted from Jade Shoals in Apra Harbor to all three reefs. Additional colonies of another species of Acropora were transplanted from Reserve Craft Bay to Reef III. By October 1976 all the Acropora at Reef II were dead and the colonies at Reefs I and III showed signs of bleaching. By January 1977 only Porites lutea was alive at Reef II. The remaining colonies had all been overgrown by algae. At Reef III the two species of Pavona were still alive, as was the Lobophyllia. Reef I had the highest survival rate, with four of the eight transplanted species still alive (Porites lutea, Pavona frondifera, Lobophyllia corymbosa, and Acropora formosa).

In the latter half of July 1976 we discovered small new colonies of Pocillopora damicornis at Reef I and on nearby stable substratum (e.g., the seawall near Sta. 15). The timing of these new sets coincided with the timing of new sets in Piti Canal, on Piti reef flat, and other reef flats of Guam. The source of larvae for the new colonies in the vicinity of Reef I was probably the adult colonies at that reef; it is unlikely that planula larvae could pass through the Piti Power Plant and still remain viable. This suggests that the transplanted colonies were still healthy recently before that time. The new colonies remained alive at least a month but eventually disappeared. New colonies were not seen on the other artificial reefs or elsewhere in the outfall region.

From the temperature data we know that the corals at Reef I are subjected to generally cooler temperatures than those at Reefs II and III. This may account for the greater mortality at the latter two reefs. On the other hand, episodic occurrences of higher-than-usual temperatures may be more significant than general temperature regimes; and such episodic occurrences are more likely to occur at the Cabras Plant than at the Piti Plant, thus having a greater impact on Reefs II and III than Reef I. The corals at all three reefs were stressed in the last week of May 1976 when Typhoon Pamela created considerable disturbance in the outfall area and left them covered with debris and black silt; this was removed one week after the typhoon. All corals were also subjected to a certain amount of siltation under normal conditions and could have been further stressed by being shifted around or grazed upon by fish.

Fish Census

A visual fish count was done in the outfall area near the Piti and Cabras Power Plants as far as Upper Piti Channel. The census was done in April 1977 by swimming back and forth over the survey area and recording the relative abundance of the species seen. The area surveyed was similar to the area surveyed in May 1972 by Jones and Larson (reported in Marsh and Gordon, 1972).

The results of the two surveys are shown in Table 6. There are some minor differences in the species composition and abundances. The number of acanthurids decreased in the 1977 survey. The larger species, *Acanthurus xanthopterus* has remained dominant and was found in small schools throughout the lagoon. An increase in number of species and individuals of the Family Apogonidae was observed. These small fish were usually found in well protected areas, particularly in openings in cement or stone walls in the outfall lagoon. *Paramia quinquilineata* and *Sphaerania orbiculatus* occurred in pairs or groups of three. *Apogon leptocanthus* was found in large schools, particularly along the western end of the lagoon. The absence of *Caranx melampygus* in the 1977 survey may reflect the transitory behavior of these fish. The number of labrid species increased between the two surveys, with *Halichoeres trimaculatus* remaining dominant. In general the numbers of species and individuals have remained constant or increased slightly for most fish families.

The association of a burrowing shrimp (species unknown) sharing a hole with the goby *Obtortiophagus koumansi* is still common, as in the 1972 survey. These organisms constitute the major benthic fauna in the study area. For a description of this shrimp-goby association see Marsh and Doty (1976).

Table 6. A checklist of fishes which compares the ichthyofauna of the Piti and Cabras outfall lagoon in 1972 and 1977. TNTC = Too numerous to count, D = Dominant (10+), C = Common (6-10), P = Present (2-5), R = Rare (1).

Fish Species	1972	1977
ACANTHURIDAE		
Acanthurus lineatus (L.)	R	-
A. triostegus (L.)	D	-
A. xanthopterus Cuvier & Valencinnes	D	D
Ctenochaetus striatus (Quoy & Gaimard)	P	-
Naso unicornis (Forskal)	P	-
Zebrasoma veliferum (Bloch)	P	R
APOGONIDAE		
Apogon leptocanthus Bleeker	P	TNTC
Paramia quinquilineata (Cuvier & Valencinnes)	-	D
Sphaerania orbiculatus (Cuvier)	-	P
AULOSTOMIDAE		
Aulostomus chinensis (L.)	-	P
BALISTIDAE		
Rhinecanthus aculeatus (L.)	P	R
R. rectangulus (Bloch & Schneider)	R	-
R. verrucosus (L.)	-	R
BLENNIIDAE		
Petroscrites mitratus (Ruppell)	P	D
CANTHIGASTERIDAE		
Canthigaster solandri (Richardson)	P	C
CARANGIDAE		
Caranx melampygus Cuvier & Valenciennes	D	-
CHAETODONTIDAE		
Chaetodon auriga Forskal	P	-
C. ephippium Cuvier	C	P
C. lunula (Lacepede)	-	P
C. trifasciatus Mungo Park	P	-
C. ulietensis Cuvier	P	-
ELEOTRIDAE		
Asterropteryx sp.	P	-

Table 6. (continued)

Fish Species	1972	1977
GOBIIDAE		
Amblygobius albimaculatus (Ruppell)	P	P
Gnatholepsis deltoides (Seale)	P	-
Oplopomus oplopomus (Cuvier & Valenciennes)	D	C
Obtortiophagus koumansi (Whitely)	TNTC	TNTC
Penophthalmus keolreuteri (Pallas)	-	C
HOLOCENTRIDAE		
Flammeo summara (Forskal)	-	C
LABRIDAE		
Epibulus insidiator (Pallas)	-	R
Halichoeres centiquadrus (Lacepede)	-	C
H. trimaculatus (Quoy & Gaimard)	C	D
Hemigymnus melapterus (Bloch)	-	R
LEIOGNATHIDAE		
Gerres argyreus (Bloch & Schneider)	P	D
Leiognathus equulua (Forskal)	P	P
LUTJANIDAE		
Lethrinus rhodopterus Bleeker	C	-
Lutjanus monostigmus (Cuvier & Valenciennes)	P	D
L. vaigiensis (Quoy & Gaimard)	C	D
Plectorhynchus pintus (Thunberg)	R	-
Scolopsis cancellatus (Cuvier & Valenciennes)	P	D
MURAENIDAE		
Gymnothorax sp.	-	P
MUGILOIDIDAE		
Parapercis cephalopunctata (Seale)	-	R
MULLIDAE		
Mulloidichthys auriflamma (Forskal)	-	P
M. samoensis (Gunther)	P	P
POMACENTRIDAE		
Abudefduf saxitalis (L.)	-	D
A. coelestinus (Cuvier)	P	C
Dascyllus aruanus (L.)	P	TNTC
Eupomacentrus lividus (Bloch & Schneider)	P	D

Table 6. (continued)

Fish Species	1972	1977
SCARIDAE		
Scarus sordidus Forskal (juveniles)	TNTC	TNTC
Scarus sp.	R	D
SIGANIDAE		
Siganus spinus (L.)	TNTC	C
SPHYRAENIDAE		
Sphyraena sp.	R	R
Sub Totals	37	38
Total	51	

One thing that should be noted is the occasional fish kills in the outfall lagoon which have occurred over the past year. Marsh and Doty (1976) observed several of these fish kills and suspected that they resulted from episodic discharges of chlorine from the power plants. They reported fewer than 25 dead fish per fish kill. Our observations report more than 25 dead fish per fish kill, and in one case over 75 fish were reported dead. Only the larger fish seem to be affected and the major species found dead include Mulloidichthys auriflamma, Lutjanus vaigiensis, Gerres argyreus, Leiognathus equulea, Siganus spinus, Parapercis cephalopunctata and Caranx melampygus. We still believe that the fish kills are the result of periodic chlorine discharges from the power plants.

Zooplankton

Zooplankton tows were made in seven areas (Fig. 35) over a period of six consecutive months, beginning in September 1976. A plankton net with a diameter of 0.5 m and a net mesh of 0.35 mm was used for all tows. The net was towed at a distance of 10 m behind a boat, and the speed of the tow was determined by releasing dye patches from the stern and recording the time it took for the dye patch to reach the mouth of the net. Triplicate dye patches were released for each tow and the mean time was used in calculations. The duration of the tow was also recorded. From these data it was possible to calculate the distance of the tow and the total volume of water filtered. The zooplankton were preserved in 5% formalin for later identification. Results appear in Table 7.

On the basis of total numbers of individual plankters per cubic meter, the Commercial Port area ranked first on four of the five months it was sampled; and either Piti Channel or Reserve Craft Bay had the second highest numbers on five of the six sampling times. Calculated means for each sampling site for all sampling times combined indicated that Commercial Port had the highest numbers of individuals by a considerable margin, followed by Piti Channel and Reserve Craft Bay. No station consistently had the highest volume of zooplankton per cubic meter; but when the 6-month means were calculated for each station it was again the Commercial Port that had the highest ranking by a considerable margin, followed by Piti Channel and Reserve Craft Bay. Hence, the results are consistent and indicate that the Commercial Port station was generally the richest area of those sampled and that Lower Piti Channel was also relatively rich. It should be pointed out that the Commercial Port area sampled was not the area where most ship operations occur but lay in the eastern end of the dredged area adjacent to the rich coral community. The Lower Piti Channel station was also probably influenced by this coral community.

Piti Canal, on the intake side of the power plants, had the smallest number of plankters on four of the five times it was sampled and the lowest average number of plankters for all sampling times

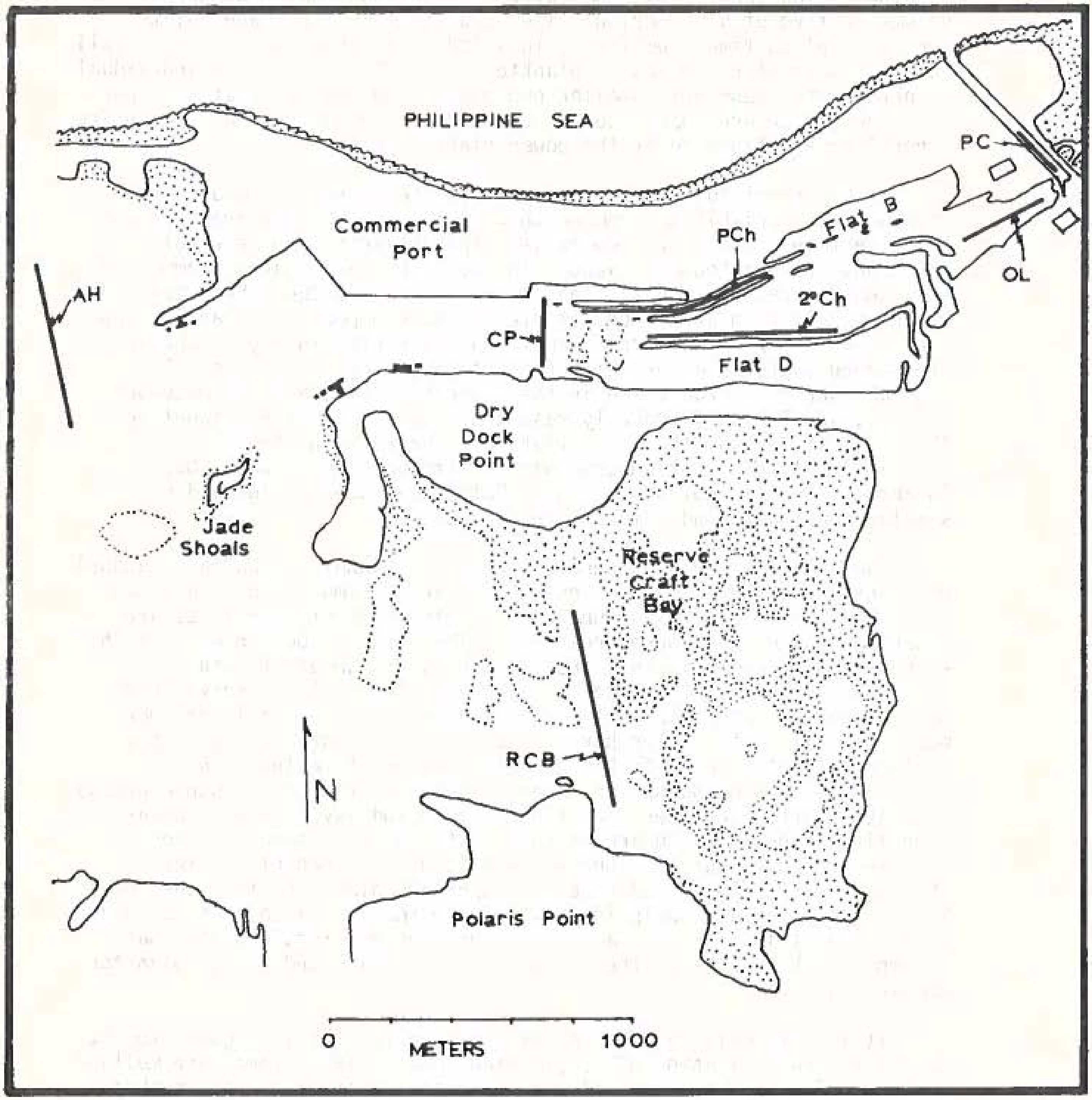

Figure 35. Location of plankton tows. See Table 7 for detailed information.

combined. However, it was the outfall lagoon that had the lowest volume on five of six sampling times and the lowest average volume for 11 sampling times combined. This indicates that, while the outfall lagoon had greater numbers of plankters than Piti Canal, the individual plankters were generally smaller organisms. In any case, it is clear that the intake area has a poorer zooplankton community than the entire general area influenced by the power plant outfalls.

With respect to composition, most of the plankton communities showed great variability from month to month and between areas. However, certain broad trends do exist. The greatest abundances of ostracods and chaetognaths appear in the outer harbor area, Commercial Port and Reserve Craft Bay. The latter area is further characterized by relatively high abundances of pteropods, copepods, crab and shrimp zoeae. The area of Commercial Port usually exhibited high abundances of copepods, pteropods and either chaetognaths or larvaceans. The high abundance of crab zoeae in the Commercial Port area in December, January, and February probably resulted from ebb tides transporting these plankters from the tidal flats and channels in the Piti area. The similarity of plankton communities between Reserve Craft Bay and Commercial Port is not surprising. Both areas are shallow and have similar substrates and temperature regimes.

The Piti area (Piti Channel, Secondary Channel and outfall lagoon) has consistently high abundances of crab and shrimp zoeae. This suggests that these shallow channels and their adjacent tide flats are spawning grounds for these organisms. The highest abundances of fish eggs were also found in this area. This is in agreement with UGML (1977), which showed fish eggs being restricted to the Reserve Craft Bay, Commercial Port, and Piti Channel areas, while fish larvae were most abundant in the outer harbor area. It was suggested that this pattern reflected the life history of a number of marine fishes in which the eggs are spawned in inshore areas and the larvae subsequently migrate to offshore waters for their growth and development. Occasionally, plankton which are characteristic of the Commercial Port area are found in the Piti Channel and Secondary Channel samples. This may result from flood tides transporting plankters from the former to the latter areas. Shipping activity in the area also affects the vertical distribution of plankton communities by disturbing the water column, which results in the mixing of the surface and deeper plankton communities.

It is difficult to draw any overall conclusions in regards to the taxonomic classification of zooplankton communities. There are multiple factors which may have an influence on plankton diversity and number in certain areas. We have not overlooked the possibility of seasonal effects, but month-month variability within samples would tend to mask any subtle seasonal changes.

Table 7. Zooplankton abundance at several sampling sites throughout the study area. Abundances in number per m of water filtered. P.C. = Piti Canal, O.L. = Outfall Lagoon, P.Ch. = Piti Channel, 2°Ch. = Secondary Channel, C.P. = Commercial Port, A.H. = Outer Apra Harbor, RCB = Reserve Craft Bay. See Fig. 35 for sampling locations.

	September 1976						
Organisms	P.C.	O.L.	P.Ch.	2°Ch.	C.P.	A.H.	RCB
foraminiferans	0.70	3.1	-0-	-0-	-	-0-	3.1
medusae	-0-	0.39	-0-	0.12	-	-0-	-0-
pteropods	-0-	-0-	-0-	-0-	-	-0-	0.30
gastropods	0.38	-0-	0.82	-0-	-	-0-	-0-
polychaete larvae	-0-	0.78	-0-	-0-	-	-0-	-0-
ostracods	-0-	-0-	-0-	-0-	-	-0-	-0-
copepods	0.06	78.	22.	13.	-	43.	892.
mysids	-0-	-0-	-0-	-0-	-	-0-	-0-
Lucifer	-0-	-0-	0.41	-0-	-	-0-	-0-
stomatopod larvae	-0-	-0-	-0-	-0-	-	-0-	0.38
crab zoea larvae	0.17	2.7	49.	83.	-	1.5	17.
shrimp zoea larvae	0.09	3.5	11.	4.0	-	3.0	14.
chaetognaths	-0-	-0-	-0-	-0-	-	0.65	9.0
larvaceans	-0-	-0-	-0-	-0-	-	-0-	3.7
fish eggs	0.96	58.	11.	-0-	-	6.9	3.6
fish larvae	0.03	5.4	7.8	1.3	-	1.7	7.8
miscellaneous	0.06	1.2	1.2	-0-	-	-0-	-0-
Total Individuals	2.4	150.	546.	102.	-	57.	951.
Total Volume (ml)	1.4	2.85	2.7	4.0	-	4.25	23.4
Vol./m^3(ml)	0.041	0.032	0.030	0.055	-	0.095	0.28

Table 7. (continued)

Organisms	P.C.	O.L.	P.Ch.	2°Ch.	C.P.	A.H.	RCB
				October 1976			
foraminiferans	1.6	0.03	-	-0-	-0-	1.9	-0-
medusae	-0-	-0-	-	-0-	-0-	0.02	3.3
pteropods	0.02	0.01	-	0.18	18.	4.0	409.
gastropods	-0-	0.02	-	0.50	-0-	0.22	-0-
polychaete larvae	0.14	0.02	-	-0-	-0-	-0-	-0-
ostracods	-0-	-0-	-	-0-	-0-	4.0	-0-
copepods	0.70	1.1	-	1.1	1470.	0.71	31.
mysids	-0-	-0-	-	-0-	-0-	0.02	7.4
Lucifer	-0-	0.01	-	-0-	-0-	0.04	9.8
stomatopod larvae	-0-	-0-	-	-0-	-0-	-0-	-0-
crab zoea larvae	0.82	3.1	-	45.	0.39	2.7	266.
shrimp zoea larvae	0.27	1.0	-	13.	0.39	0.26	23.
chaetognaths	0.02	-0-	-	0.51	3.11	5.0	54.
larvaceans	0.02	-0-	-	-0-	38.	6.0	5.8
fish eggs	1.7	2.5	-	-0-	1.2	3.3	-0-
fish larvae	0.02	0.06	-	0.26	-0-	0.07	2.5
miscellaneous	-0-	0.02	-	0.04	-0-	0.02	2.4
Total Individuals	5.4	7.9	-	61.	1530.	28.	814.
Total Volume (ml)	1.3	1.7	-	3.2	29.6	2.1	78.0
Vol./m^3 (ml)	0.029	0.019	-	0.031	0.32	0.038	0.90
				November 1976			
foraminiferans	1.1	1.3	-0-	0.09	-0-	-0-	0.33
medusae	0.05	-0-	-0-	1.3	4.0	-0-	-0-
pteropods	0.05	-0-	765.	30.	3920.	11.	34.
gastropods	-0-	-0-	85.	-0-	10.	-0-	0.26
polychaete larvae	0.09	-0-	-0-	-0-	-0-	2.1	-0-
ostracods	0.09	-0-	2.00	-0-	4.0	9.1	0.09
copepods	2.0	0.04	903.	1.6	26.	5.1	4.7
mysids	0.09	-0-	-0-	-0-	-0-	0.18	-0-
Lucifer	-0-	-0-	45.	0.01	8.0	0.63	0.60
stomatopod larvae	-0-	-0-	-0-	-0-	-0-	-0-	-0-
crab zoea larvae	1.4	2.7	82.	23.	4.0	12.	22.
shrimp zoea larvae	-0-	0.09	17.	0.90	2.0	7.1	22.
chaetognaths	-0-	-0-	8.0	1.5	-0-	14.	32.
larvaceans	-0-	-0-	6.2	1.7	46.	1.4	0.09
fish eggs	8.25	2.4	6.0	3.8	2.0	0.36	0.66
fish larvae	-0-	0.04	2.0	0.36	-0-	0.18	0.71
miscellaneous	0.19	0.03	-0-	-0-	-0-	0.09	-0-
Total Individuals	13.	6.6	1920.	64.	4030.	64.	118.
Total Volume (ml)	2.4	0.9	240.	10.4	255.	7.8	12.8
Vol./m^3 (ml)	0.11	0.011	1.6	0.13	3.1	0.10	0.084

Table 7. (continued)

Organisms	P.C.	O.L.	P.Ch.	2°Ch.	C.P.	A.H.	RCB
				December 1976			
foraminiferans	-	0.52	-0-	1.2	-0-	-0-	-0-
medusae	-	-0-	0.62	0.04	2.6	5.0	1.3
pteropods	-	0.11	100.	2.1	102.	18.	47.
gastropods	-	-0-	8.4	0.04	0.96	3.1	-0-
polychaete larvae	-	-0-	-0-	-0-	0.32	-0-	0.22
ostracods	-	-0-	0.93	0.09	3.2	97.	2.2
copepods	-	0.38	363.	-0-	9.3	28.	6.8
mysids	-	-0-	-0-	-0-	-0-	-0-	0.22
Lucifer	-	0.02	33.	0.09	14.	-0-	1.3
stomatopod larvae	-	0.03	-0-	-0-	-0-	0.63	0.22
crab zoea larvae	-	17.	66.	5.7	18.	1.9	56.
shrimp zoea larvae	-	0.63	58.	0.22	25.	3.1	9.1
chaetognaths	-	-0-	13.	-0-	8.0	152.	64.
larvaceans	-	-0-	5.6	0.04	1.6	6.9	3.5
fish eggs	-	1.8	19.	4.6	3.8	-0-	3.5
fish larvae	-	0.26	0.93	0.85	0.32	2.5	0.88
miscellaneous	-	0.01	-0-	-0-	1.3	-0-	-0-
Total Individuals	-	20.	670.	15.	191.	318.	196.
Total Volume (ml)	-	1.5	16.1	3.9	5.9	28.2	16.6
Vol./m^3 (ml)	-	0.024	0.18	0.060	0.13	0.36	0.13
				January 1977			
foraminiferans	1.2	2.0	-0-	0.08	-0-	-0-	-0-
medusae	-0-	-0-	-0-	0.09	0.40	-0-	0.83
pteropods	-0-	-0-	8.5	1.7	264.	4.2	257.
gastropods	-0-	-0-	15.	-0-	1.8	-0-	0.06
polychaete larvae	-0-	0.31	-0-	-0-	-0-	0.09	-0-
ostracods	-0-	-0-	11.	2.1	41.	41.	-0-
copepods	0.92	6.5	139.	12.	217.	30.	13.
mysids	-0-	-0-	-0-	-0-	-0-	-0-	2.7
Lucifer	-0-	-0-	19.	-0-	8.0	0.56	1.7
stomatopod larvae	-0-	-0-	-0-	-0-	-0-	-0-	-0-
crab zoea larvae	0.88	3.0	57.	15.	22.	2.1	148.
shrimp zoea larvae	0.20	1.7	14.	9.3	6.1	2.9	16.
chaetognaths	-0-	-0-	10.	0.67	17.	32.	92.
larvaceans	-0-	-0-	4.3	-0-	0.70	3.9	4.2
fish eggs	2.2	7.6	3.8	2.4	1.1	0.16	1.5
fish larvae	0.01	0.71	1.1	0.75	0.08	2.3	2.4
miscellaneous	-0-	0.03	0.2	-0-	0.03	-0-	0.19
Total Individuals	5.3	22.	284.	44.	581.	120.	540.
Total Volume (ml)	1.1	1.3	8.1	4.7	14.3	6.3	11.9
Vol./m^3 (ml)	0.024	0.015	0.089	0.59	0.16	0.081	0.14

Table 7. (continued)

	February 1977						
Organisms	P.C.	O.L.	P.Ch.	2°Ch.	C.P.	A.H.	RCB
foraminiferans	0.82	0.51	-0-	0.12	-0-	-0-	-0-
medusae	-0-	-0-	-0-	-0-	0.22	-0-	-0-
pteropods	-0-	-0-	0.91	0.43	194.	3.4	104.
gastropods	0.12	-0-	2.7	-0-	0.76	-0-	-0-
polychaete larvae	-0-	0.04	-0-	-0-	-0-	-0-	-0-
ostracods	-0-	-0-	0.70	-0-	2.9	60.	1.7
copepods	1.2	0.29	157.	0.96	170.	43.	89.
mysids	-0-	-0-	-0-	-0-	0.13	-0-	-0-
Lucifer	-0-	-0-	1.4	-0-	20.	-0-	0.91
stomatopod larvae	-0-	-0-	-0-	-0-	-0-	-0-	-0-
crab zoea larvae	0.70	3.4	26.	5.7	57.	1.9	127.
shrimp zoea larvae	0.03	1.8	9.2	1.3	5.3	0.82	11.
chaetognaths	-0-	-0-	9.4	0.24	14.	47.	72.
larvaceans	-0-	-0-	6.8	-0-	2.4	13.	4.0
fish eggs	3.7	5.1	5.0	1.9	2.0	-0-	2.6
fish larvae	-0-	0.07	-0-	-0-	0.61	1.9	0.32
miscellaneous	-0-	0.07	-0-	-0-	-0-	-0-	0.03
Total Individuals	6.5	11.	220.	11.	470.	171.	413.
Total Volume (ml)	1.3	0.7	6.1	2.7	19.5	12.2	16.4
Vol./m^3 (ml)	0.032	0.008	0.042	0.026	0.24	0.16	0.19

OTHER OBSERVATIONS

Occasional spot checks of daytime surface dissolved oxygen levels have been made at five stations in the study area over four years. Data for five stations are presented in Table 8. The value reported for Sta. 1 (intake) for the 1973 survey was taken at 1425 hours, 24 August 1972. The value reported for the Piti Power outfall location (Sta. 12) for the 1973 survey was taken at 1400 hours, 24 August 1972. Since dissolved oxygen determinations for the 1974 report were taken at irregular intervals during daylight hours, the value reported for Station 24 (Commercial Port) represents the mean of four readings taken on 27 June 1973, 18 September 1973, 11 October 1973, and 5 February 1974. The values at Stations 15, 12 (Piti outfall) and 21 in Table 8 represent the means of three readings taken on 1 November 1973, 4 December 1973 and 16 January 1974. The value for Station 1 represents a single reading taken 16 January 1974. Reported data from the 1975 survey for Stations 24, 15 and 21 were taken at 1500 hours, 22 June 1975. Data for the 1977 survey were taken at all five stations between 1300 and 1500 hours, 27 May 1977.

A Two-Way Analysis of Variance test showed no significant differences in dissolved oxygen concentrations between stations or

Table 8. Dissolved oxygen values (mg/l) at five locations in the study area over four years. Dissolved oxygen values are the means of two titrations each from two DO bottles (total of four titrations). See Fig. 3A for station locations.

Date of Report	STATIONS Sta. 24	Sta. 1	Sta. 15	Sta. 12	Sta. 21
1973	-	9.87	-	7.28	-
1974	6.24	6.91	6.69	6.67	6.57
1975	6.87	-	7.58	-	8.18
1977	6.43	7.24	6.97	7.09	6.82

years (P>.001). It is also apparent from the data that the dissolved oxygen values at all stations for the four years exceed 100% saturation. The fact that oxygen levels in the study area exceed saturation levels during sunny days indicates a healthy state, with power plant operations having no adverse effects on the levels of dissolved oxygen.

It should be noted that only one dissolved oxygen determination was done at the Cabras Plant outfall (27 May 1977, 1330 hours). The value recorded (6.98 ppm) was well above saturation value and within the range of values reported in Table 8 for other stations in the study area.

Samples for reactive phosphorus were taken on two sampling dates in 1973 at various stations in the study area (Marsh and Gordon, 1974). Additional sampling done in 1977 showed no significant changes in reactive phosphorus at stations duplicated from the former sampling time. The lowest recorded values for 1973 and 1977 were 0.12 and 0.10 microgram-atoms per liter (μg-at P liter^{-1}) respectively, at Station 24 (Fig. 3A). The highest value recorded in 1973 was 0.50 μg-at P liter^{-1} at an area adjacent to the point where raw sewage from the Piti Plant enters the outfall lagoon. The 1977 value for this area was 0.22 μg-at P liter^{-1}.

A comparison of samples for nitrite- and nitrate-nitrogen taken in January 1974 and May 1977 showed similar results at duplicated stations. All nitrite values were still below detectable limits. Nitrate values for 1977 ranged between 0.14 and 0.37 μg-at N liter^{-1}. This is within the same order of magnitude as the 1974 data. The spot checks for nitrogen, like those for phosphorus, reveal no changes since the Cabras Plant began operations.

On 22 May 1976 Typhoon Pamela passed over Guam with winds in excess of 180 mph. The damage sustained in the study area had only short term effects. As previously mentioned in the report, lower than normal minimum temperatures at some stations, particularly the tide flats, were reported. Both the Cabras and Piti Power Plants were temporarily shut down. On 1 June 1976 both Piti Plant outfalls were reported operational. Only Unit 1 of the Cabras Plant was operational at least two months after the typhoon. The Cabras outfall showed a light current and a thin surface layer of heated water at Station 16. There did not appear to be any increase in previously recorded temperatures at the outfall areas upon continued operations of the power plants.

The physical damage to the areas was extensive. Debris, particularly limbs, twigs and leaves of the tree *Casuarina equisetifolia*, was seen scattered throughout the outfall lagoon and Piti Channel. The detritus settled on the bottom and was partially buried, apparently undergoing decay and exerting an oxygen demand on the interstitial·waters...As a result, a black anaerobic sediment layer appeared much nearer the surface of the sediments than usual occurring within a few centimeters of the loose surface. Some shifting in the shoreline, tidal flats and sand bars also occurred, and many of the Casuarina trees toppled into the water. Approximately 1 1/2-2 months after the storm, the area had more or less recovered and for all practical purposes was restored to its previous condition.

There continues to be significant recreational use of the general study area as was reported by Marsh and Doty (1976). Records furnished by the Division of Fish and Wildlife, Dept. of Agriculture, Guam and observations made during weekly sampling times, indicate that fishing frequently occurs in the area. Pole-and-line fishermen were usually seen at the western end of Piti Channel where it meets with the dredged area of Commercial Port. Net fishermen were occasionally sighted on the tidal flats. The most common use is as a picnicking area, especially on weekends. Fourteen consecutive weekend checks of the area showed between 7 and 18 persons picnicking at any given time. The outfall lagoon is used as a mooring facility by sailboat owners. There are an average of six boats moored in the lagoon at any given time. This number increases during storm conditions.

A recording tide gauge was operational in the outfall lagoon at a point indicated in Fig. 3A for several weeks between March and May 1977. A typical daily record is presented in Fig. 36. A standing wave can be clearly seen superposed on the tidal curve, thus leading to changes in water level besides those induced by the tide. There is a tendency for the standing wave to be damped out during the lower low water of each 24-hour record. During other phases of the tide the standing wave has a height ranging from 0.1 to 0.35 feet and usually falling between 0.2 and 0.3 ft. The period (time from crest to crest) of the standing wave is consistent and is approximately 44 minutes. We do not know if this standing wave also occurs in the Commercial Port area or Outer Apra Harbor, but previous filed observations cause us to think that it does occur on Flat C.

Finally, on at least three occasions there was an observable change in the Cabras effluent water. The water of the Cabras outfall is usually clear, however, on these three occasions the water became extremely turbid (visibility <1 m) and rust colored particulate matter could be seen drifting downstream. This condition lasted approximately 10 minutes and then returned to normal. It is not known how frequent these discharges are or possible effects they may have on the surrounding environment.

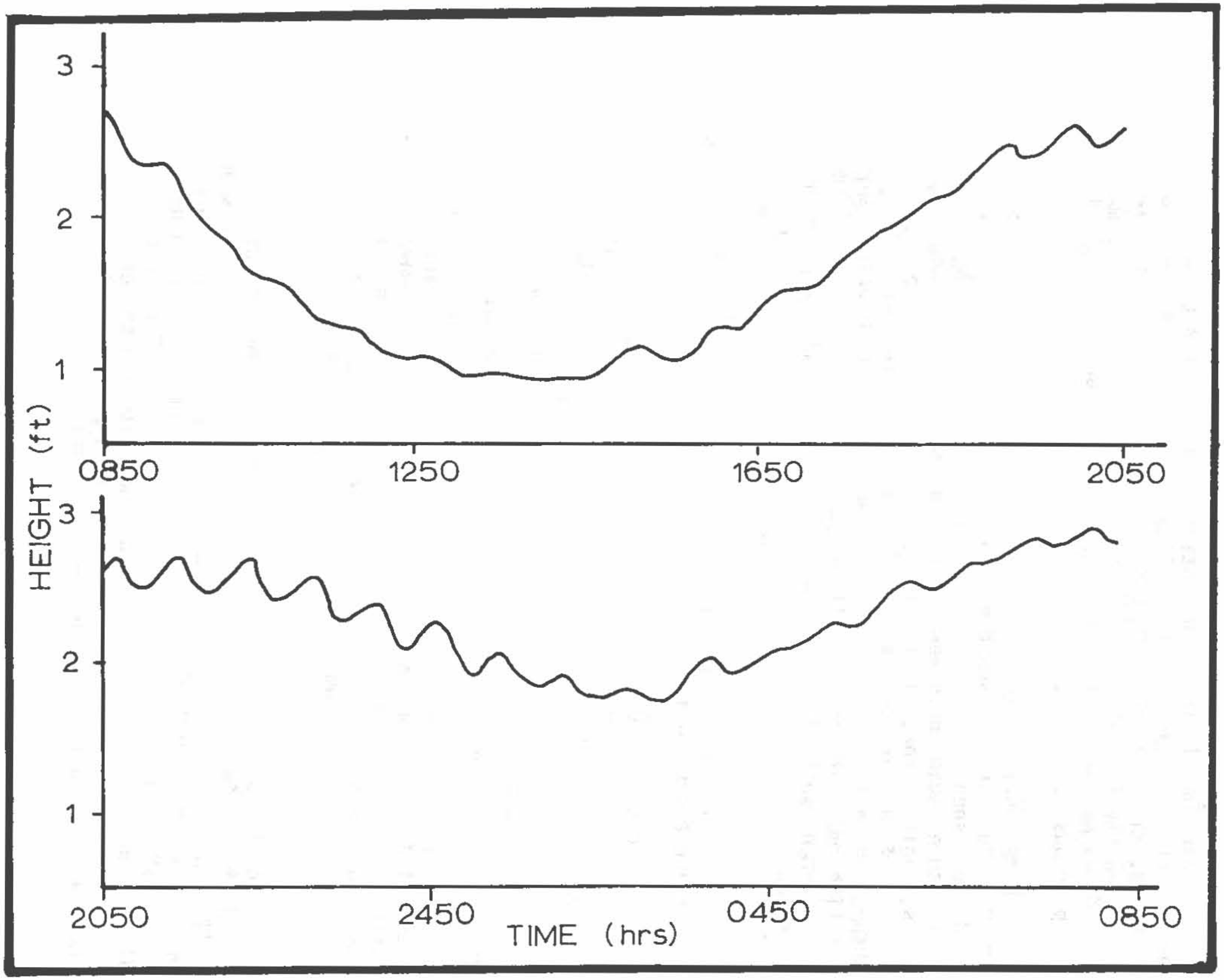

Figure 36. Typical daily tide cycle in the study area. See Fig. 3A for location of tide gauge.

SUMMARY AND CONCLUSIONS

When these studies began it was realized that before-and-after evaluations of the impact of the Cabras Power Plant would be very difficult if these depended primarily on biological observations. Biological communities have a great deal of natural variability and may exhibit year-to-year or seasonal changes even when they are not subject to man-caused or natural stresses. We have reported a number of examples in this and earlier reports. For instance, there is the natural die-off of the brown algae Sargassum and Turbinaria which grow so luxuriantly just behind the reef margin of West Piti Bay part of the year and then die off in the summer months with low-tide exposure to the air. We have noted the particularly heavy set of juvenile Diadema urchins that occurred one year and eventually came to be more strongly represented in the adult population than other year classes. We noted the heavy set of new colonies of the coral Pocillopora damicornis that occurred in only one year out of five, not only in our study area but throughout Guam. Another example is provided by the annual runs of rabbitfish, Siganus, which may be very heavy some years and practically nonexistent other years. These examples should suffice to point out that natural variability is the rule rather than the exception. Any attempts to assess human-caused stress must take this natural variability into account. Two natural stresses which occurred during our studies were episodic abnormally low tides, in the last months of 1972, and Typhoon Pamela, which struck Guam in May 1976. The former stress was more biologically significant than the latter in West Piti Bay; because of the depauperate nature of the outfall area, neither stress had serious impact there. Because of the short-term, one-time occurrence of these stresses, it was much easier to evaluate their impact than the impact of any long-term, lower-level stress caused by the power plants.

The realization of natural biological variability influenced early thinking and design for this study. It was realized that biological observations in themselves were not sufficient and might not even be the most important observations to be made. It was considered necessary to have extensive before-and-after temperature observations in the outfall region so that any observed biological changes could be compared to observed temperature changes, thus deemphasizing natural biological variability as an explanation. If it were observed that new Cabras Plant operations did not expand particular thermal regions beyond the pre-existing conditions with only the Piti Plant operating, then Cabras Plant influence could be eliminated as a cause if biological changes were observed. Moreover, because of sampling problems and the primitive state of knowledge about many organisms in the tropics generally and Guam in particular, the detection of biological changes was considered likely to be more difficult to document than changes in the temperature regime. This would be particularly so if the changes were subtle, since subtle biological changes are more likely to be masked by sampling and random "variation" than are temperature changes. Hence, an early decision was made to emphasize temperature observations as much as biological observations. This decision appears to have been correct. There have apparently been no major temperature changes since the Cabras Plant began operation. Thus, any biological changes which occurred are not attributable to the thermal impact of the power plants. In fact, we have not observed any major biological changes in the outfall area in the last five years.

Cabras Power Plant effluent temperatures commonly range up to 36° and have been observed to go as high as 37°C, as compared with intake temperatures which are generally less than 32°, often less than 30°, but which did go to 34° on one occasion. Prevailing Cabras outfall temperatures are higher than Piti outfall temperatures were previously (usually less than 33°) or are now (usually less than 31 or 32°). The higher Cabras temperatures are confined to an area near the outfall and have not resulted in an extension of the areas enclosed by specific isotherms elsewhere in the study region. There has been no significant upward temperature shift at a station approximately 325 m downstream of the Cabras outfall. A distinctive plume from the Piti Plant could often be delineated on Flat B before Cabras operations began, and a plume from the Cabras Plant can now be distinguished on that flat.

Solar heating is significant on the tidal flats and can raise temperatures as high as the effluent water from the Cabras Plant. However, the natural cycle is such that temperatures on Flat D, unaffected by the power plants, often drop to 26°C at night. Temperatures on Flats B and C are influenced by the power plants, Flat B more so than Flat C, and have less daily variation than does Flat D. There are seasonal variations, not exceeding 2 or 3°C, at the intakes, outfalls, tidal flats, and channels. Daily and seasonal variations are smaller on Flat B than Flat C and smaller on Flat C than Flat D. Higher temperatures are correlated with the daytime occurrence of low spring tides and lower temperatures fall in the months when these low tides occur at night. Average temperatures, as calculated from observations with maximum/minimum thermometers, are higher on the tidal flats than in the channels during the summer months but not the rest of the year. Flat B has the highest average temperature of the three tidal flats and Flat D the lowest. The power plants impose a more constant temperature on the outfall area than would otherwise occur. This more constant temperature is in the upper part of the natural range, but plant-induced maxima are not higher than natural maxima.

Flat B has the lowest elevation of the three tidal flats and is not exposed to the air by low tides. Flat D has the highest elevation and much of it is exposed. The eastern portion of Flat C is also exposed at low tides. There is direct movement of water from the Cabras outfall onto Flat B. Dye studies show that a significant amount of effluent water also moves onto Flat C. A small portion of water from the power plants might move very slowly onto Flat D under some tidal conditions, but this has no significant influence on the thermal regime there. There is no evidence for an increase in current velocities in Lower Piti Channel since the Cabras Plant began operations, and there is still an occasional flow reversal there on strongly-rising tides. Flow reversals also occur in the Secondary Channel and at the western end of Flat D. Records from a tide gauge in the outfall lagoon revealed a standing wave, and this standing wave probably affects the tidal flats as well.

The most biologically diverse area in the outfall region is a patch reef at the western end of Flat B. This contains the coral species Pavona frondifera, which has not been found anywhere else on Guam. The next most biologically diverse areas are the portion of the outfall lagoon immediately adjacent to the Piti outfalls and Lower Piti Channel. The dominant biological feature of much of Piti Channel is a burrowing shrimp-goby association; the sponge Spirastrella vagabunda and the green alga Halimeda opuntia are also very common there. The sponge is also common on the tidal flats, as are the seagrass Enhalus acoroides and various burrowing organisms. Algae, crustaceans, and molluscs occur throughout the outfall region and have very patchy distributions. Despite differential influence of the power plants on the three tidal flats, they are biologically similar. Plankton tows suggest that the area south and west of GORCO pipeline is a spawning area for fish and crustaceans. Visual fish transects in the outfall lagoon before and after the Cabras Plant began operations showed no distinctive differences. Overall, there is no evidence for significant biological changes in the outfall region since the onset of Cabras Plant operations.

Transplanted corals showed best survival at a station in the outfall lagoon downstream of the Piti Plant but upstream of the Cabras Plant, poorest survival at a station in Upper Piti Channel approximately 325 m downstream of the Cabras Plant, and intermediate survival at a station in Lower Piti Channel. The laboratory experiments of Jones, Randall, and Wilder (1976) indicate upper tolerance limits for most corals between 30 and 33°C, so it may be concluded that the thermal influence of the power plants would be a significant factor excluding corals from the area even if conditions were otherwise favorable for coral growth. However, other factors inhibit or prevent coral growth over much of the outfall region. Much of the substrate is shifting sediment which is too unstable for coral growth, and low-tide subaerial exposure of large areas of the tidal flats prevents such growth there. Other physical factors influencing the biological composition of the region include water motion and the amount of suspended material in the water. The power plants obviously increase water circulation and probably enhance water clarity in the outfall lagoon and Piti Channel by sweeping away the finer suspended particles. These are beneficial factors for some organisms and inhibitory factors for others. In general, the thermal impact of the power plants has a negative influence on biological communities in the outfall lagoon and Upper Piti Channel but is only one of several factors influencing those communities. We have found no evidence that the thermal impact alone is excluding organisms that would otherwise be present.

Episodic events are probably the most important consideration from the standpoint of environmental impact of both the Piti and Cabras Power Plants. For instance, this report describes fish kills which we have commonly found in the outfall area in the past year, just as has been reported previously. We suspect that these fish kills result from excess chlorine or other chemicals being used in the cooling water system and being allowed to escape into the outfall lagoon. The incident of rust-colored effluent being released from the Cabras Power Plant, discussed earlier in this report, indicates that chlorine is not the only chemical released. Because fish kills are usually discovered only after the fact, it is difficult to link them to specific episodes at the power plants.

Release of chemicals may not be the only episodes of significance. Last year (Marsh and Doty, 1976) we presented continuous temperature recordings made at the Cabras outfall and noted sudden rises or drops of as much as 2°C in the temperature record. We attributed this to the switching in or out of parallel circulating pumps in the cooling-water system. The temperature shock thus caused to organisms in the outfall area could be more significant than gradual temperature changes. Moreover, these records indicate that power plant management has some control over effluent temperatures. Proper management can do much to minimize the thermal impact of plant operations if there is a commitment to do so.

Occasional checks of dissolved oxygen, reactive phosphorus, and inorganic nitrogen compounds showed no before-and-after differences associated with the Cabras Power Plant.

The outfall region is utilized fairly extensively as a recreational area. Net fishermen and pole-and-line fishermen are often seen. A number of picnickers use the area on weekends. The outfall lagoon is utilized as a sailboat anchorage, particularly during storms.

Construction activities associated with the building of the Cabras Power Plant have probably had a more serious and lasting environmental impact to date than have plant operations. The negative impact has been primarily on the intake side, and much of it was due to a bulldozer operating outside the prescribed area when dredging operations in Tepungan Channel were nearly completed. This damage could have been avoided if Guam Power Authority and its contractors had been more careful in following the recommendations made in the original report early in this study (Marsh and Gordon, 1972). In fact, these recommendations were incorporated into the dredging permit issued to Guam Power Authority by the U. S. Army Corps of Engineers but were not carefully followed. The environmental damage resulted in little or no benefit to Guam Power Authority or its contractors.

There was also heavy siltation in the Piti Channel outfall region during construction. The impact was not as serious here, since the bottom was already composed primarily of shifting sediments and did not support a particularly diverse benthic community. The area had been extensively dredged and altered before construction of the Cabras Plant began. Post-construction biological recovery to the previous state was fairly rapid and complete; and the area now is much the same as it was before construction began. Hence, construction impacts were minimized because of the nature of the site chosen.

Some comments on methodology are in order. As noted in the section above, our temperature data were gathered using three basic approaches. Of the recording devices, the Ryan thermographs were totally unrealible and gave temperature readings which were clearly wrong; no amount of tampering succeeded in remedying this. The high purchase price of these instruments was not justified. The Dickson "minicorders" could measure temperature only within a 2-m radius and were mounted on floats anchored in situ, with the recorder enclosed in a box for protection. The devices gave some useful data, and tracings from them were presented in previous reports (Marsh and Gordon, 1973, 1974). However, they were not really suitable for use in salt water and deteriorated rapidly. The YSI telethermometer with recorder worked moderately well where it could be mounted in a stable position on the shore and where line power was available. It could not be used throughout the study area because the thermistor probes were not long enough. The use of a battery-powered recorder would have alleviated this problem somewhat, but the entire study area could have been covered only by expending a considerable amount of money for additional instruments. Some representative data from the telethermometer were presented by Marsh and Doty (1976). In general, the information obtained from the use of continuously recording devices did not justify the expense and effort involved.

The synoptic isotherm plots, surface temperature measurements with a bucket thermometer or battery-powered telethermometer, were utilized extensively in this and previous reports to describe temperature regimes before and after the Cabras Plant began operations and to draw conclusions about its impact. These data can be relatively precise but necessitate a large expenditure of time and labor to get a comprehensive coverage.

A third kind of temperature data were obtained by placing a number of maximum/minimum thermometers at various sites and reading and resetting these on a periodic (usually weekly) basis. These instruments are relatively inexpensive, and their use can result in a reasonably large amount of data over a period of time. The data so obtained are good at showing general trends and require a comparatively small investment in time. They are particularly useful when plotted according to the method designed by Doty and presented in Figs. 8 and 9 of this report. It is gratifying and useful to know that the various data obtained by the three general methods led us to similar conclusions. At this point, we would feel justified in relying primarily on data from the maximum/minimum thermometers, with occasional telethermometer observations to allow isotherm plots and vertical profiles.

Finally, while our studies have dealt only with the marine environment, we suspect that the most serious long-term environmental problem associated with power plant operations at the Piti site is the impact on air quality.

RECOMMENDATIONS

1. All cooling-water pumps should be run at maximum capacity during the daytime and early evening hours, when the plant load is greatest. Outfall temperatures should be carefully monitored and used as a guideline for operating the pumps. Careful management can insure that effluent temperatures are kept to the lowest possible level and that episodic high-temperature incidents are avoided.

2. The episodic release of chlorine and other chemicals should be investigated by management and eliminated if possible. In any case, the levels of chlorine used in the condensers should be carefully monitored and held to minimum possible values to prevent excess residual in the effluent stream. Since the use of chlorine is apparently a routine procedure, analysis of the effluent stream in the outfall channel should also be a routine procedure with each usage. When there is any release of any chemicals the effluent stream should be sampled in the outfall channel and analyzed by plant chemists, with the results kept on file. The Guam Environmental Protection Agency and Guam Division of Fish and Wildlife should be notified when release of chemicals is anticipated to allow them to evaluate the impact in the outfall lagoon.

3. Maximum/minimum thermometers should be placed in the water adjacent to the intake and outfall sites and read periodically by plant personnel. Daily readings should be considered, and the readings should be spaced no longer than a week apart in any case. It would be desirable to place thermometers at additional sites in the outfall lagoon as a routine monitoring procedure.

4. Plant personnel should be given sufficient training to appreciate the necessity for careful operations and environmental protection. If plant management shows sufficient concern and motivation, negative environmental impacts can be minimized.

5. Guam Power Authority should adopt an administrative procedure for insuring that plant operations are periodically evaluated for environmental impact and that they adhere to regulatory agencies' water quality standards as these are updated.

6. Plant personnel should be instructed that the marine environment adjacent to the plant site is not to be used as a site for dumping debris. Underwater areas adjacent to the site should be periodically inspected and cleaned up by plant personnel.

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APPENDIX

Tables A-1 and A-2 give a qualitative listing of organisms found in the Piti-Cabras outfall study area between April 1972 and March 1977. Some of the organisms listed appeared as a single occurrence and may not presently be found in the study area. Any organisms now in the study area and not appearing in the tables may be recent additions and therefore would not be included.

The area locations appear in Fig. 2 . Area I includes the Cabras and Piti outfalls and the adjacent lagoon. Area II encompasses the area of Piti Channel from Station 18 to Station 23. Area III includes Tidal Flats B, C and D, and the western end of the Secondary Channel. Area IV consists of a patch reef located directly east of the dredged area of Commercial Port.

Much of the data were obtained while doing routine field observations during the past year, while some were compiled from previous technical reports (see References Cited). It should not be assumed that these tables are complete because individual species may have been overlooked while census were being made.

Table A-1. A checklist of marine plants found in the Piti-Cabras outfall study area between April 1972 and March 1977.

	AREA I	II	III	IV
Division Cyanophyta				
Hormothamnion enteromorphoides B. & F.	X			
Microcoleus lyngbyaceus (Kutz.) Crouan	X	X	X	X
Rivularia polyotis Bornet & Flahault		X	X	
Schizothrix calcicola (Ag.) Gomont		X	X	
Schizothrix mexicana Gomont	X	X		
Division Chlorophyta				
Avrainvillea obscura J. Ag.	X	X	X	
Caulerpa racemosa (Forssk.) J. Ag.				X
Caulerpa serrulata (Forssk.) J. Ag.				X
Chaetomorpha indica Kutz.	X			
Enteromorpha clathrata (Roth) J. Ag.			X	
Halimeda macroloba Decaisne		X	X	X
Halimeda opuntia (L.) Lamx.	X	X	X	X
Division Phaeophyta				
Dictyota bartayresii Lamx.	X	X		X
Hydroclathrus clathratus (C. Ag.) Howe	X			
Feldmannia indica (Sonder) Womersley & Bailey		X		
Padina tenuis Bory	X	X	X	X
Sargassum polycystum C. Ag.	X			
Sphacelaria tribuloides Meneghini				X
Division Rhodophyta				
Champia sp.	X	X	X	
Gelidiella cf. myriocladia (Boerg.)	X		X	
Gelidiopsis intricata (Ag.) Vickers		X		X
Gracilaria salicornia (Mert.) Grev.	X	X		X
Hypnea esperi Bory	X	X	X	X
Jania capillacea Harvey				X
Levellea jungermanniodes Harvey				X
Polysiphonia tepida Hollenberg	X	X	X	X
Rhodymenia sp.	X			
Spyridia filamentosa (Wulfen) Harv.			X	
Division Anthophyta				
Enhalus acoroides (L.f.) Royle			X	
Halophila minor (Zoll.) Hartog	X		X	

Table A-2. A checklist of the macroinvertebrates found in the Piti-Cabras outfall study area between April 1972 and March 1977.

	AREA			
	I	II	III	IV
Phylum Porifera				
Cinachyra australiensis (Carter)				X
Spirastrella vagabunda (Ridley)	X	X	X	X
Terpios sp.				X
Phylum Cnidaria				
Class Scyphozoa				
Cassiopea andromeda (Forskal)	X		X	
Class Anthozoa				
Family Pocilloporidae				
Pocillopora damicornis (L.)				
Family Agariciidae				
Pavona decussata Dana				X
Pavona frondifera (Lamarck)				X
Pavona (Polyastra) obtusata (Quelch)				X
Family Poritidae				
Porites andrewsi Vaughan				X
Porites australiensis Vaughan				X
Porites cocosensis Wells				X
Porites lutea Milne Edwards & Haime	X	X	X	X
Porites (Synaraea) convexa Verrill				X
Porites (Synaraea) iwaymaensis Eguchi				X
Family Faviidae				
Leptastrea purpurea (Dana)				X
Family Oculinidae				
Galaxea clavus (Dana)				X
Phylum Annelida				
Eurythoe sp.		X		
Sabellastarte indica (Savigny)	X			X
Phylum Mollusca				
Class Gastropoda				
Family Cerithidae				
Cerithium morus Bruguiere			X	
Cerithium nodulosum Bruguiere	X	X		
Cerithium ravidum Philippi	X	X		
Family Conidae				
Conus rattus Bruguiere	X			

Table A-2. (continued)

	AREA I	II	III	IV
Family Cymatiidae				
Cymatum nicobaricum (Roding)	X	X		
Cymatum pileare (L.)	X			
Family Cypraeidae				
Cypraea annulus L.	X			
Cypraea erosa L.	X			
Cypraea margarita Dillwyn	X			
Cypraea moneta L.	X	X		
Cypraea tigris L.	X	X	X	
Family Littorinidae				
Littorina scabra (L.)	X		X	
Family Muricidae				
Drupa fragum Roding		X		
Drupa ricina L.	X			
Morula triangulatum (Pease)		X		
Morula uva (Roding)		X	X	
Family Naticidae				
Natica qualtieriana Recluz	X			
Polinices pyriformis Recluz	X	X		X
Family Neritidae				
Nerita albicilla L.	X	X		
Nerita plicata L.	X			
Nerita polita L.		X		
Family Patellidae				
Patella sp.	X			
Family Phenacolepatidae				
Phenacolepas crenulata (Broderip)	X	X	X	
Phenacolepas sp.		X		
Family Planaxidae				
Planaxis sulcatus (Born)	X	X	X	
Family Strombidae				
Lambis lambis (L.)	X	X		X
Strombus luhuanus L.	X	X		X
Strombus mutabilis Swainson	X	X		
Family Trochidae				
Trochus niloticus L.	X	X		
Family Vasidae				
Vasum turbinellus L.	X	X		

Table A-2. (continued)

	AREA I	AREA II	AREA III	AREA IV
Class Amphineura				
Acanthochitin sp.	X	X		
Class Bivalvia				
Charma sp.		X	X	
Crassostrea culculletta		X	X	X
Gafrarium tumidum L.		X	X	X
Isognomon sp.		X	X	X
Malleus malleus (L.)		X	X	X
Pinna sp.	X	X		X
Septifer bilocularis L.		X	X	
Phylum Arthropoda				
Class Crustacea				
Calappa hepatica L.	X	X		
Calcinus elegans (H. Milne Edwards)	X			
Calcinus laevimanus (Randall)	X			
Calcinus latens (Randall)	X	X	X	
Cardiosoma sp.	X	X	X	X
Carpilius maculatus (L.)			X	
Clibanarius humilis (Dana)	X	X	X	
Clibanarius stratiolatus (Dana)	X	X	X	
Dardanus megistos (Herbst)	X		X	
Dardanus scutellatus (Dana)			X	
Macropthalmus sp.	X			
Uca chlorophthalmus crassipes (Adams & White)	X	X		
Uca vocans (L.)			X	
Additional hermit crabs	X		X	
Portunid crabs	X		X	
Supra-littoral grapsid crabs	X	X	X	
Xanthid crabs		X		
Phylum Echinodermata				
Actinopyga echinites (Jaeger)	X			
Bohadschia argus (Jaeger)	X	X		X
Bohadschia bivittata (Mitsukuri)	X	X		
Bohadschia marmorata (Jaeger)	X		X	
Diadema setosum (Leske)	X	X		X
Echinometra mathaei (de Blainville)	X			
Euapta sp.	X			
Holothuria atra Jaeger	X			X
Holothuria cinerascens (Brandt)	X			
Holothuria impatiens (Forskal)	X			
Holothuria leucospilota Brandt	X			
Opheodesoma grisea (Semper)	X	X		