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THE MARINE LABORATORY

Technical Report No. 6

A THERMAL STUDY OF PITI CHANNEL, GUAM, AND ADJACENT AREAS, AND THE INFLUENCE OF POWER PLANT OPERATIONS ON THE MARINE ENVIRONMENT

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A THERMAL STUDY OF PITI CHANNEL, GUAM, AND ADJACENT AREAS, AND THE INFLUENCE OF POWER PLANT OPERATIONS ON THE MARINE ENVIRONMENT

by

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INTRODUCTION[1]

This report presents the results of studies conducted from January, 1972, through April, 1973, in Piti Channel and adjacent tidal flats and in the Government of Guam Commercial Port area of Apra Harbor, Guam. This locality is the receiving area for heated water leaving the condensers of the Piti Power Plant operated by the U. S. Navy Public Works Center. It is scheduled to be the receiving area for heated water from the condensers of the Cabras Island Power Plant presently under construction by the Guam Power Authority. The same area is also expected to receive heated water from an additional generating facility planned for the Cabras Island site in the future.

Cooling water for the Piti Power Plant is pumped in from the west end of Piti Bay, which is separated from the outfall area by the Cabras Island causeway. Specifically, Tepungan Channel, which cuts across the inner reef flats of West Piti Bay, is the major source of cooling water for the existing power plant. The causeway is cut by Piti Canal, which serves as an auxiliary source of cooling water for the power plant, especially at low tides. Tepungan Channel has recently been enlarged to accommodate the increased demands of the generating facilities presently under construction and planned for the future. The features referred to here can be located on the map in Figure 1.

Approximately 64,000 gallons per minute (4 cubic meters per second) is presently pumped through the Piti Power Plant; it is designed to raise the temperature of this water a maximum of 10°F (5.6°C). The Cabras Island units presently under construction will pump at least an additional 120,000 gpm (7.6 m^3/sec) into the outfall area, with a temperature rise of 10-15°F (5.6-8.3°C). Future construction of planned generating facilities will eventually result in the pumping of a maximum of 400,000 gpm (25.2 m^3/sec) into Piti Channel, including the 64,000 gpm now being pumped.

The generating capacity of the Piti Power Plant is 74 megawatts. The two Cabras Island units presently under construction will have a capacity of 66 MW each and are expected to be in operation late in 1974. Construction of two more 66 MW units will not begin until after that date.

It is desirable to try to understand the ecological effects of such a large volume of heated water entering Piti Channel and adjacent tidal flats and then passing into the Commercial Port area. The purpose of this report is to provide a basis for understanding at least some of the potential ecological effects. Particular attention is focused on the influence of the existing Piti Power Plant, since this gives a qualitative indication of what may be expected from additional inputs of heated water into the area. Our attention has focused on understanding the patterns of temperature in the area and how these can differ with time of day, stage of the tidal cycle, weather, season of the year, and variable plant loading.

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[1] The views expressed by the authors are their own and do not necessarily reflect those of the Marine Laboratory, the University of Guam, or the Government of Guam.

This should allow an assessment of effects of the new generating facilities after they go into operation. We are still working on the "before" portion of a "before-and-after" study. Our objective so far has been to get an overall understanding of major thermal patterns under the widest possible range of conditions for the entire area, including the portion of Outer Apra Harbor which might have its thermal properties altered by future power plant operations.

Our studies of Piti Channel began in January, 1972. A report, entitled "A Marine Environmental Survey of Piti Bay and Piti Channel, Guam," was submitted to Guam Power Authority in June, 1972. The report presented a general ecological survey of Piti Channel and adjacent areas and focused on the probable effects of construction activities for the new power plant; thermal patterns and the likely effects of new plant operations were not discussed. The U. S. Army Corps of Engineers considered that report in issuing a permit for the filling of submerged land on the construction site but specified that ecological studies should continue.

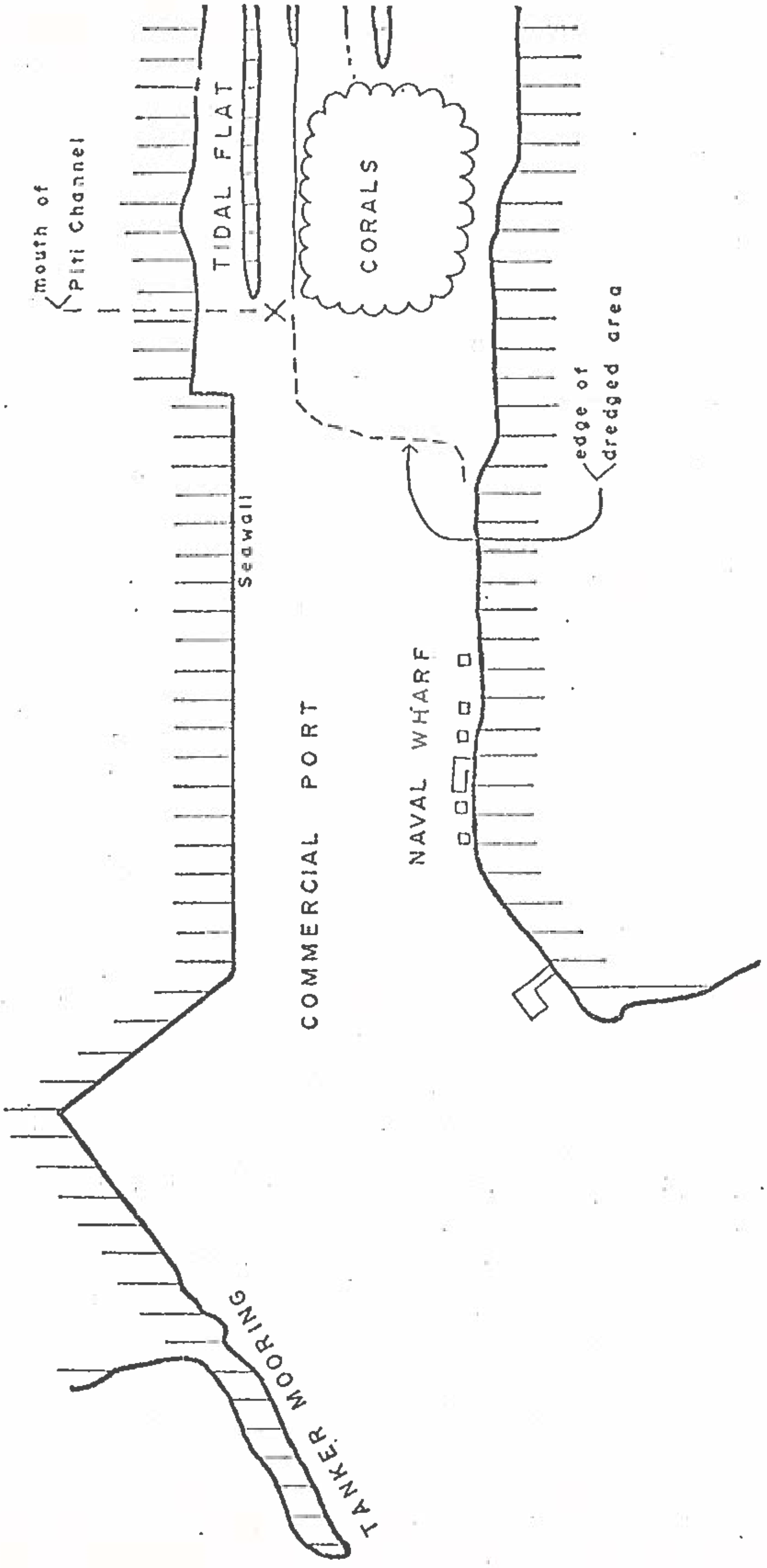
Our statements and projections are based on the assumption that there will be no significant alterations in the study area except those discussed here. If the area is altered by additional construction activity or additional effluent discharges in the future, then the statements and conclusions of this report must be reassessed.

METHODS

Extensive instantaneous temperature measurements were made from a small boat or by wading on the tidal flats; these were done with hand-held mercury thermometers and with a battery-powered telethermometer with thermistor probes. Continuously recording Ryan thermographs, with temperature-sensitive expandable metal coils, and Dickson "Minicorders," with temperature sensitive bulbs filled with an expandable fluid, were used to get seven-day temperature records at selected locations. Operating difficulties with the continuously recording devices limited the amount of reliable data that could be gathered. However, we have sufficient repetition with the same and different instruments to determine the major patterns and to give us confidence in our conclusions.

Extensive information on water movement throughout the study area was obtained by observing the velocity and direction of movement of patches of fluorescein dye. In addition, we have extensive data from a TSK electromechanical current meter anchored at the mouth of Piti Channel where it joins the dredged area of the Government of Guam Commercial Port. This meter records current velocity and direction and can be left in place for three days at a time. Again, we have had difficulties with the operation of the instrument but have sufficient information to allow us to understand major patterns.

We have continued to make visual observations of biological phenomena in the area since the submission of our last report. Gill nets have occasionally been strung across the mouth of Piti Channel to see what species and sizes of fish are moving into and out of the area. Suspended


mouth of Piti Channel
TIDAL FLAT
CORALS
edge of dredged area
Seawall
COMMERCIAL PORT
NAVAL WHARF
TANKER MOORING

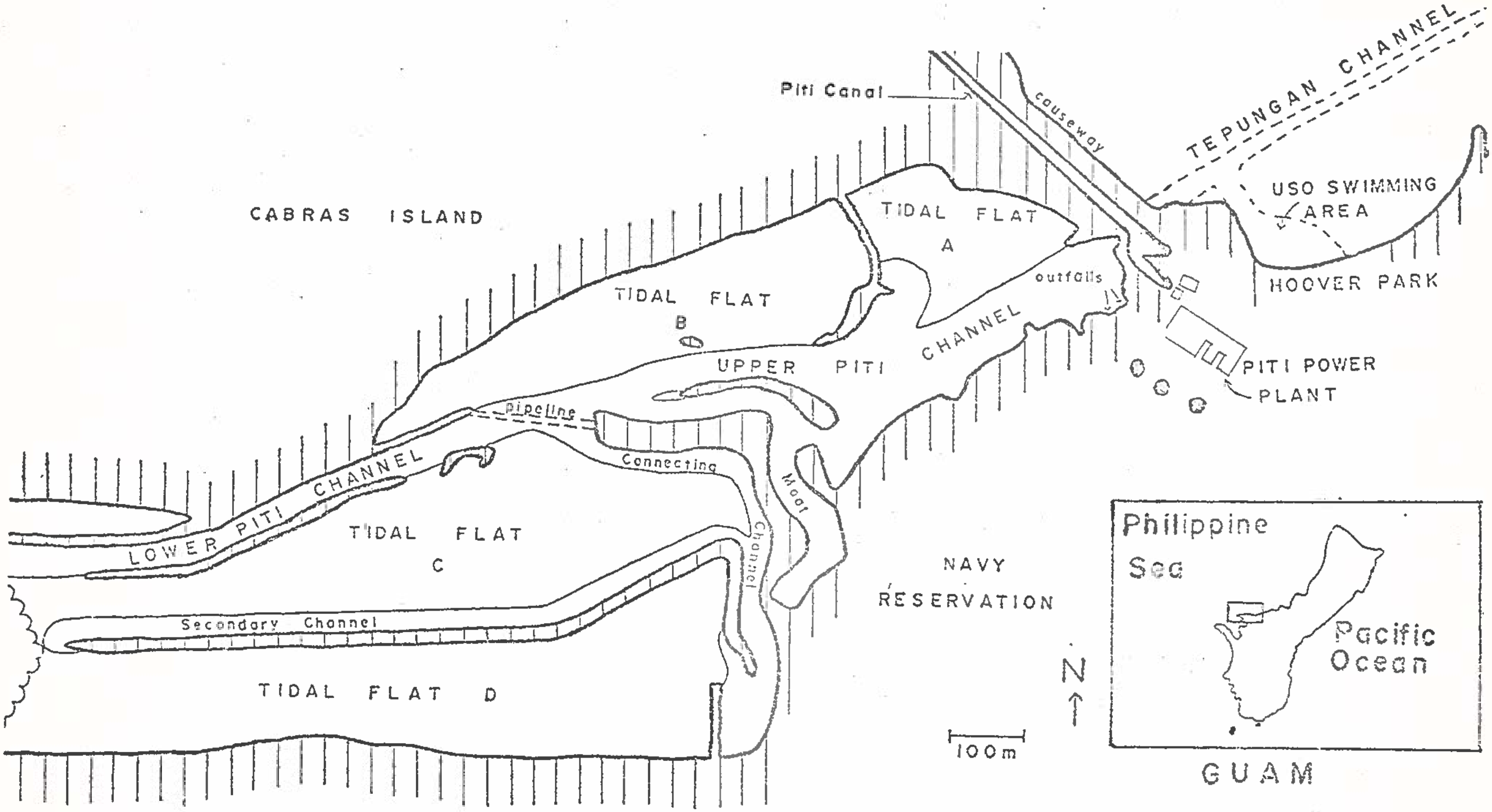


Figure 1. Map of the study area, showing important features discussed in the text. A. (top) Western half of the study area. Outer Apra Harbor lies west of this area. B. (bottom) Eastern half of the study area. Tidal Flat A is the construction site for the Cabras Island Steam Power Plant and has now been filled.

sediments throughout the length of channel have caused water visibility to be poor in the past few months, however; this suspended material resulted from construction activities at the upper end of the channel.

Our observations have been spaced to include all stages of the tidal cycle for both neap and spring tides, all times of day, all kinds of weather, and all seasons of the year. This allowed us to gain an understanding of the entire range of conditions to be expected.

OBSERVATIONS

Description of the Area

As shown in Figure 1, there are three kinds of physical features in the study area: channels, tidal flats, and an area of coral growth. The deeper areas are composed primarily of 2 channels, which are connected with each other. Piti Channel is the main channel and conducts heated water from the Piti Power Plant outfalls to Apra Harbor proper. Its depth is approximately 2 m(6.6ft) below Mean Low Low Water, except where it is partially blocked by the GORCO pipeline. That part of the channel east of the GORCO pipeline will be referred to in this report as Upper Piti Channel, while that part west of the pipeline will be referred to as Lower Piti Channel. A dead-end moat (see Fig. 1) connects with the south side of Upper Piti Channel at one point. A secondary channel extends across the tidal flats south of Piti Channel and roughly parallel to that channel. It adjoins a long, narrow, man-made island. This secondary channel is connected with Piti Channel via a single smaller channel.

The tidal flats are broken up into several different areas, as indicated in Fig. 1. Tidal Flat A is the construction site for the new power plant and has now been filled. Tidal Flat B may be covered by as much as .75 m (2.5 ft) of water at high spring tides, Tidal Flat C by .5 m (1.6 ft), and Tidal Flat D by 1 m (3.3 ft). All tidal flats are mostly exposed to the air at low spring tides, although scattered depressions may retain some water at such times.

An area of live coral growth lies at the western end of Tidal Flats C and D and just east of the dredged area for Navy Wharf E and the Government of Guam Commercial Port. The bottom in this area is approximately 2 m (6.6 ft) below MLLW, and many of the coral heads grow up to the low water level. The coral heads considerably reduce, but do not completely block, the total cross-sectional area available for tidal movement of water between the Commercial Port and Tidal Flats C and D.

Just east of the tidal flats is the dredged berthing area for commercial and military ships (see Fig. 1). It is approximately 10 m (33 ft) deep. Further east, this area connects with Outer Apra Harbor.

The substrate in the channels and tidal flats consists primarily of loose sediments of sand and silt, with scattered rubble and occasional larger rocks. The tidal flats consist primarily of fine-to-moderate sized particles of sand and silt. The channels are floored by somewhat larger sized particles derived from coral skeletons and from the green calcareous alga *Halimeda*.

A general biological description of the tidal flats and channels was given in the June, 1972, report submitted to Guam Power Authority. Additional observations are presented here. Algae of the genus Halimeda form conspicuous clumps on the bottoms of the channels and may also occur in slightly shallower areas, but not on the tidal flats where they would be exposed at low tides. The lagoon immediately adjacent to the existing power plant outfalls has many conspicuous clumps of the red alga Gracilaria and smaller clumps of brown algae. Scattered clumps of brown algae, especially Padina, occur throughout the tidal flats but are killed off during part of the year (generally from about July to November) by daytime low-tide exposure to the air. Localized clumps of sea grass also occur commonly. Burrowing organisms, particularly snails and worms, are common on the tidal flats and rework the sediments extensively. These cause the surfaces of the sediments to be extremely irregular. A single unidentified species, probably a polychaete worm, appears to be responsible for a large percentage of the burrowing activity.

A conspicuous biological feature of the secondary channel and depressions on Tidal Flat D, wherever rocks, scrap metal, or other solid substrates occur, is the large number of oysters growing there. These may attain a size of several inches and are sometimes harvested by local people. These oysters do not occur on any of the available hard substrates, such as sea walls and pilings, associated with Piti Channel or the power plant outfall structures; we do not know the reason for this.

The corals growing at the western end of Tidal Flats C and D consist primarily of heads of the genus Porites. Many boring polychaete worms, sea urchins (especially Diadema), damsel fish, and assorted crustaceans are associated with these coral heads. Some staghorn corals of the genus Acropora are also found here.

Fish of many species are conspicuous throughout the deeper channel areas and are often present in large numbers. A checklist for the outfall lagoon and upper Piti Channel was given in our last report. Many of these fish may come and go from the harbor. Many move onto the tidal flats at high tide and retreat back into the channels at low tide. Net fishermen often set their nets to trap fish leaving the eastern end of Tidal Flat D on a falling tide, particularly with the occurrence of the low spring tides when the flats become almost completely exposed to the air. On one occasion (29 June 1972) we observed a catch of at least 50 fish, representing an estimated biomass of at least 75 pounds, of Mugilidae (mullets), Leiognathidae (soapys or ponyfish), and Lutijanidae (snappers). The channels are also fished by people using a hook and line. Table 1 gives a list of fish caught in a gill net set at the mouth of Piti Channel during 3 days of October 1972.

Water movement

Two mechanisms are responsible for water movement in Piti Channel and adjacent areas. Cooling water from the Piti Power Plant is dumped into the area at its upper (eastern) end and flows down Piti Channel to the harbor. Since this cooling water is drawn from Piti Canal and the Piti reef flats on the eastern side of the Cabras Island causeway (see Fig. 1),

Table 1. List of fish caught in a gill net set at the mouth of Piti Channel on October 12, 19, and 26, 1972.

Sphyraena jello (barracuda)

Acanthurus xanthopterus (surgeonfish)

Scomberoides sancti-petri (jack)

Scarops rubriviolaceous (parrotfish)

Caranx melampygus (jack)

Mulloidichthys auriflamma (goatfish)

Cheilinus trilobatus (wrasse)

Gazza sp. (soapy)

Rhinecanthus aculeatus (triggerfish)

Pseudobalistes sp. (triggerfish)

Aetobatus narinari (eagle ray)

Upeneus arge (goatfish)

Ctenochaetus striatus (surgeonfish)

Scarus ghobban (parrotfish)

Bothus pantherinus (flounder)

and not from Piti Channel, one effect of pumping water through the power plant is to increase general water circulation in Piti Channel and adjacent areas. Water also moves into and out of the area as the tides rise and fall.

Fig. 2 shows observed patterns of water movement for different tidal stages. It can be seen that water in upper Piti Channel always moves westward, away from the plant. Water in Lower Piti Channel may reverse and flow eastward during some stages of at least some tidal cycles; water movement here is more often westerly, however. Tidal Flats A and B flood from the adjacent upper Piti Channel and receive heated water from the power plant during a rising and high tide. During falling tides westward flows develop in the secondary channel, and during rising tides reverse flows occur. In the connecting channel weak southeasterly flows have occasionally been observed on both rising and falling tides. This indicates that some effluent water from the power plant may find its way into the secondary channel and adjacent areas via the connecting channel, although this volume is relatively small in relation to the volume of tidal exchange. Tidal Flat C may thus receive some effluent water directly from the power plant but is probably covered mostly by water received from the harbor through tidal exchange. Tidal Flat D receives its water primarily through tidal exchange and is likely not affected by effluent water from the power plant.

From the standpoint of water turbulence and current velocity, Piti Channel may be divided into 3 regions. The upper region is the outfall lagoon immediately adjacent to Piti Power Plant (Fig. 1). There is a great deal of turbulence in this area caused by an outflow of approximately 4 m^3/sec (64,000 gpm) when both of the large outfall pipes are in use. A man-made shoal immediately in front of one of the outfall pipes also increases water turbulence and mixing. This turbulence gives way to undirectional outward flow within 100 m (328 ft); flow velocities in the upper region range from .19 to .83 m/sec (.6 to 2.7 ft/sec). The middle region extends downstream in Piti Channel for about another 900 m (approx. 2953 ft), or approximately 200 m (656 ft) westward of the GORCO pipeline. Observed velocities in this region have ranged from .05 to .3 m/sec (.16 to 1 ft/sec). In the third region, which extends for the remainder of Lower Piti Channel (approx. 800 m, or 2625 ft, beyond the middle region), the channel narrows somewhat. Flow velocities are greater, ranging from .10 to .42 m/sec (.33 to 1.4 ft/sec). Although there is some overlap in these reported ranges for the 3 regions, individual observations in a given region tend to vary up or down with the values in other regions. As water moves from the channel into the harbor it enters a much larger area, of course, and velocity decreases to zero or near-zero.

In addition to flow velocities, the volume of water transported through a given cross-sectional area of channel is of interest. Volume transport data were gathered on July 10, 1972, at stations in Piti Channel, the secondary channel, and the connecting channel (see Fig. 9 for station locations). Official tide records (National Oceanic and Atmospheric Administration) report the following observed tides in Inner Apra Harbor for that day: 0542 hours, 2.3 ft; 1336 hours, -1.0 ft; 2000 hours, 2.2 ft (all heights based on MLLW Datum). Flow data were gathered between 1100

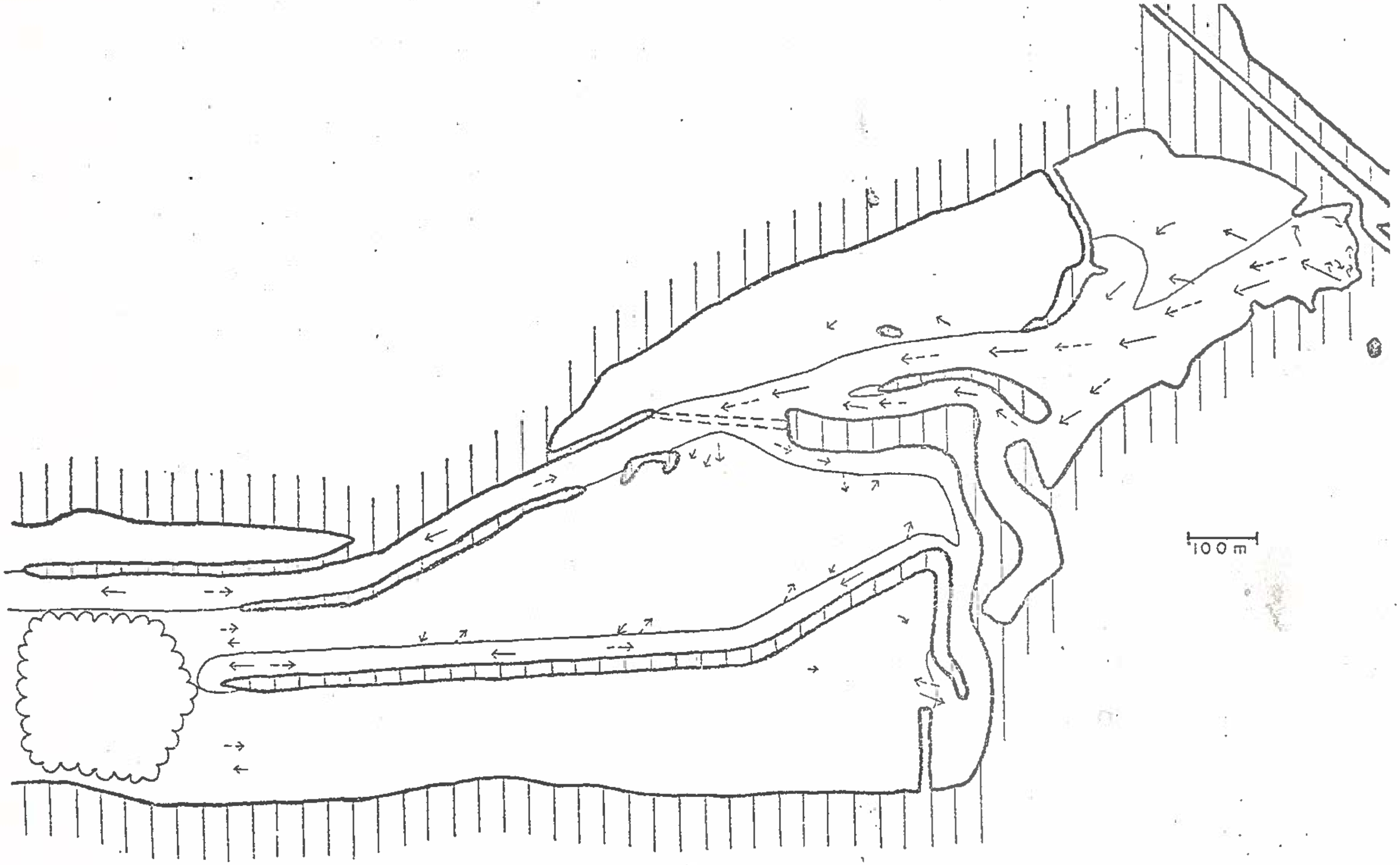


Figure 2. Generalized current patterns in the channels and tidal flats. For the region east of the pipeline, solid arrows indicate currents at high tides and broken arrows indicate currents at low tides. For the area west and south of the pipeline, solid arrows indicate currents on falling tides and broken arrows indicate currents on rising tides. The length of the arrows is roughly proportional to the velocity of the currents.

and 1600 hours. The results are presented in Table 2. It can be seen from the table that the greatest velocities and volume transports occurred in Piti Channel, as we expected. Intermediate velocities and volume transports were observed in the secondary channel, and the lowest values occurred in the small connecting channel. As the day progressed, values in Piti Channel and the secondary channel declined until there was a reversal of flow approximately 2 hours after the time of low tide. Hence, the highest values were found at the middle portion of the falling tide cycle, with lower values coming near the time that the tidal flow turned. This is not surprising. Values in the connecting channel were reasonably constant throughout the observation period, and no reversal of flow occurred. As the flow in the secondary channel reversed with the rising tide, some of the warmer plant-derived water in the connecting channel could be forced onto Tidal Flat C.

Velocities in Lower Piti Channel for this falling spring tide generally exceeded the range of values (reported above) observed at other times. We may take the maximum volume transport (22 m^3/sec, or 350,000 gpm) and subtract from it the plant output (4 m^3/sec, or 64,000 gpm) to get the volume transport due to tidal flow (18 m^3/sec, or 288,000 gpm). If we assume that this tidal flow does not change and that future plant output increases to 12.6 m^3/sec (200,000 gpm), then the calculated velocity at the station in question will increase to .85 m/sec (2.8 ft/sec) if the cross-sectional area of Lower Piti Channel does not change. If future plant output increases to 25.2 m^3/sec (400,000 gpm), then the calculated velocity will increase to 1.2 m/sec (3.9 ft/sec) for the same cross-sectional area of the channel. These calculations give the maximum velocities to be expected in Lower Piti Channel and apply only for the midpoint of a falling spring tide.

A large volume of data is available from the current meter anchored at the mouth of Piti Channel on a number of occasions. Fig. 3 plots the direction and velocity data obtained on one such occasion. In this figure the current direction designated as "in-flowing" generally includes the compass points between 0° and 100°, the direction designated as "out-flowing" generally includes the compass points between 200° and 300°. Data which did not fall consistently within either of these ranges for a given period of time are designated as "variable." It can be seen from Fig. 3 that there was generally outflow on a falling tide and inflow on a rising tide. This was what might be expected. Periods of outflow and inflow were usually separated by periods of variable flow. The periods of outflow tended to be sustained for longer periods of time than the periods of inflow. We presume that this reflects the reinforcement of tidal movement by plant output at times of falling tides and the partial negation of tidal flow by plant output at times of rising tides.

Figure 3 also shows that maximum velocities generally come at mid-tide and lower velocities at or near the times of dead high and dead low tides. Again, this is not surprising and reinforces the pattern found with the dye studies. Moreover, the velocity peaks were higher for out-flowing tides than for inflowing tides.

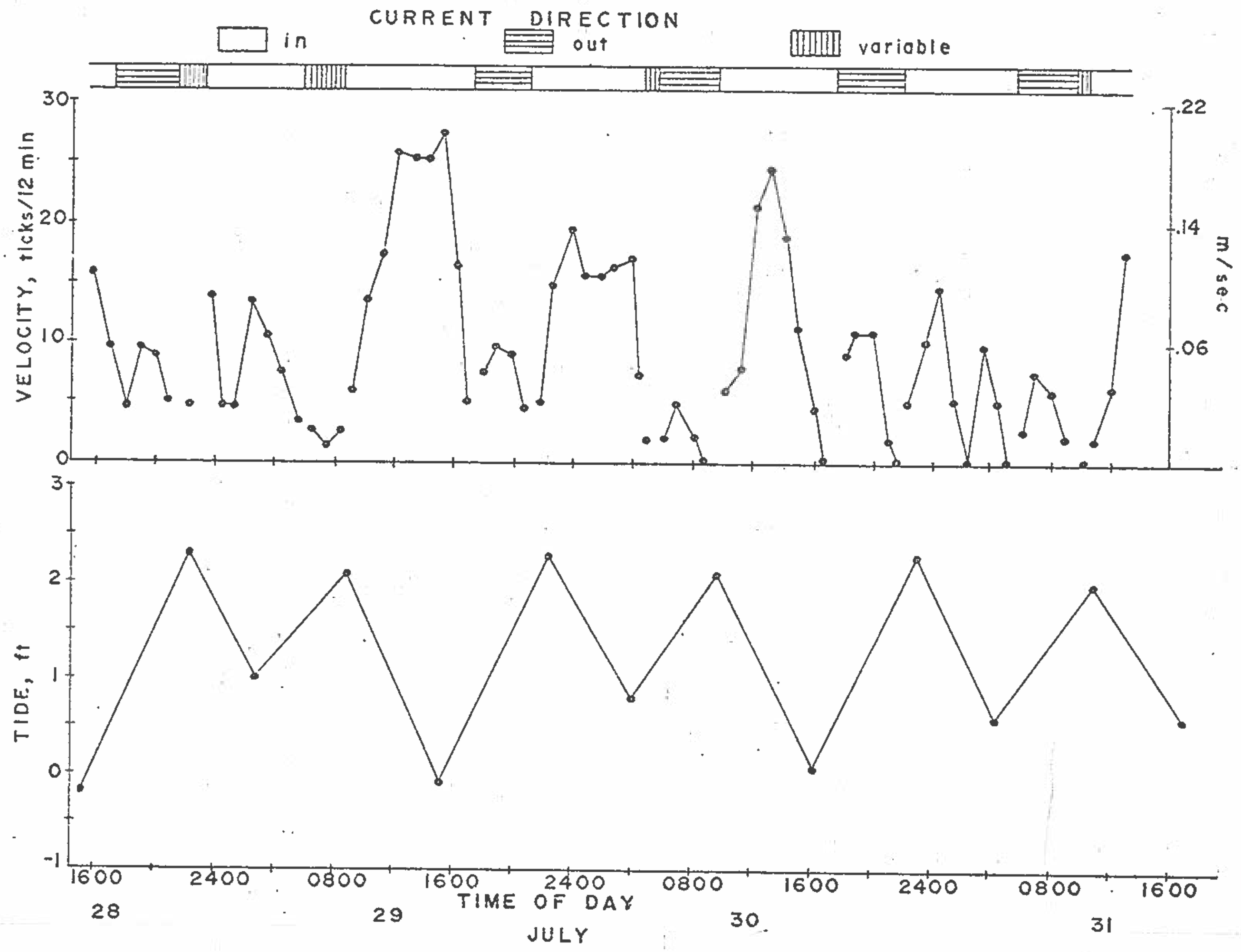


Figure 3. Current directions and velocities recorded by the TSK current meter at the mouth of Piti Channel, 28-31 July 1972. Gaps in the velocity record coincide with changes in the current direction.

Longer periods of outflow and inflow and higher velocities occurred at times of larger tidal fluctuations than at times of lesser tidal fluctuations. This results from the larger volume of water that moves into and out of Piti Channel and adjacent tidal flats through the mouth of Piti Channel at times of greater tidal fluctuation.

The maximum velocity calculated from the current meter data is about .22 m/sec (.72 ft/sec) for a falling tide with a fluctuation of about 1 m (3.3 ft), this is approximately one-third the maximum velocity observed at Station 27 in Lower Piti Channel on 10 July 1972 (see Table 2). However, the cross-sectional area of the channel at the location of the current meter is approximately 73 m^2(2580 ft^2), or about twice the cross-sectional area for the dye station. Hence, the maximum volume transport calculated at the mouth of the channel is about 16 m^3/sec (560 ft^3/sec), as compared with the value of 22 m^3/sec (780 ft^3/sec) for the narrower part of Lower Piti Channel. This leaves some discrepancy between the two figures, but it can probably be accounted for by the observation that near the mouth of Piti Channel water may leave the south side of the channel and exit to the harbor via the area of coral growth at high tides, thus decreasing the flow through the mouth of the channel itself. Of the calculated volume transport of 16 m^3/sec at the mouth of the channel, about 4 m^3/sec (64,000 gpm) may be accounted for by water pumped from the plant; the rest must be due to tidal exchange.

The data presented in Fig. 3 are representative of most of our data obtained from the current meter. However, we have an occasional current meter tape that cannot be analyzed according to the pattern described above, so that we see apparent outflows on a rising tide and vice versa. We believe that the majority of the data,as illustrated by Fig. 3, represent the true pattern and that the apparent discrepancy with some of the current meter data,is due to improper functioning of the meter rather than being an invalidation of the pattern described.

Temperature Patterns for Piti Channel and Adjacent Tidal Flats

Temperatures measured with the telethermometer and mercury thermometers over the course of 15 months covered the range of tidal conditions, times of day, weather conditions, plant loading, and seasons. We have attempted to get synoptic observations over fairly large areas rather than concentrate on many fine details for more restricted areas. It is possible to see some general patterns in these observations when they are all considered together and to form an overall picture of what can usually be expected with regard to temperature.

Water from the plant condensers enters the outfall lagoon through two outfalls. The eastern-most pipe empties the cooling water from three plant units. Its height is just above mean water level. The other outfall is submerged and empties the cooling water from two plants units. Hence, more effluent flows out the above-water outfall, and the temperature immediately in front of this outfall is higher than immediately in front of the submerged outfall. The maximum difference we have observed is 3° C (5.4°F), but differences of 1°C (1.8°F) or less are the usual case. However, these differences are not important from the standpoint of environmental

Table 2. Water flow in the channel areas on July 10, 1972, between 1100 and 1600 hours. Cross-sectional areas of the channels are calculated for the major portions of the channels with significant water movement and do not include the shallow edges with little or no water movement. Locations of the stations are shown in Fig. 9.

Station	Time	Depth.		X-Sect. Area		Velocity		Volume Transport		Direction
		m	(ft)	m^2	(ft^2)	m/sec	(ft/sec)	m^3/sec	(ft^3/sec)	
27 (Piti Channel)	1110	1.9	(6.2)	36	(390)	.61	(2.9)	22	(780)	W
	1230	1.8	(5.9)	33	(360)	.58	(1.9)	19	(680)	W
	1320	1.6	(5.2)	31	(330)	.47	(1.5)	15	(500)	W
	1430	1.6	(5.2)	31	(330)	.44	(1.4)	14	(460)	W
	1530	1.8	(5.9)	33	(360)	.23	(.75)	7.5	(270)	W
	1615	very slight movement eastward								
9 (Connecting Ch.)	1130	1.4	(4.6)	18	(190)	.16	(.52)	3.0	(100)	SE
	1243	1.4	(4.6)	18	(190)	.19	(.62)	3.4	(120)	SE
	1355	1.2	(3.9)	16	(170)	.21	(.69)	3.4	(120)	SE
	1450	1.2	(3.9)	16	(170)	.25	(.82)	4.0	(140)	SE
	1550	1.2	(3.9)	16	(170)	.18	(.59)	2.9	(100)	SE
8 (Secondary Ch.)	1140	1.8	(5.9)	17	(180)	.43	(1.4)	7.3	(250)	W
	1255	1.6	(5.2)	15	(160)	.31	(1.0)	4.6	(160)	W
	1408	1.5	(4.9)	14	(150)	.19	(.62)	2.7	(93)	W
	1508	1.6	(5.2)	15	(160)	.12	(.39)	1.8	(62)	W
	1600	very slight movement eastward								

considerations, since the water in the outfall lagoon is strongly agitated by the force of flow from both outfalls and is well mixed within 100 m (328 ft) of the outfalls. No further consideration will be given here to differences in temperature between the two outfalls.

Water temperature in the outfall lagoon is affected by plant loading, which usually changes with the time of day. The major peak in plant load occurs in the late afternoon and early evening hours, according to personnel at the Piti Plant. Smaller peaks occur at about 1100 and 1400 hours daily. The plant is designed so that cooling water flowing through the condensers is expected to rise a maximum of 5.6°C (10°F). On several occasions, we have observed that water flowing from one of the outfalls is no warmer than water in the intake channel, and it was obvious that no plant load was being imposed. The effect of such an occurrence, of course, was to lower temperatures in the outfall lagoon below the usual range.

The temperature of the intake water also affects temperature of the outfall water, since the temperature rise in the plant condensers is not a function of the intake temperature. Hence, outfall temperatures will rise as intake temperatures rise. Observed temperatures in Tepungan Channel, one of the intake sources, have varied from 27.0 to 31.5°C (80.6 to 88.7°F), with the highest temperatures coming at times of low tides on sunny afternoons, when the water entering this channel is heated as it flows across the Piti Reef Flats on the eastern side of the Cabras Island Causeway. Hence, solar heating indirectly affects the temperature in the outfall area. Observed temperatures in Piti Canal, another source of cooling water, are generally lower than in Tepungan Channel and are usually less than 29°C (84.2°F). Water from these two intake sources is mixed in varying proportions before it enters the two parts of the plant.

Representative isotherm plots drawn from the mercury thermometer and telethermometer data are shown in Figs. 4-8. Such plots have the advantage of giving a synoptic picture but also have the disadvantage of perhaps suggesting more clear-cut temperature boundaries than actually exist. We have the data to draw more than 40 isotherm plots for the Piti Channel/tidal flat area or the harbor, but the figures presented here give an idea of the "typical" picture and the range of observations. Table 3 presents additional data for selected stations at other times.

Figure 4 shows plotted isotherms for 2 May 1972 between 1030 and 1200 hours, or approximately 1 hr to 2 1/2 hr after high tide. The thermal plume from the power plant can be seen extending westward in Piti Channel, with the tidal flats on either side having lower temperatures. However, the other channels and the tidal flats have temperatures of 30°C (86°F) or higher; and at least half of their total area has temperatures of at least 31°C (87.8°F). This latter temperature also prevails in Lower Piti Channel. We attribute these relatively high temperatures on the tidal flats to solar heating in the case of Tidal Flat D and to a combination of solar heating and plant effects in the case of Tidal Flats A and B.

Figure 5 shows isotherms for 18 May 1972 between 1000 and 1130 hours, or approximately at the time of high tide (1012 hours). There is a definite thermal plume extending from the outfall lagoon onto Tidal Flat A. However, throughout the channels and tidal flats, temperatures are generally about 1°C (1.8°F) lower than for 2 May. Although the patterns

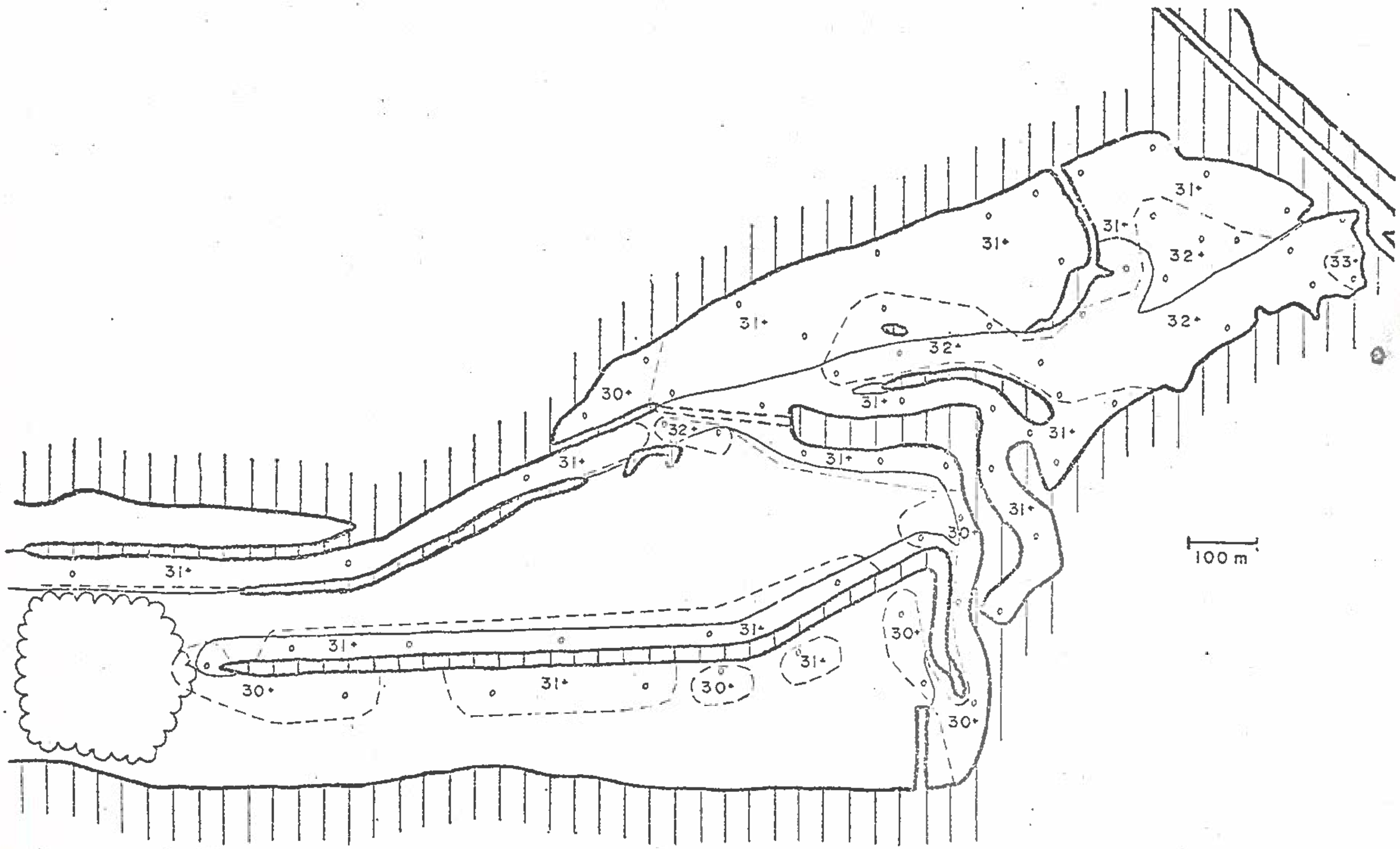


Figure 4. Isotherm plot for 2 May 1972, 1030-1200 hours. A high tide of 2.0 ft occurred at 0824 hours. Temperatures in a given area were just equal to, or higher than, the number in that area. The hollow circles indicate locations of actual observations.

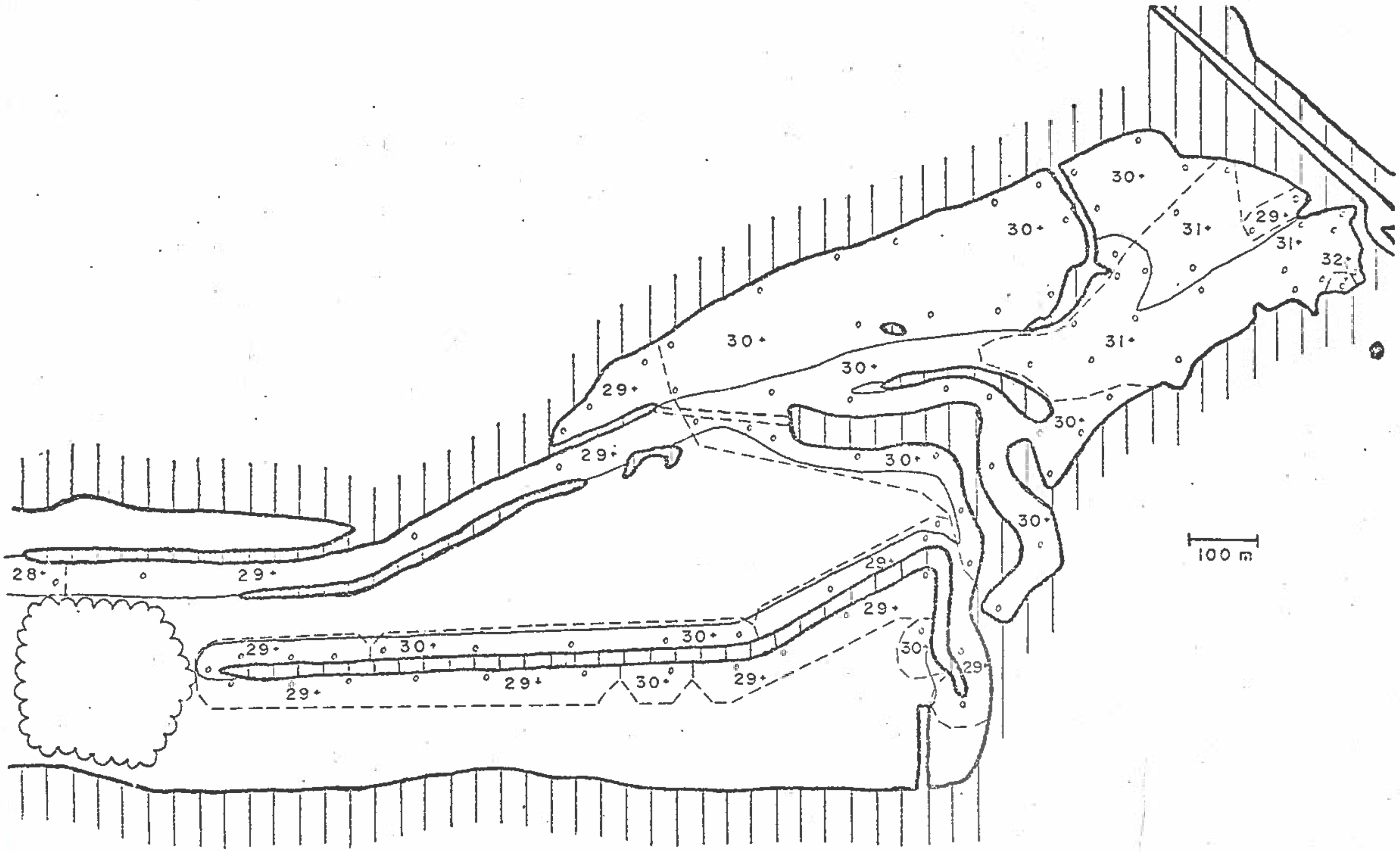


Figure 5. Isotherm plot for 18 May 1972, 1000-1130 hours. A high tide of 1.9 ft occurred at 1012 hours. The sky was sunny with scattered clouds.

for the two days are similar the actual temperatures are different. Figs. 4 and 5 represent commonly observed conditions and we consider these patterns to be "typical."

Figure 6 shows isotherms for the afternoon of 18 May, or the same day for which the morning isotherms are shown in Fig. 5. Temperatures were taken between 1500 and 1630 hours on a falling tide. Low tide occurred at 1806 hours. It can be seen from a comparison of Figs. 5 and 6 that there was a general temperature increase throughout all channels and tidal flats between the times that temperatures were taken for the morning and afternoon isotherm plots. Since the tide was falling, water was moving off the tidal flats into the channels. The temperature increase on the tidal flats must be due to solar heating and not to the thermal plume from the power plant. This is certainly the case for Tidal Flat D and probably the case for Tidal Flats A and B, which were partially blocked from receiving plant effluent by exposed shoals. The tidal flats are as hot as, or hotter than, most areas of Piti Channel. This clearly demonstrates that solar heating is just as significant as heated water leaving the power plant in causing high temperatures on the tidal flats, at least on a falling tide for the afternoon of a sunny day. Stations on Tidal Flat D, which could not be affected by the power plant, actually had temperatures 1°C (1.8°F) higher than a station immediately adjacent to the plant outfall (34.7 vs 33.7°C or 94.5 vs 92.7°F). Water draining from the tidal flats mixes in the channels, particularly Piti Channel with water from the power plant, and temperatures in the channels reflect the effects of both. Fig. 6 is based on tidal flat temperatures which are near the upper limit of our observed range for the entire study period, but the patterns and actual temperatures are typical for the stated conditions.

Figure 7 shows isotherms for the morning of an overcast day, 11 August 1972. The temperatures were taken between 1000 and 1200 hours on a falling tide; high tide was at 0754 hours. Figure 7 indicates generally low temperatures on the tidal flats, as low as 27°C (80.6°F) on Tidal Flat D. These tidal flat temperatures are at the lower end of the observed range for our 15-month study but are representative for overcast conditions. Temperature patterns throughout the tidal flats were generally more patchy than usual. Temperatures in Piti Channel were higher than tidal flat temperatures but within the usual range. A plume of warmer water can clearly be seen extending from Piti Channel onto the middle of Tidal Flat B, with cooler tidal flat waters lying on either side of it. In this case plant effluent, and not solar heating, was responsible for raising the temperatures on Tidal Flat B.

Figure 8 shows plotted isotherms for temperatures taken between 1345 and 1545 hours on a mostly overcast day, 7 March 1972. The tide was falling, with high tide having occurred at 1118 hours. The most striking thing about Figure 8 is the generally low temperatures which prevailed throughout the channels and tidal flats. It is obvious from the temperature immediately adjacent to the outfall (29.8°C, or 85.6°F) that there is a reduced plant load, and this is reflected in the low temperatures in Upper and Lower Piti Channel. The temperatures on the tidal flats for this cloudy afternoon were as much as 5°C (9°F) lower than for the afternoon of a sunny day

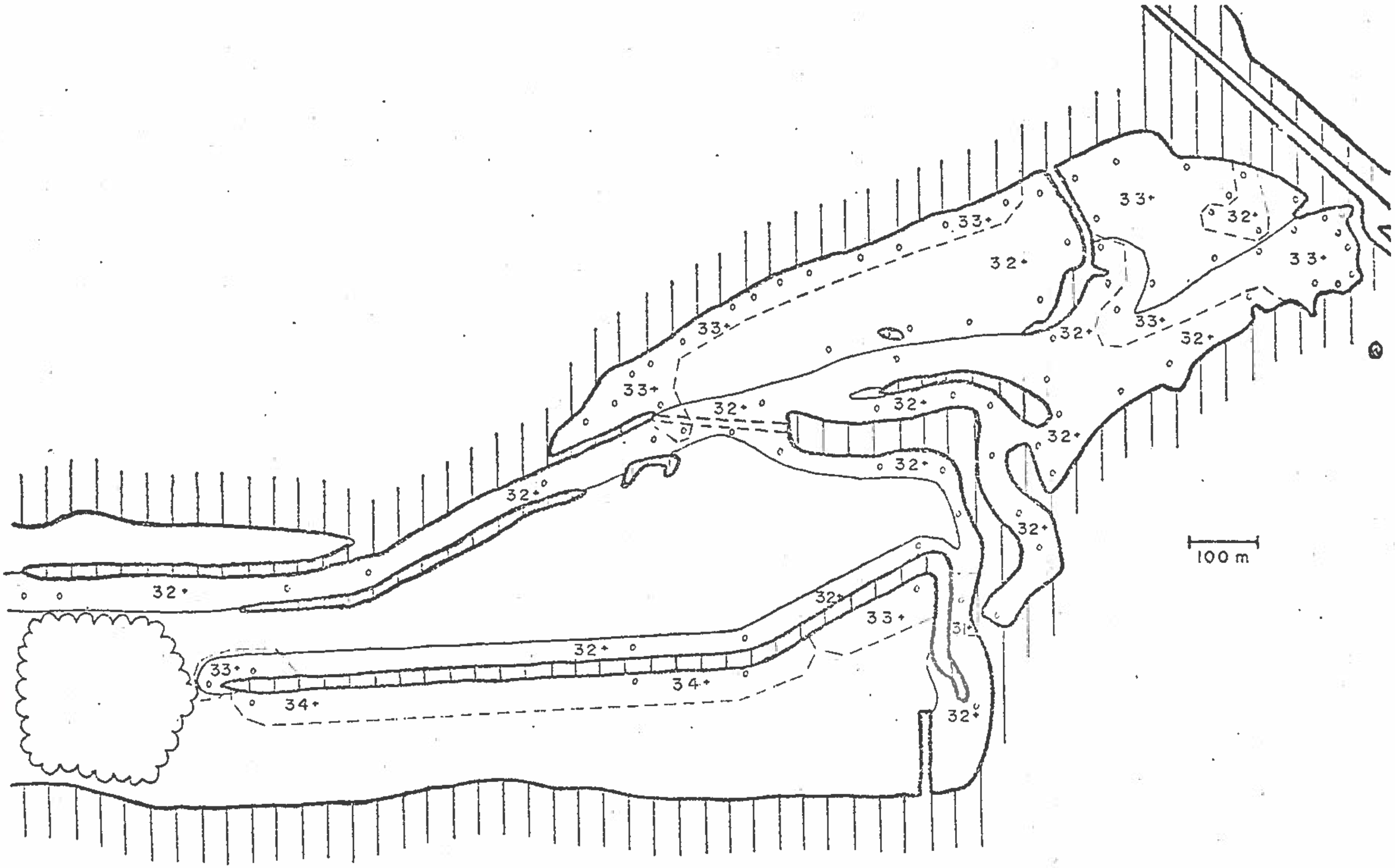


Figure 6. Isotherm plot for 18 May 1972, 1500-1630 hours. A low tide of -0.4 ft occurred at 1806 hours. The sky was sunny with scattered clouds.

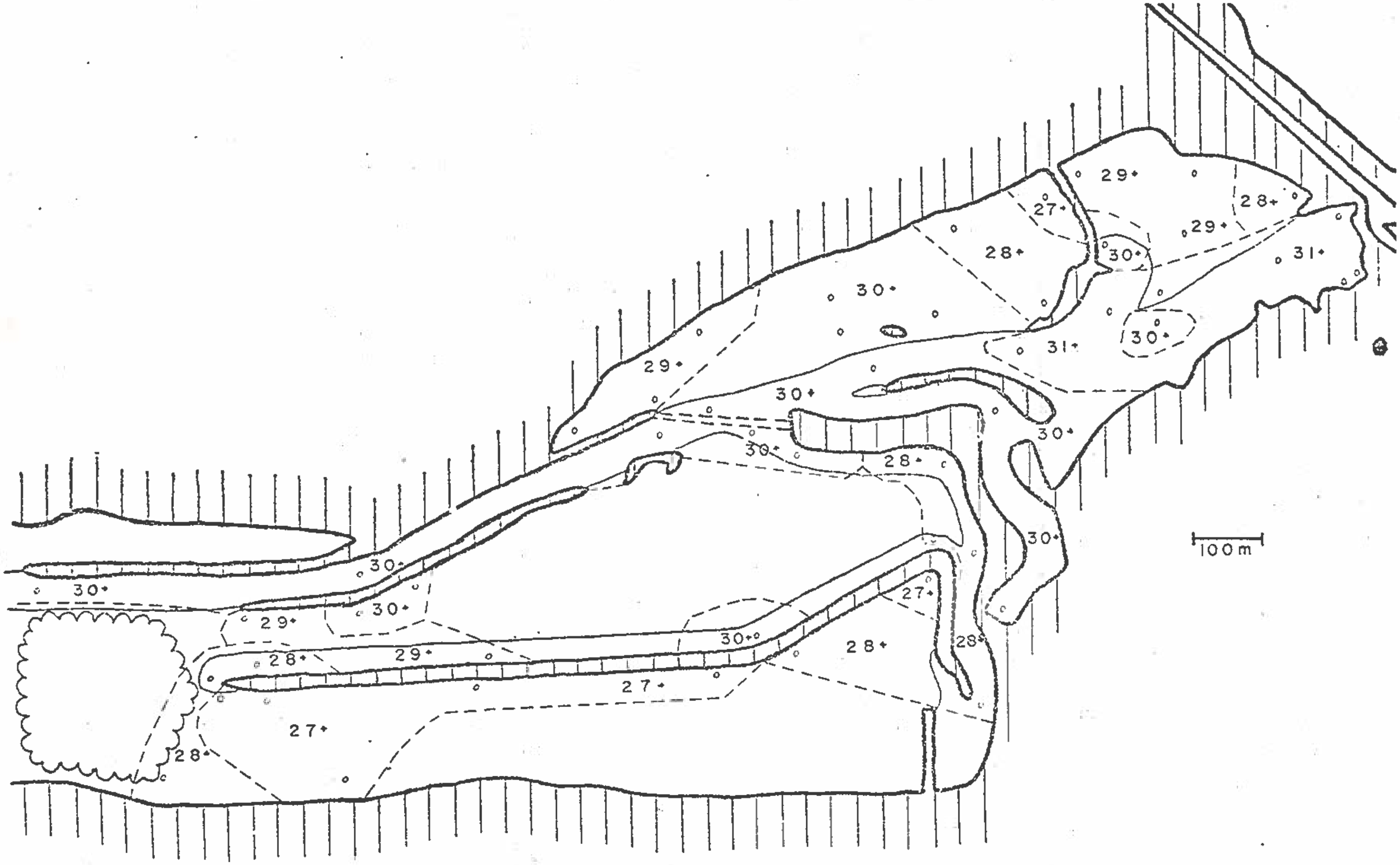


Figure 7. Isotherm plot for 11 August 1972, 1000-1200 hours. A high tide of 1.9 ft occurred at 0754 hours, and a low tide of -0.3 ft occurred at 1506 hours. The sky was mostly overcast.

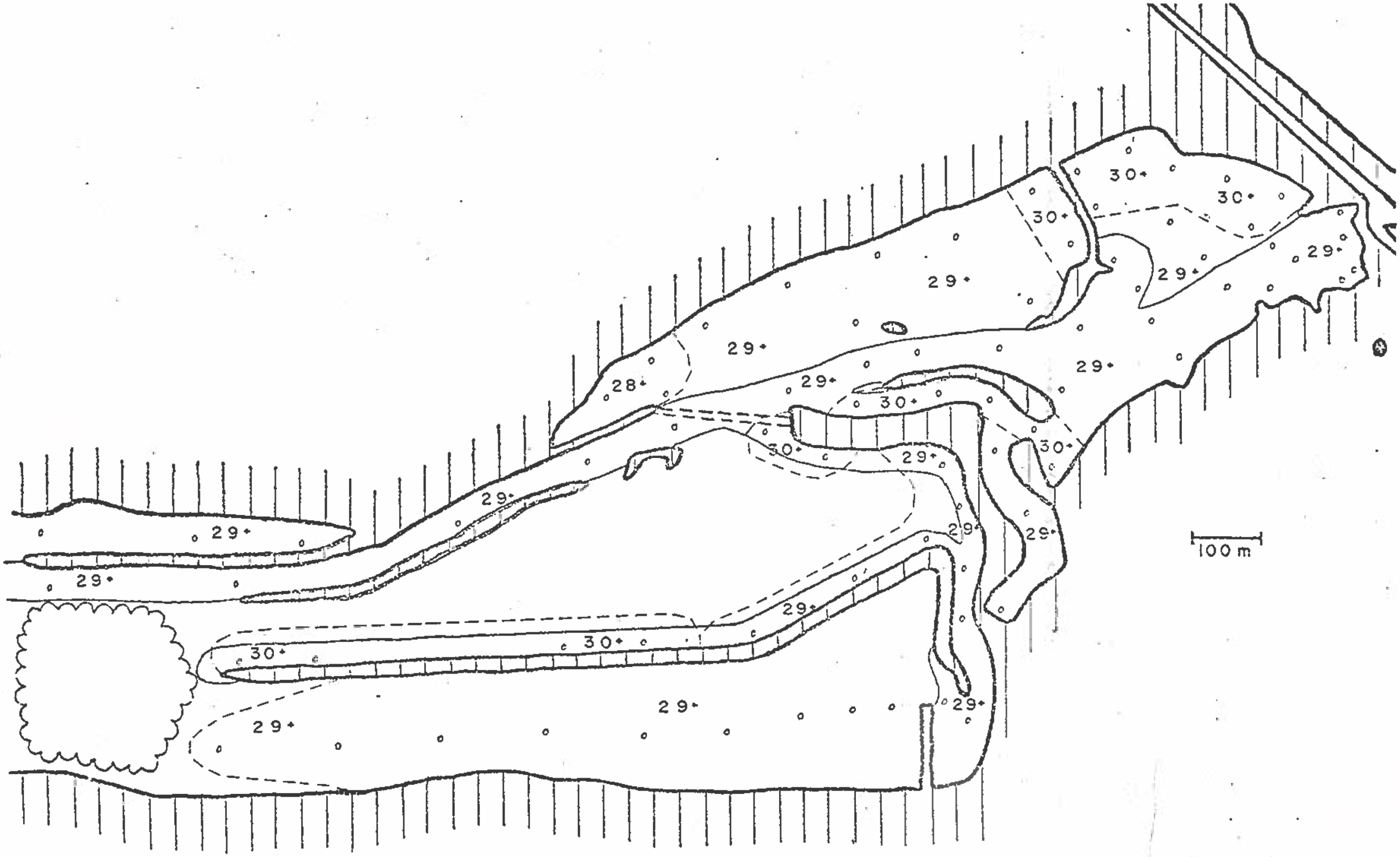


Figure 8. Isotherm plot for 7 March 1972, 1345-1545 hours. A high tide of 2.2 ft occurred at 1118 hours, and a low tide of 0.2 ft occurred at 1812 hours. The sky was mostly overcast.

(see Fig. 6) but were about 2°C higher than for an overcast morning (Fig. 7).

The isotherm plots discussed above are sufficient to give an idea of the temperature range and usual conditions for the channels and tidal flats. It is not necessary to present additional isotherm plots here, although we have the data to do so. Further data are presented in Table 3, which shows observed temperatures for selected stations (see Fig. 9) on different dates. Table 3 provides the basis for the following discussion.

Observed temperatures in the outfall lagoon ranged from 29.8°C to 35.2°C (85.6 to 95.4°F). The lowest value occurred on a cloudy day in March, 1972, when only one plant outfall (the one above water level) was operating. Intake water temperature was approximately 27.5°C (81.5°F). Observed temperatures in the outfall lagoon generally run 4-5°C (7.2-9.0°F) above observed temperatures in the intake channel and canal, but occasionally exceed a 5° rise. The maximum temperature in the outfall lagoon was observed on several occasions during the afternoons of bright sunny days. Temperatures greater than 32°C (89.6°F) are the rule in the outfall lagoon, and values higher than 33°C (91.4°F) are common.

The diurnal pattern that emerges is one of consistently higher afternoon temperatures than morning temperatures. This was confirmed by hourly observations taken with the telethermometer for a duration of 24 hours on 24-25 August 1972. Temperatures peaked at 35.2° in midafternoon and reached a low point of 31.8°C (89.2°F) after midnight. We consider this diurnal pattern to be typical for the area, but this was the only occasion when we ever observed temperatures in excess of 35°C (95°F) associated with the plant outfall.

Turbulent waters in the outfall lagoon give rise to a one-way flow away from the plant within 100 m. Extensive observations have been made at Stations 4 and 5 (see Fig. 9), approximately 300 m downstream from the plant outfalls. The temperatures of these two stations are usually the same or nearly the same. This indicates that water from the power plant flows around the south side of the small island there as well as down the main channel on the north side of the island. Temperatures in the moat, which adjoins the main body of water at this point, are usually lower at the end of the cul-de-sac than at the mouth. Dye drops have indicated little water circulation in the moat. The highest readings for all the Piti Channel stations were observed on the afternoons of sunny days. This parallels the situation for the outfall lagoon, as might be expected.

Successive stations, starting at the outfall lagoon and proceeding directly downstream to the mouth of Piti Channel and beyond, usually have successively lower temperatures; but occasionally a given station has the same temperature as the preceding upstream station. The temperature change between Stations 3 and 4 ranged from 0 to 2.4°C(0 to 4.3°F); between Stations 4 and 6, from 0 to 1.2°C (0 to 2.2°F); and between Stations 6 and 7, from 0 to 3.0°C (0 to 5.4°F).

Table 3. Temperature (°C) for various dates, times, and weather conditions at selected locations. See Fig. 9 for station locations.

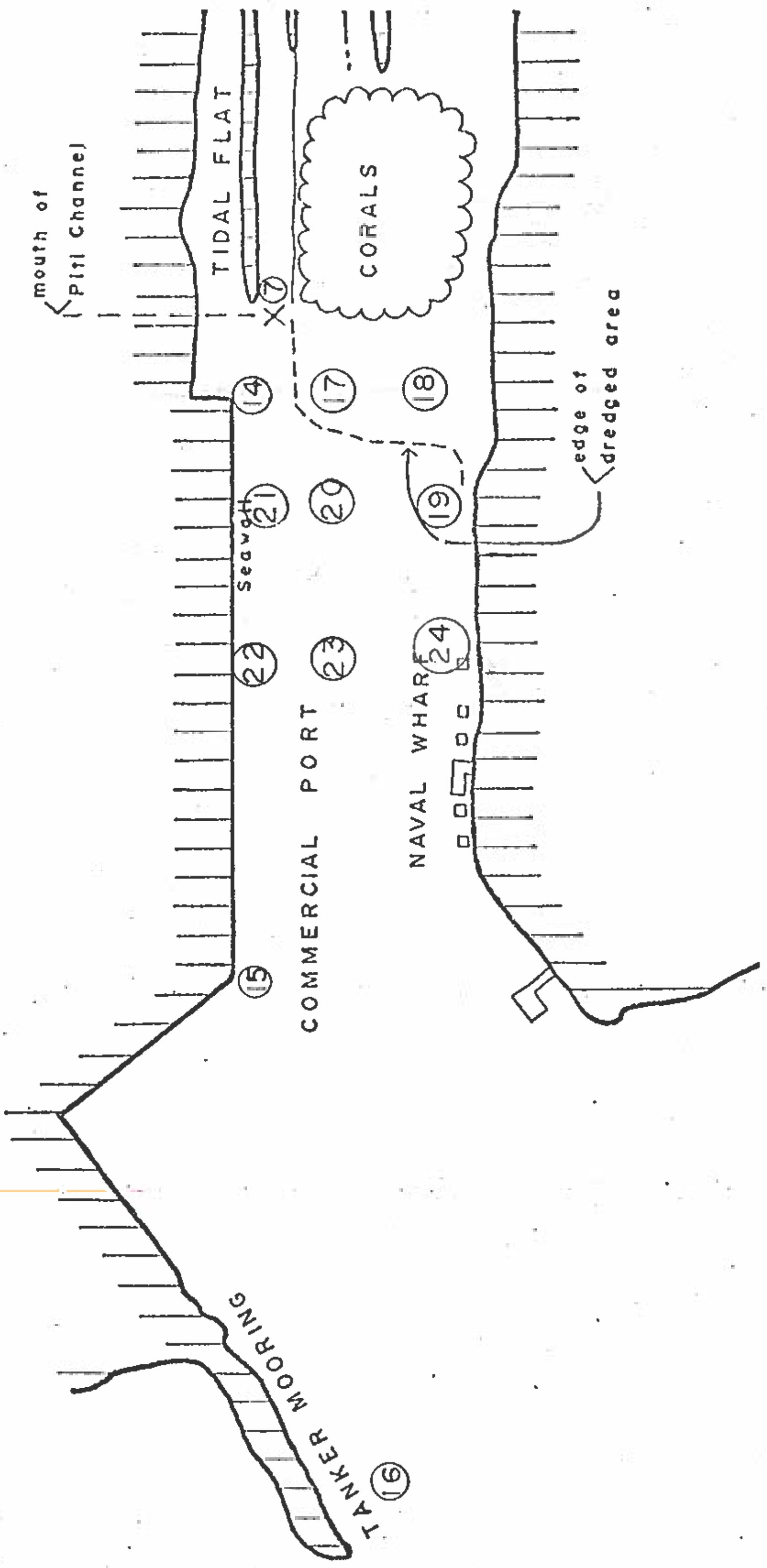
Date and Time	Weather	1	2	3	4	5	6	Stations 7	8	9	10	11	12	13	14	15	16
27 Jan. 72 Midday	Mostly sunny	-	-	32.0	31.8	-	31.0	28.9	-	-	31.9	-	-	-	-	-	27.2
1 Feb. 72 Afternoon	Mostly sunny	-	-	33.0	31.5	30.5	30.9	29.2	-	-	31.5	31.0	28.5	-	-	-	27.5
10 Feb. 72 Afternoon	Mostly sunny	-	-	33.0	33.0	33.0	32.8	31.2	32.8	32.1	-	-	-	32.8	-	-	28.0
17 Feb. 72 Midday	Mostly sunny	-	-	32.3	31.9	31.9	31.2	-	-	-	31.2	31.5	30.8	-	-	-	28.0
22 Feb. 72 Afternoon	Mostly sunny	-	-	32.8	31.8	30.8	31.0	29.0	-	-	32.0	31.1	29.0	-	-	-	27.1
24 Feb. 72 Afternoon	Mostly sunny	-	-	32.2	31.8	31.0	31.0	28.0	-	-	32.0	31.6	29	-	-	-	27.5
29 Feb. 72 Afternoon	Mostly sunny	-	-	32.9	31.4	31.0	31.4	30.8	-	31.1	31.5	31.5	31.8	31.1	-	-	28.8
7 Mar. 72 Afternoon	Mostly cloudy	27.5	-	29.8	29.8	30.0	29.9	29.9	29.5	30.0	29.8	29.8	28.4	29.2	-	-	27.5
16 Mar. 72 Afternoon	Partly cloudy	27.0	-	34.5	31.9	30.8	30.8	-	-	31.1	31.1	31.8	-	-	-	-	27.2
23 Mar. 72 Afternoon		28.5	-	33.3	32.8	-	32.8	30.0	-	31.8	-	-	-	-	28.3	-	27.9
20 Apr. 72 Afternoon	Mostly sunny	30.8	29.2	34.6	33.6	-	33.4	32.6	-	33.1	-	-	-	-	-	-	-
2 May 72 Morning	Mostly sunny	28.0	-	33.1	32.0	31.2	32.0	31.0	31.0	31.1	32.0	32.0	30.1	30.7	30.00	-	28.5
11 May 72 Midday	Mostly sunny	28.7	-	33.1	32.1	31.5	31.7	31.3	-	31.6	31.7	31.5	-	-	-	-	28.5
13 May 72 Morning	Sunny	-	-	32.1	31.0	30.7	30.2	28.4	30.0	30.6	31.0	30.9	29.3	29.6	-	-	27.6
18 May 72 Afternoon	Sunny	-	-	33.7	32.7	32.5	32.5	32.1	32.8	32.5	33.0	32.7	33.2	34.7	-	-	28.3
31 May 72 Afternoon		-	-	33.6	32.6	32.1	32.7	32.8	-	32.1	-	-	-	-	-	-	28.7
9 June 72 Afternoon		-	-	33.8	33.3	33.2	33.0	32.3	-	-	-	-	-	-	-	-	-

Table 3. (Continued)

Date and Time	Weather	Stations															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
13 June 72 Midday		29.4	-	33.1	32.8	32.4	32.4	32.4	-	31.6	32.1	32.5	-	-	-	-	29.8
6 July 72 Midday	Partly overcast	28.8	28.5	33.2	32.7	32.5	32.2	31.4	31.6	32.1	-	32.2	30.6	30.7	-	-	-
13 July 72 Midday		28.8	29.2	34.6	34.2	-	-	33.6	-	-	-	-	33.6	-	-	-	-
19 July 72 Afternoon	Sunny	29.4	29.2	34.2	34.0	-	33.2	32.7	-	-	-	-	-	-	-	-	-
25 July 72 Midday	Overcast	-	-	34.2	32.6	32.6	31.4	30.8	30.4	31.5	-	-	29.4	29.9	-	-	-
27 July 72 Midday	Partly cloudy	28.3	28.3	33.1	32.2	31.6	31.8	31.5	31.4	31.1	-	31.6	-	31.4	-	-	-
4 Aug. 72 Morning	Overcast	27.6	-	32.7	32.0	31.2	31.3	27.4	30.3	31.0	-	29.0	-	-	-	-	-
7 Aug. 72 Midday	Mostly overcast	28.6	28.0	32.6	32.3	31.8	32.0	31.9	31.4	31.8	-	31.1	30.9	30.0	31.4	30.6	30.2
9 Aug. 72 Morning	Sunny	-	27.9	32.2	32.1	32.1	32.0	-	-	-	31.3	32.0	31.8	-	-	-	29.3
9 Aug. 72 Midday	Sunny	31.5	-	-	-	-	32.3	32.1	32.0	32.0	-	-	-	32.0	31.4	-	30.6
11 Aug. 72 Morning	Overcast	27.7	27.4	31.6	31.0	-	-	29.6	-	-	29.8	-	-	-	-	-	-
11 Aug. 72 Midday	Overcast	28.3	-	-	-	30.2	30.8	30.0	30.0	28.4	-	30.6	29.4	27.6	-	-	-
14 Aug. 72 Morning	Overcast	27.4	27.8	32.6	31.6	31.4	31.2	-	-	-	30.8	31.4	29.0	-	-	-	-
14 Aug. 72 Midday	Overcast	28.2	-	32.8	-	-	-	-	30.2	31.0	-	-	-	28.6	-	-	-
16 Aug. 72 Morning	Sunny	27.0	28.0	33.0	31.0	30.8	30.8	-	-	-	-	30.4	-	-	-	-	-
16 Aug. 72 Midday	Sunny	-	-	-	-	-	-	29.8	30.8	30.8	-	-	-	30.8	-	-	-

Table 3. (Continued)

Date and Time	Weather	Stations 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
18 Aug. 72 Morning	Sunny	27.4	27.8	32.8	30.8	30.6	30.6	30.6	-	-	30.2	30.4	-	-	-	-	-
18 Aug. 72 Midday	Rainy	28.4	-	-	-	-	31.2	30.8	31.0	31.0	-	-	30.3	30.4	29.4	-	29.0
21 Aug. 72 Morning	Overcast	27.4	-	33.0	30.8	30.6	30.2	30.4	-	30.4	-	-	-	-	30.2	29.4	28.6
21 Aug. 72 Midday	Overcast	29.4	-	-	-	-	31.0	31.0	31.0	31.2	-	31.0	-	-	-	-	-
22 Aug. 72 Morning	Scattered clouds	-	-	-	-	-	-	31.8	-	-	-	-	-	-	30.6	-	29.8
22 Aug. 72 Midday	Scattered clouds	-	-	-	-	-	-	32.0	-	-	-	-	-	-	30.2	29.6	29.5
22 Aug. 72 Afternoon	Scattered clouds	-	-	-	-	-	-	34.1	-	-	-	-	-	-	30.8	30.2	30.0
24 Aug. 72 Late afternoon	Cloudy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24 Aug. 72 Midnight	Cloudy	-	-	-	33.0	32.8	32.8	-	30.8	31.0	-	-	-	-	-	-	-
7 Sept. 72 Morning	Sunny	-	-	-	-	-	-	32.0	-	-	-	-	-	-	31.5	31.4	29.4
7 Sept. 72 Midday	Sunny	-	-	-	-	-	-	33.6	-	-	-	-	-	-	32.9	32.4	31.1
14 Sept. 72 Morning	Scattered clouds	-	-	-	-	-	-	30.8	-	-	-	-	-	-	31.1	31.0	30.3
21 Nov. 72 Morning		-	-	32.2	31.5	30.8	30.7	28.9	-	29.4	29.6	-	-	-	-	28.1	28.0
21 Nov. 72 Early evening	Partly cloudy	-	-	-	-	-	32.5	31.3	31.9	32.0	-	-	-	-	28.1	27.9	28.0


mouth of Piti Channel
TIDAL FLAT
CORALS
⑦
⑭
⑰
⑱
edge of dredged area
⑲
⑳
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NAVAL WHARF
COMMERCIAL PORT
⑮
TANKER MOORING
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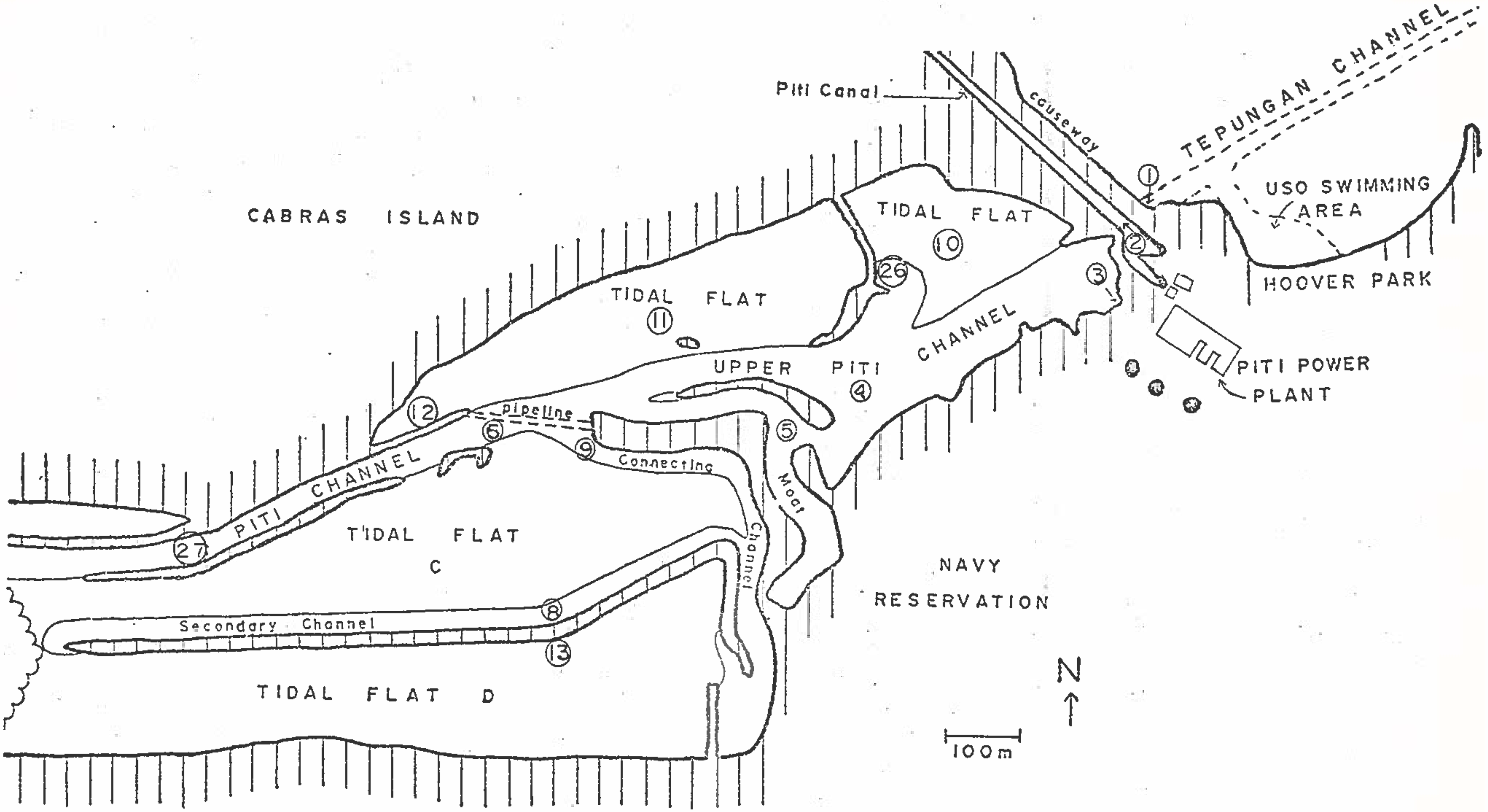

Figure 9. Locations of stations discussed in the text and in Table 3. Station 28 is at Signal Buoy 1 in the outer harbor (see Fig. 19), and Station 29 is at a mooring buoy near the mouth of the harbor.

Temperatures within 1°C (1.8°F) of the outfall temperature were confined to the outfall lagoon for about 1/2 our observations and extended as far as Station 4 (see Fig. 9) for about 1/2 the time. The temperature drop from the outfall to the mouth of the channel ranged from 0 to 5.3°C (0 to 9.5°F). The observation of no temperature drop came on a cloudy day (7 March 72) when the outfall temperature was only 29.8°C (85.6°F) and is thus not surprising (see Fig. 8). However, a drop of only .1°C (.2°F) occurred on the morning of 9 August 1972 on a falling tide when the outfall temperature was 32.2°C (90.0°F). The day was sunny, and there were no unusual conditions which might explain the lack of a temperature drop. This condition was not found under similar situation on other days. The maximum observed drop occurred on a rainy day (4 August 72) when the outfall temperature was 32.7°C (90.9°F). The outfall water was confined to Piti Channel and did not spread onto the adjacent reef flats. The thermal plume extended into lower Piti Channel but did not reach the mouth of the channel. The temperature drop between the outfall and the mouth of the channel usually exceeds 2°C (3.6°F) and often exceeds 3°C (5.4°F). Temperatures at the mouth of the channel were sometimes the same as ambient harbor temperature, 28°C (82.4°F) or lower, indicating that thermal effects from the power plant do not always extend to this location. This usually occurred on rising tides, as might be expected. (See the previous discussion of data from the current meter placed in the mouth of the channel.)

Less extensive temperature observations have been made in the secondary channel and the connecting channel (Stations 8 and 9, Table 3 and Figure 9). Temperatures in these channels usually are within 1°C (1.8°F) of each other and of the temperatures at the GORCO pipeline (Station 6, Table 3) and appear to have a similar pattern of temporal variation. The secondary channel usually has a fairly even temperature distribution throughout its length but may occasionally have higher or lower temperatures at its eastern end (values not shown in the table). The connecting channel may have an even temperature distribution throughout its length but often is as much as 1°C (1.8°F) warmer at its northern end where it adjoins Piti Channel. The southern cul-de-sac of the connecting channel is relatively deeper and wider than the rest of this small channel and is partially shaded by adjacent terrestrial vegetation. Hence, this end is often cooler than the rest of the channel.

Extensive observations have been made on the reef flats to see how these areas are affected by solar heating. Temperatures on Reef Flats A and B range from 29 to 33.4°C (84.2 to 92.1°F). Lower temperatures occur in the mornings and on cloudy days; higher values tend to occur in the afternoons of sunny days. An isolated corner of Tidal Flat B (See Table 3, Station 12) often had lower temperatures than the remainder of that tidal flat. There have been occasions when it was possible to see an obvious plume of warmer water from the power plant moving onto these reef flats at times of higher tides, as noted in the previous discussion of isotherm plots. This could only be seen on cloudy days when reef flat waters surrounding the plume exhibited lower temperatures. On sunny days it has not been possible to detect an obvious plume from the plant since solar heating raised water temperatures throughout the tidal flats. Water from the power plant is probably not raising reef flat temperatures to higher levels than they would be raised by solar heating alone.

Further information about the effect of solar heating on reef flat temperatures comes from observations on Reef Flat D. There is little if any movement of water from the power plant onto this reef flat. Hence, it serves as a natural control area for examining how high reef flat temperatures can be raised by solar heating alone. Observed temperatures on Reef Flat D have ranged from 27.6°C (81.7°F) on cloudy days to 34.7°C (94.5°F) on sunny days. At a given time temperatures on this reef flat may range from 2° below to 2°C (3.6°F) above the temperature in Lower Piti Channel. A comparison of Figs. 5 and 6 shows the extent of solar heating between morning and afternoon of the same day and indicates that temperatures may rise by as much as 5°C (9°F). Examination of Figs. 6 and 8 shows that temperatures on Reef Flat D may differ between the afternoons of cloudy and sunny days by as much as 5.5°C (9.9°F). More often than not, Tidal Flat D has lower temperatures than Tidal Flat B.

Extensive observations have not been made on Tidal Flat C, but it is shallower than Reef Flat D and is influenced at least as much by solar heating as is Reef Flat D.

The telethermometer has been used on numerous occasions to take temperatures at 30 and 50 cm below the surface as well as at 1-m intervals below the surface. Observations throughout the outfall lagoon and upper Piti Channel indicate that temperatures at the surface and at depth are the same and that the water is well mixed vertically. Vertical stratification sometimes occurs in the moat after a rain, when cooler but less saline water forms a layer on top of the warmer but more saline water below.

At the mouth of Piti Channel, thermal stratification sometimes occurs for part of the tidal cycle but not for all of it. Table 4 illustrates this point with data taken on 26 October 1972. During a rising and high tide (first three columns of Table 4) and the succeeding falling and low tide (next two columns) the temperature was relatively constant from top to bottom, although it was higher on the falling and low tide than on the preceding rising and high tide. Approximately an hour after low tide there was a difference of 4.4°C (7.9°F) between the surface temperature and the temperature at 2 m, as inflowing harbor water moved under the warmer surface water with the rising tide. Vertical stratification was observed on other occasions near the time of low tides.

No clear-cut seasonality trends are apparent in our data, although it is possible that we could be missing subtle trends. Weather and time-of-day differences are clearly greater than possible seasonality differences.

The continuously recording Minicorders have been maintained at three locations: the outfall lagoon (Station 3), Station 4, and the mouth of Piti Channel (Station 7) see Fig. 9 for station locations. Sample records are shown in Figs. 10 and 11. The pattern typically observed for the outfall location (Fig. 10) shows a daily cycle with a single broad peak and a single broad dip. With a few exceptions the peak comes in the

Table 4. Temperatures (°C) at various times and depths at the mouth of Piti Channel on 26 October 1972. The tides were as follows: -2.1 ft at 0418 hours, 1.1 at 1130, 0.1 at 1612, 1.2 at 2118.

Depth (m)	Time					
	0720	0905	1010	1500	1623	1736
0	28.8	28.6	28.8	33.7	33.7	33.1
.5	28.8	28.6	28.8	33.8	33.8	33.1
1	28.4	28.6	28.6	33.8	33.8	31.6
2	28.4	28.5	28.5	33.8	33.6	28.7

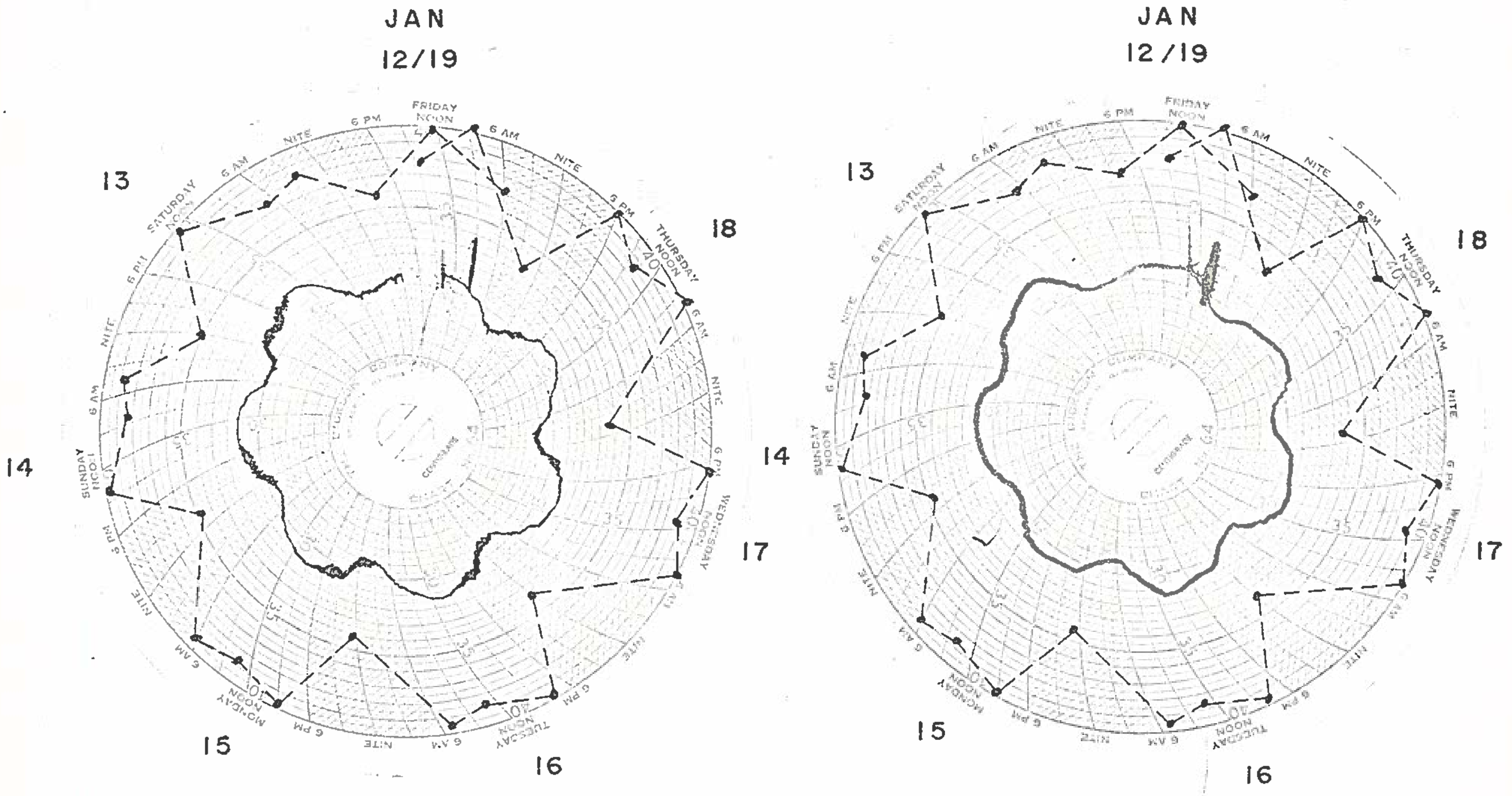

Figure 10. Sample temperature records from the Minicorders located at the outfall (Station 3, Figure 9) and at Station 4 (Fig. 9), 12-19 January 1973. The record on the left is for Station 3 and the record on the right for Station 4. The dashed lines indicate tidal fluctuations and were drawn by hand.

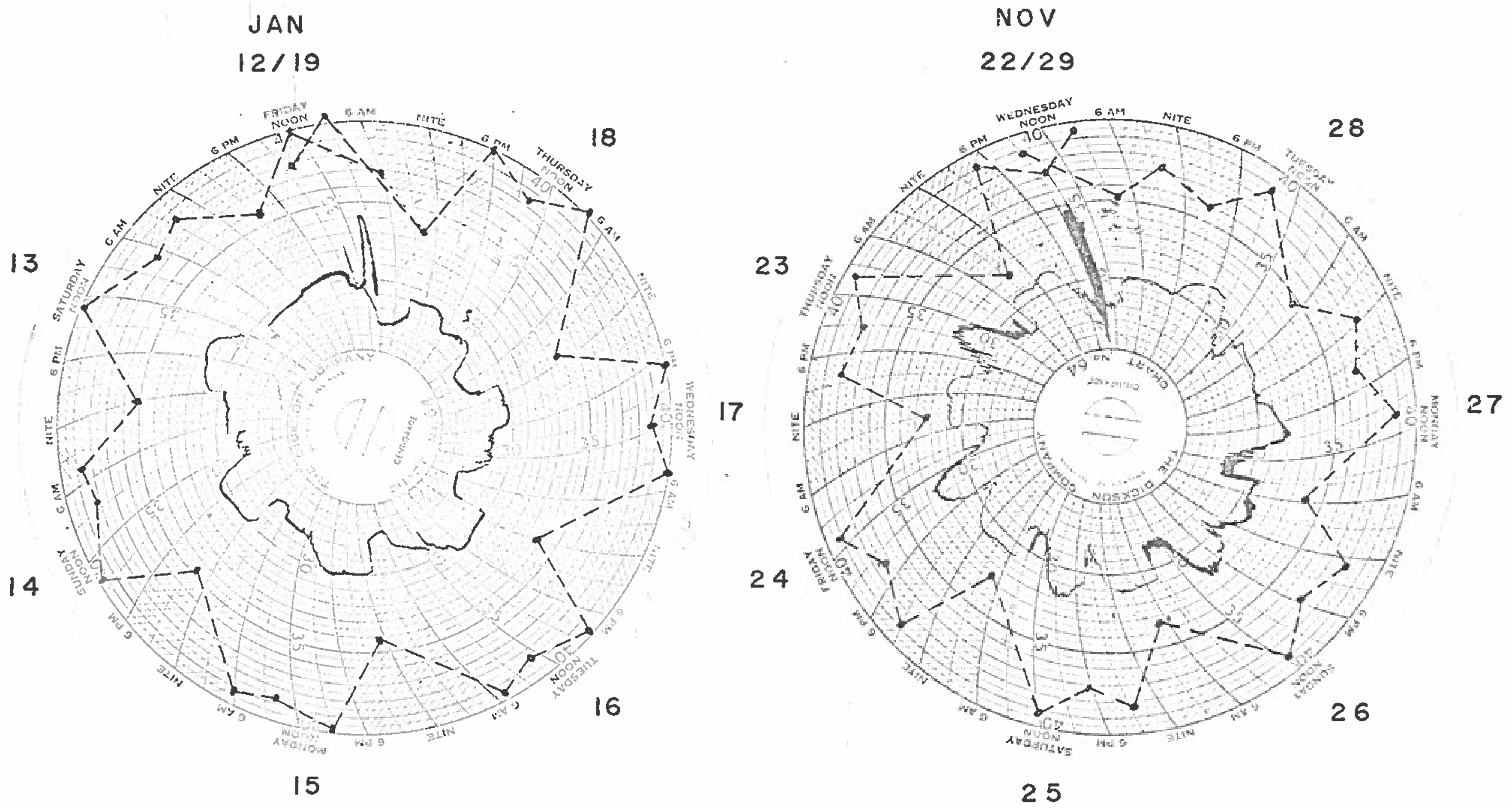

Figure 11. Sample temperature records from the Minicorder located at the mouth of Piti Channel (Station 7, Fig. 9). The record on the left is for 12-19 January 1973 and the record on the right for 22-29 November 1972. The outer lines indicate tidal fluctuations.

late afternoon and early evening hours and the dip comes after midnight and in the early morning hours. The broad peak seems to correlate well with the time of highest intake temperatures (and therefore highest outfall temperatures) reinforced by peak plant loading. The broad dip likewise correlates with the time of lowest intake temperatures in Tepungan Channel and minimal plant loading. The daily pattern is in agreement with the 24-hour telethermometer series for 24-25 August 1972. The range of temperatures recorded by the Minicorder is approximately the same as that reported above for the telethermometer data, with some peaks above 34°C (93.2°F) and some dips below 30°C (86°F).

For Station 4 the continuous temperature recordings show the same pattern as for the outfall location, with a single broad daily peak in the late afternoon and a single broad dip after midnight. A given recording usually parallels the outfall recording for the same time interval. The temperature at Station 4 usually ranges from 0 to 1°C (0 to 1.8°F) lower than the outfall temperature.

The continuous temperature recordings for the mouth of Piti Channel (Fig. 11) usually show two daily peaks and two daily dips. These peaks and dips seem to correlate roughly with low and high tides, respectively, although the correlation is not as clear-cut as might be expected. The temperature peaks for this location generally come within 1°C (1.8°F) of the temperature at Station 4, but the dips may drop as low as 4.0-4.5°C (7.2-8.1°F) lower than the Station 4 temperature. This indicates that the thermal influence of the power plant is much greater at low tides than at high tides at the mouth of Piti Channel, as might be expected. Again, the continuously recorded data show approximately the same range as the telethermometer data, although we regard the telethermometer data as more precise and accurate. The continuous records also indicate that temperatures at the mouth of Piti Channel drop to ambient harbor temperature on almost every rising tide.

It is clear from this discussion of temperatures in Piti Channel and on adjacent tidal flats that the Piti Plant has a minimal thermal impact on the tidal flats and possibly on Piti Channel itself, except for the outfall lagoon immediately adjacent to the plant. Higher temperatures than might otherwise be expected can be attributed to the plant only on cloudy days when solar heating is not significant but when water from the plant outfalls maintains temperatures above 30°C (86°F) in Piti Channel and some portion of Tidal Flat B. (Tidal Flat A has now been filled for construction of the new generating facility.) The diurnal pattern of temperatures caused by the plant parallels and reinforces the diurnal pattern caused by solar heating. The major alteration caused by the plant is probably the higher nighttime temperature in Piti Channel than would be expected without the plant.

Temperature Patterns in the Harbor

Temperature observations were made in Apra Harbor to determine the extent of thermal influence there. Observations were concentrated on a grid system in the berthing area for the Commercial Port (see Fig. 9), but stations in the outer part of the harbor were established to serve as controls.

Repetitive observations were carried out over the course of several individual days and tidal cycles. Representative results are presented in Figures 12-16.

Figures 12 and 13 show the daily pattern observed on 26 October 1972 when we saw the maximum temperature fluctuations in the berthing area of the Commercial Port. It can be seen from the figures that as long as there was a rising tide in the morning, temperatures at all stations (including the mouth of Piti Channel) remained at ambient harbor temperature. As high tide was reached and then the tide began to fall, temperatures at all stations in the Commercial Port increased and then stabilized shortly before dead low tide. Stations closer to the mouth of Piti Channel showed the greatest increases, but thermal influence from the power plant was evident all the way out to the tanker mooring at Station 16. Figure 16 shows plotted isotherms for temperatures taken between 1500 and 1604 hours, the time of most extensive thermal influence in the harbor.

Figures 14 and 15 show the vertical profiles for representative stations at successive times throughout the day. It can be seen that the outsurge of plant effluent water from Piti Channel was confined primarily to the upper 1 m of the water column. Similar patterns were found for the other stations. Water deeper than 2 m remained at ambient harbor temperature and was not influenced by the thermal plume. It seems clear that heating in the harbor was confined to the surface of the water and did not influence the greater depths. As shown in Table 4, there was also thermal stratification at the mouth of Piti Channel an hour after the afternoon low tide.

Figure 16 shows the situation when there was a low morning tide and a high tide in the afternoon; only representative stations are graphed. On this date, as the tide rose in the afternoon, ambient harbor temperature eventually prevailed throughout the area. Again, no daily fluctuation was seen in the control stations in the outer harbor. It is clear that the thermal influence of the power plant in the harbor comes at low tides and is not related to the time of day. Similar results were obtained on other dates not presented here.

Low-tide surface temperatures in the Commercial Port area are affected by heated water flowing off the tidal flats as well as by plant effluent flowing down Piti Channel, but we cannot separate these two heat sources. The berthing area usually appeared to be well mixed laterally, so that stations on the southern side (which probably received water directly from the reef flats rather than from Piti Channel) had temperatures which closely paralleled those on the north side of the berthing area (which were more directly influenced by water flowing out Piti Channel). Thus, temperatures on the south side were always within 1°C (1.8°F) of those on the north side and were neither consistently higher nor lower. It did appear that temperatures on the north side could change more quickly than these on the south side on some occasions.

Table 3 shows temperatures observed at a series of stations in the berthing area and in the outer harbor on several different days. Influence of the water from the power plant clearly extends as far westward as the tanker mooring (Station 16), where increases of up to 1°C occurred on some occasions.

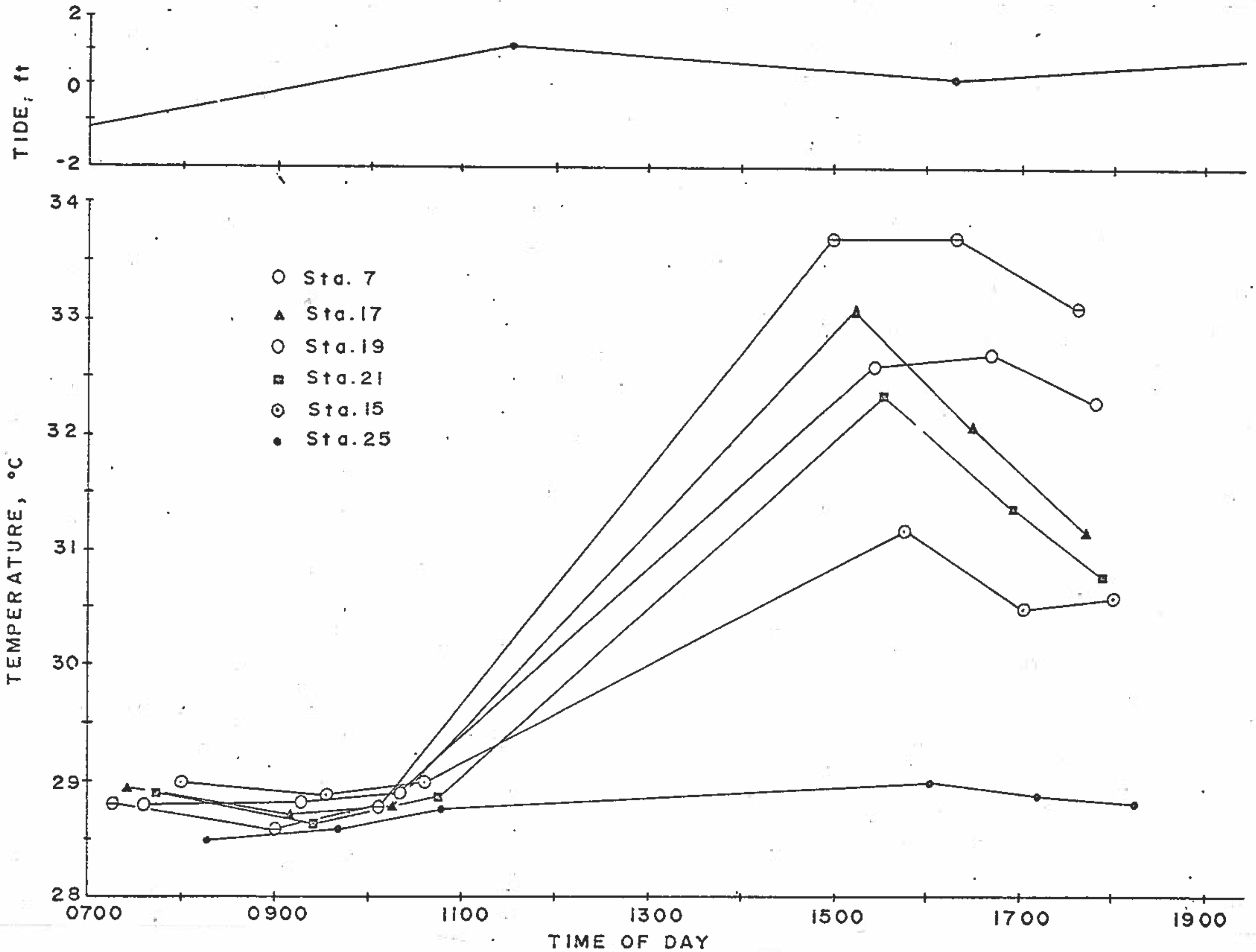

Figure 12. Temperatures at selected stations in the Commercial Port area, 26 October 1972. See Figure 9 for station locations.

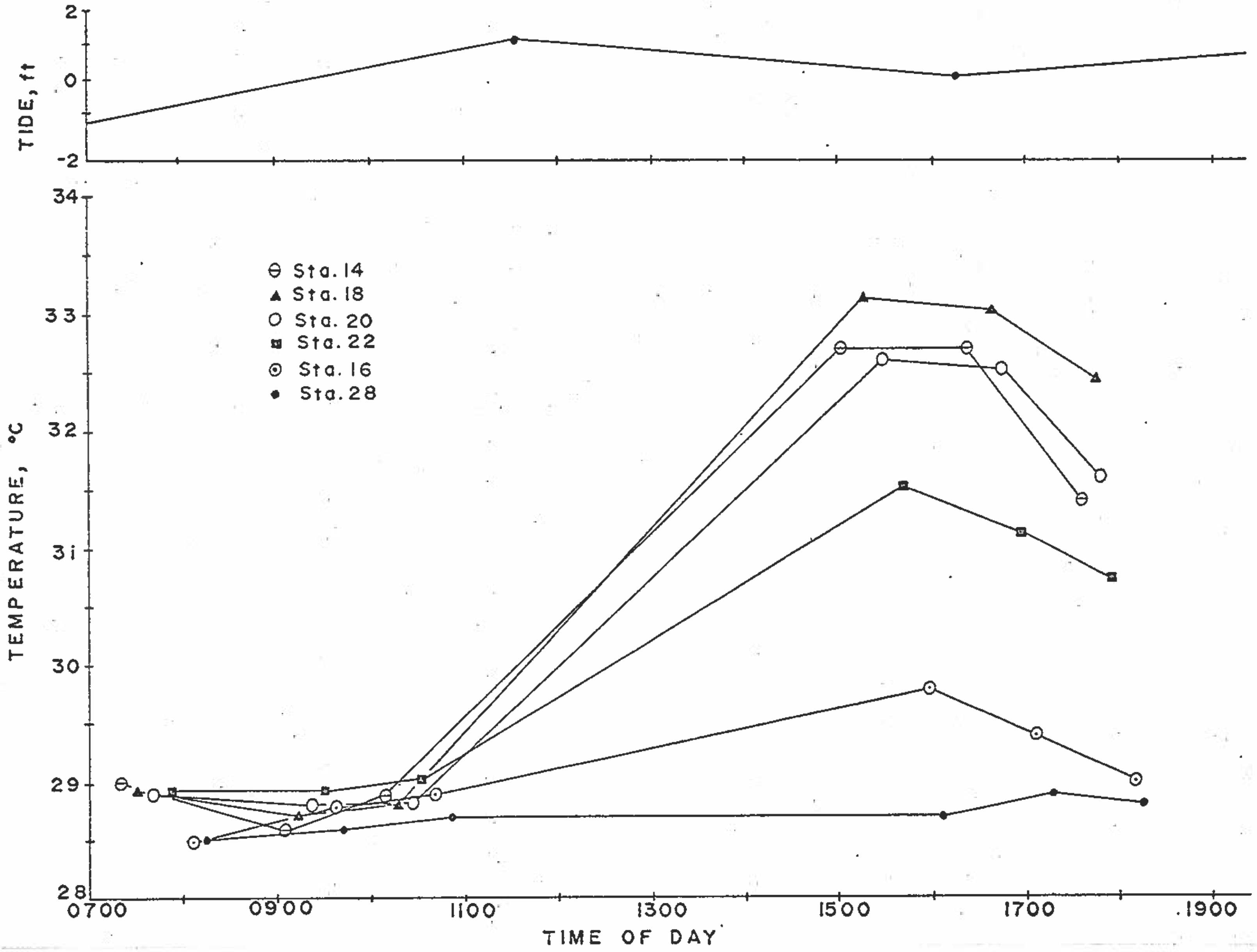

Figure 13. Temperatures at selected stations in the Commercial Port area and Outer Apra Harbor, 26 October 1972. Station 28 is at Signal Buoy 1 (see Fig. 19) in the outer harbor. See Figure 9 for other station locations.

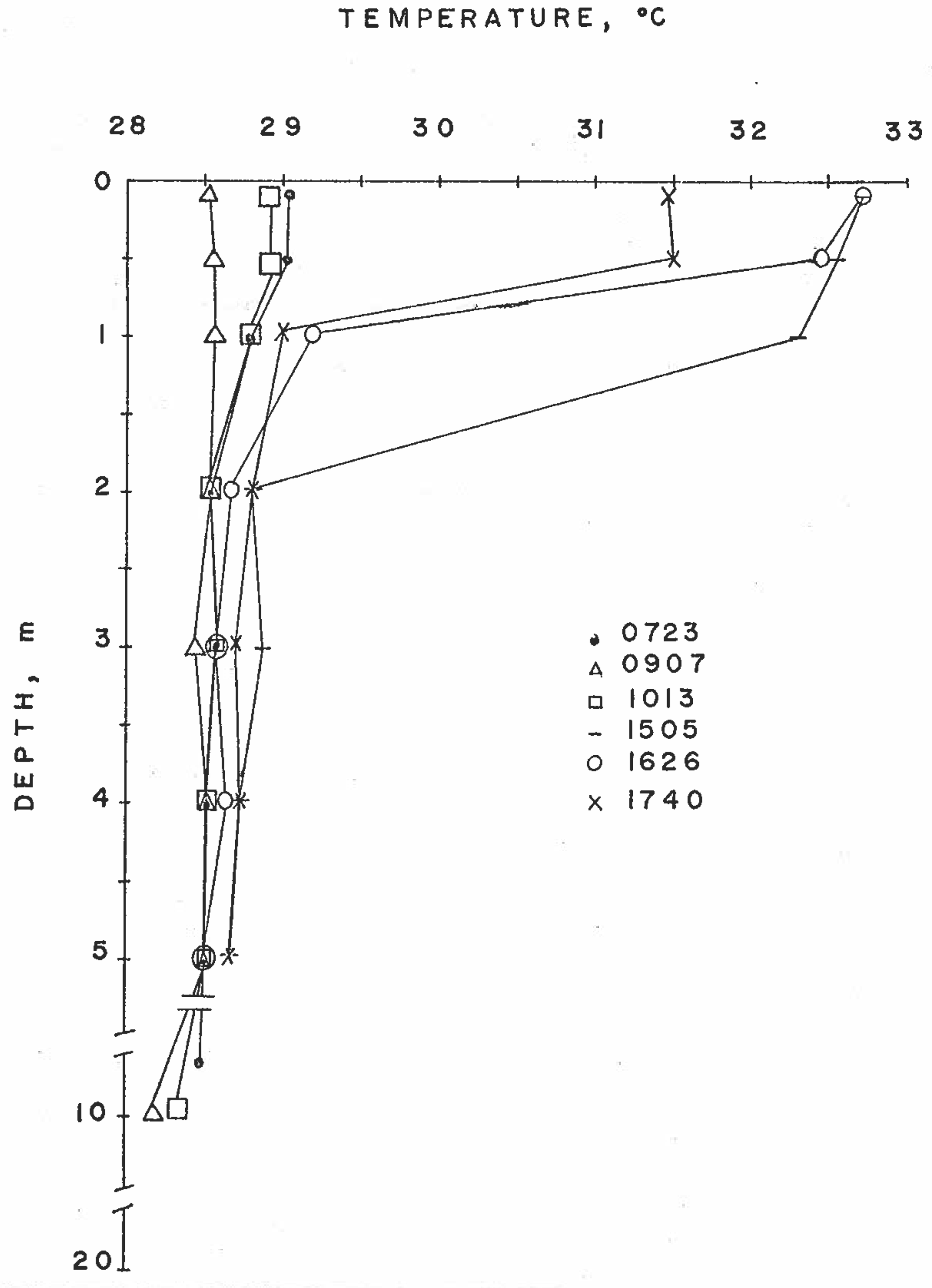

Figure 14. Temperature-depth profile for Station 14 (Fig. 9) for various times of day on 26 October 1972.

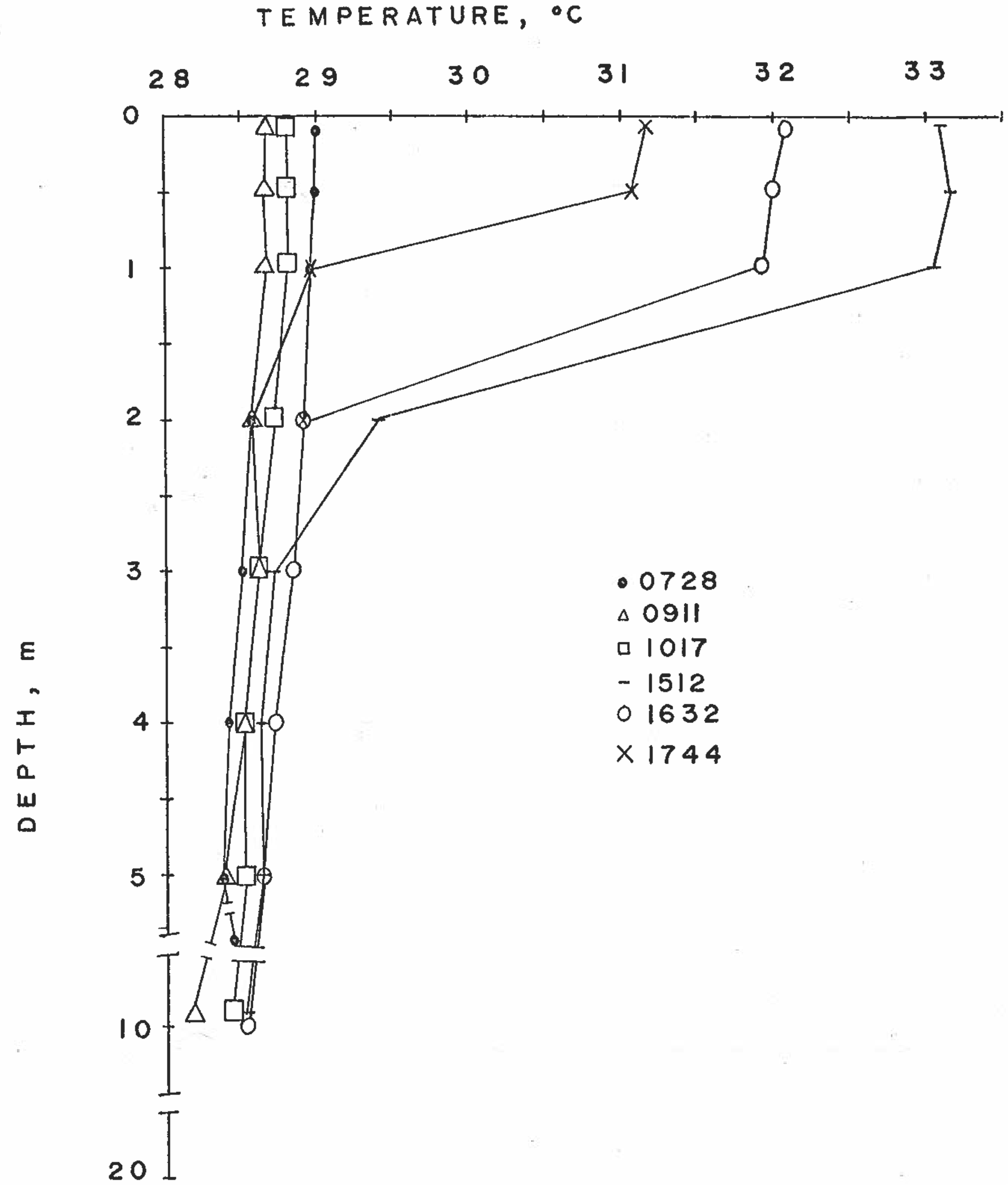

Figure 15. Temperature-depth profile for Station 17 (Figure 9) for various times of day on 26 October 1972.

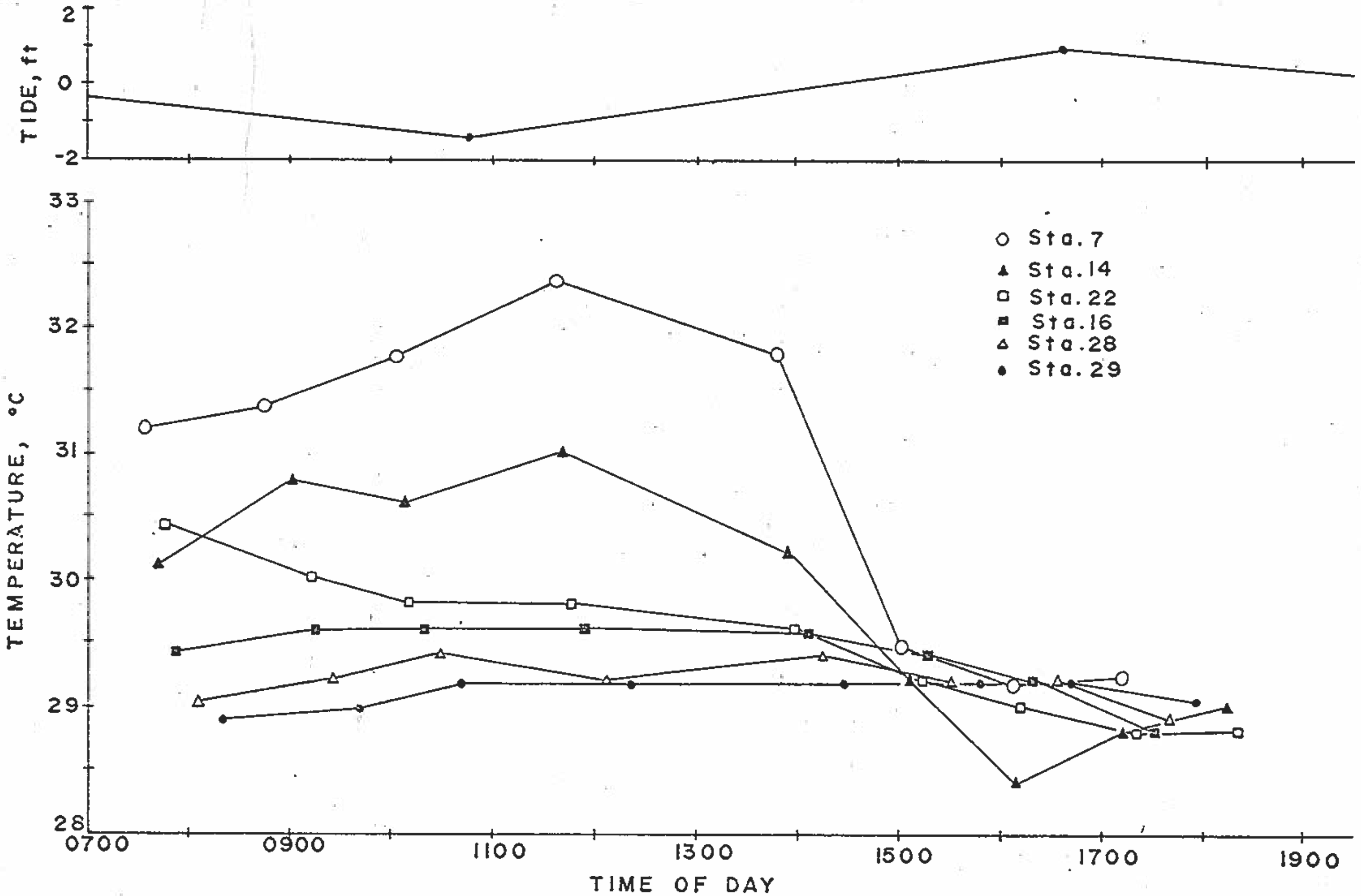

Figure 16. Temperatures at selected stations in the Commercial Port area, 19 October 1972. Station 28 is at Signal Buoy 1 (see Fig. 19) in the outer harbor, and Station 29 is at a mooring buoy near the mouth of the harbor. See Fig. 9 for other station locations.

Other Observations

Salinity determinations were made on four occasions for scattered locations in the study area by using a hand-held refractometer. Almost all values fell in the range 35.0 - 36.1 ppt. Lower values of 34.4 ppt were sometimes found at the point where a sewer outfall from the power plant empties fresh H_2O onto the outfall lagoon. Values as low as 33.9 ppt were found after heavy rains at the dead end of the moat and in isolated, shallow corners of the tidal flats subjected to terrestrial runoff. One such location had a value of 28.3 ppt on one occasion. A high value of 37.1 ppt was found on one occasion in Tepungan Channel. Salinity fluctuations are slight in the study area and are not affected by operation of the power plants, except for the influence of the sewer.

Dissolved oxygen values were also determined on four occasions for scattered locations by the Winkler technique. More often than not, values were between 6.0 and 7.0 mg/l, but values between 7.0 and 8.0 were common. On one occasion a single value of 9.74 was observed in the secondary channel. Values as low as 5.64 were found at the site of the sewer outfall. Except for the sewer outfall, all values were near saturation or exceeded saturation. It appears that the power plant effluent has no adverse effect on daytime oxygen levels in the outfall area.

A 24-hour cycle of observations was conducted on 24-25 August 1972 for three stations: Tepungan Channel (Sta. 2), the outfall location (Sta. 3), and a deep (approx. 3m) hole on Tidal Flat A (Sta. 26; see Fig 9). Results are shown in Table 5. For the intake station and the hole on Tidal Flat A, diurnal values fluctuated widely above and below saturation with high points in the middle of the day and low points at dawn. This probably reflected daytime oxygen production by planktonic and benethic photosynthesizing organisms and nightime respiration by the entire biological community. Values were much less variable at the plant outfall. This is probably due to turbulence (as a result of pumping water through the plant) causing rapid oxygen diffusion out of and into the water during daytime and nightime hours, respectively, thus maintaining dissolved oxygen in the outfall water closer to saturation values than in the intake water. It is clear that the plant has no adverse effects on levels of dissolved oxygen in the effluent cooling water.

Dissolved oxygen values were determined at the surface, midwater, and bottom for three stations in the Commercial Port area on 27 March 1973. Water at all stations and depths was saturated or supersaturated with oxygen. This is probably representative of harbor waters generally and suggests optimal conditions with respect to dissolved oxygen.

On two occasions pH determinations were made for scattered stations in Piti Channel and on the reef flats. Values ranged from 7.90 to 8.15, a normal range for seawater.

Table 5. Temperatures (°C) and dissolved oxygen (mg/l) at three locations during a 24-hour period, 24-25 August 1972. Dissolved oxygen values are the means of two titrations each from two DO bottles (total of four titrations). See Fig. 9 for station locations.

Intake (Sta. 2)			Outfall (Sta. 3)			Tidal Flat A Hole (Sta. 26)		
Time	DO	Temp.	Time	DO	Temp.	Time	DO	Temp.
1027	7.26	28.8	1000	6.97	33.8	1012	6.52	32.2
1215	10.16	29.8	1200	7.49	34.6	-	-	-
1425	9.87	30.0	1400	7.28	35.6	1410	8.03	32.7
1610	9.19	29.6	1600	6.96	34.8	-	-	-
1815	7.31	28.6	1755	7.47	34.4	1805	8.16	32.7
2015	8.10	28.8	2000	6.81	33.6	-	-	-
2220	6.67	28.0	2155	7.16	33.5	2205	7.81	32.8
0015	6.55	27.6	2400	6.99	33.5	-	-	-
0225	6.05	27.2	0155	7.47	32.8	0205	6.91	31.0
0420	4.88	27.2	0400	6.69	33.0	-	-	-
0625	4.69	27.0	0555	8.20	32.6	0605	5.20	30.4
0810	6.63	27.4	0755	6.01	32.0	-	-	-
1105	8.32	28.8	1005	7.15	32.5	1015	6.44	31.2

On 6 July 1972 we noticed a strong chlorine smell while snorkeling in the outfall lagoon. Tests made with a field kit indicated chlorine levels greater than 5 ppm. This was the only occasion when we ever detected any chlorine with the test kit, although a strong smell was noticeable several other times when the water was not tested. The smell usually disappeared within a few minutes.

Fish kills have occasionally been noticed. The most extensive one occurred on 19 July 1972 when at least 10 species and more than 40 individuals of dead fish were found in the vicinity of the outfall. It is likely that more dead fish could have been found with a careful search. We have seen smaller fish kills on other occasions and scattered individual dead fish on numerous occasions. We suspect that the fish kills may be caused by chlorine from the plant but have not detected chlorine in the water at the times of observed fish kills. The kills could have been due to chlorine which rapidly dispersed and thus was not detectable when we saw dead fish at some later time.

A pyrheliograph has been maintained on the roof of the USO building near the study area to record the amount of solar radiation striking a horizontal surface. This gives an upper limit on the amount of solar energy that can be absorbed by water standing on the shallow tidal flats. For comparative purposes, a pyrheliograph has also been maintained on the roof of the University of Guam Science Building in Mangilao. Results are shown in Figure 17. There appears to be a slight seasonal trend in solar input, with lower values occurring from July through March and higher values occurring from April through June. However, variation from week to week can be as great as the apparent general trend in seasonal variation, and variation between the two recording localities is also rather high. It does not show in our figure, but day-to-day variation can also be as high as seasonal variation. This pattern of rather high variation from week to week, day to day, and place to place results from rainy or overcast vs. sunny weather conditions and indicates that short-term changes are more significant than seasonal patterns with regard to solar heating of water on the tidal flats. This reinforces the similar observation that has already been made from actual temperature measurements on the tidal flats.

PROJECTIONS

We have attempted some rough projections of temperature patterns to be expected in the harbor after the Cabras Island units now under construction go into operation. While these projections are not very refined, we do think they are informative. Our assumptions are such that the projections give the maximum area that might be affected by water temperatures more than .3°C (.5°F) above ambient; it is likely that a smaller area will be affected most of the time.

Our general procedure for calculations is given here.

(1) We first calcuate the tidal volume of water moving from the channels and tidal flats into the Commercial Port area on a falling tide with

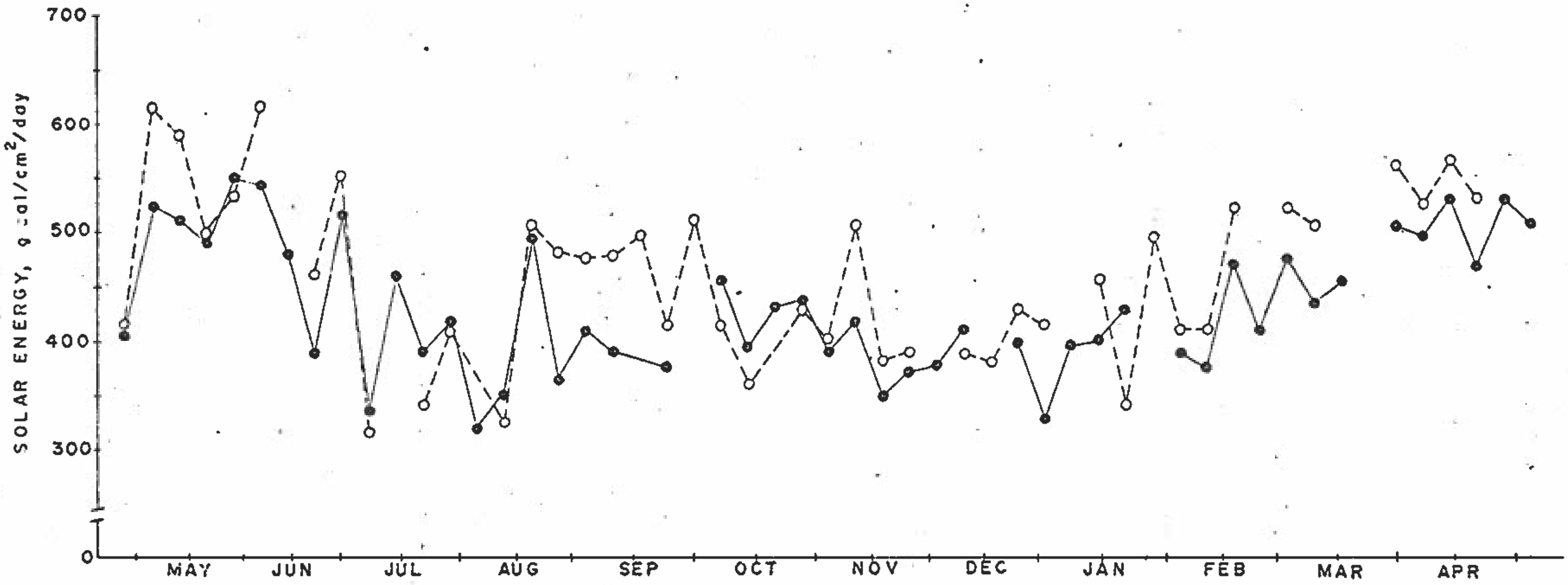

Figure 17. Pyrheliograph records for May 1972 through April 1973. The solid lines and closed circles represent a station on the roof of the USO building at Piti, Guam; and the broken lines and open circles represent a station on the roof of the University of Guam Science Building at Mangilao, Guam. Most points represent the mean of seven daily observations, but a few points represent fewer than seven observations.

a 1-m range (we assume that this water has the same temperature as plant effluent because of solar heating) and add to this the volume of water presently pumped through the Piti Power Plant during a falling tide interval (assumed to be 6 hours). (2) We assume that this water occupies a lens 1 m thick in the Commercial Port (Figures 14 and 15) and a horizontal area equivalent to that seen in our most extreme observation (Fig. 18). (3) This volume of warmer-than-ambient water in the harbor (Step 2) is then taken as a percentage of the calculated volume of water entering the harbor because of plant output and tidal outflow (Step 1). The former volume (Step 2) is smaller than the latter volume (Step 1) because the heated water (solar and power plant heating) loses part of its heat through mixing with cooler water and loss to the atmosphere. (4) The percentage found above is then applied to calculate the volume of warmer-than-ambient water in the harbor as a result of calculated future plant output plus tidal exchange. (5) The future volume of warmer-than-ambient water is assumed to occupy a lens 1 m deep and the total area it occupies is then calculated. Actual calculations follow.

Table 6 shows the calculated tidal volume leaving the channels and tidal flats on a falling tide with a 1-m fluctuation. For the channels this simply represents a layer of water 1 m thick overlying a deeper water column. For the tidal flats the approximate depths at high spring tides are given; and we assume that these flats have no water at low spring tides, although a little water is actually retained in depressions. The total tidal volume of water leaving the study area and entering the harbor was approximately 409,000 m^3 before the filling of Tidal Flat A by construction activities. With Tidal Flat A filled the total volume now is approximately 385,000 m^3. Outflow from the Piti Power Plant is approximately 4 m^3/sec (64,000 gpm), or about 14,300 m^3/hr. The total plant outflow for a 6-hr falling-tide period would therefore be about 86,000 m^3, the assumption of a time interval this long certainly maximizes the calculation of plant effects in the harbor. The sum of plant output and tidal volume is 495,000 m^3.

Figure 18 shows the maximum extent of above-ambient temperatures in the harbor under present conditions. The total area with temperatures detectable as .3°C higher than ambient temperature is approximately 421,000 m^2. If this lens of water is 1 m deep, then the total water volume with above-ambient temperature is 421,000 m^3, or 85% of the calculated input into the harbor during the falling-tide period. This percentage figure will be used in the next calculation.

If we assume a future plant output of 272,000 m^3 per 6-hr tidal cycle (equivalent to 200,000 gpm from the existing and future generating facilities) and a tidal outflow of 385,000 m^3 per tidal cycle (corrected from the above figure of 409,000 m^3 because of the filling of Tidal Flat A), then the total flow into the Commercial Port area is 657,000 m^3 for a falling tide. If 85% of this represents the water volume of above-ambient temperature in the harbor, and if it occupies a surface lens 1 m thick, then the maximum possible surface area of the harbor with temperatures just barely detectable as .3°C higher than ambient is 558,000 m^2. This is an increase of 32% over the area presently affected by warmer tidal flat and plant outfall waters. The maximum area likely to be affected under such new conditions is plotted in Figure 19.

Table 6. Areas (determined by planimetry), depths, and calculated volume of tidal exchange for a 1-m range between high and low tide. Indicated depths of the channel tracts are not the actual surface-to-bottom depths but represent instead the tidal fluctuation. Indicated depths of the tidal flat tracts are the surface-to-bottom depths at high tide. See Fig. 1 for location of the various tracts.

Tract	Area (m^2)	Depth (m)	Tidal Volume (m^3)
Upper Piti Channel	74,300	1	74,300
Lower Piti Channel	31,900	1	31,900
Secondary and Connecting Channels	26,200	1	26,200
Moat	10,000	1	10,000
	Total, Channel tracts		142,400
Tidal Flat A	31,400	.75	23,600
Tidal Flat B	70,600	.75	53,000
Tidal Flat C	126,000	.50	63,000
Tidal Flat D	126,900	1.0	126,900
	Total, Tidal Flats		266,500
	Overall total, channel tracts + tidal flats		408,000

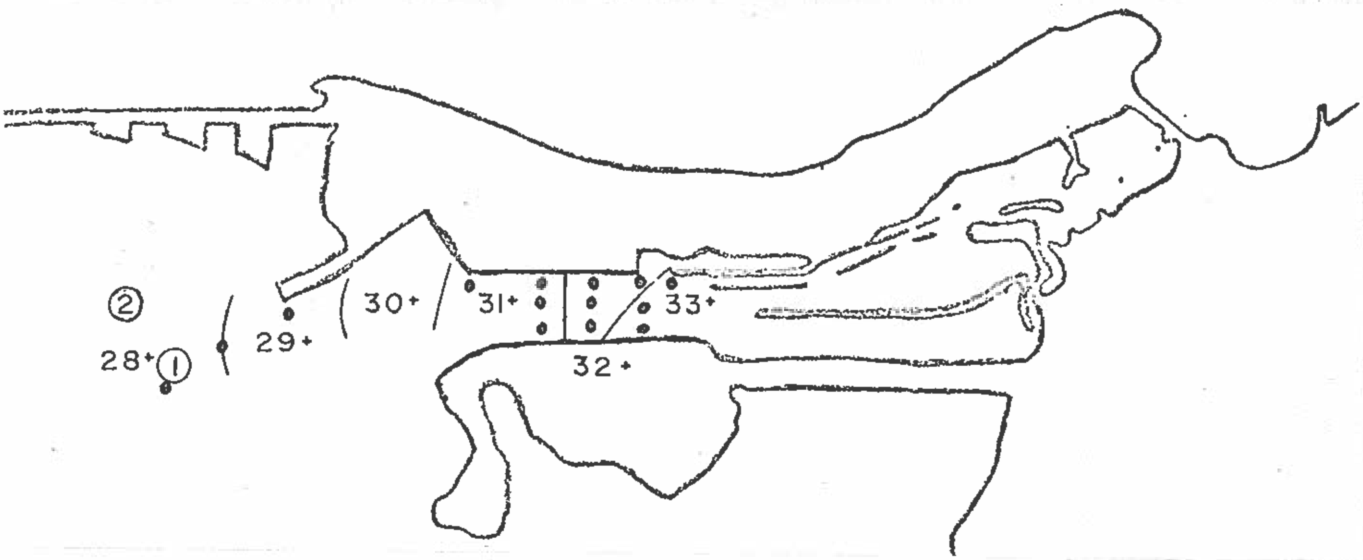

Figure 18. Isotherm plot for the Commercial Port area between 1500 and 1600 hours, 26 October 1972.

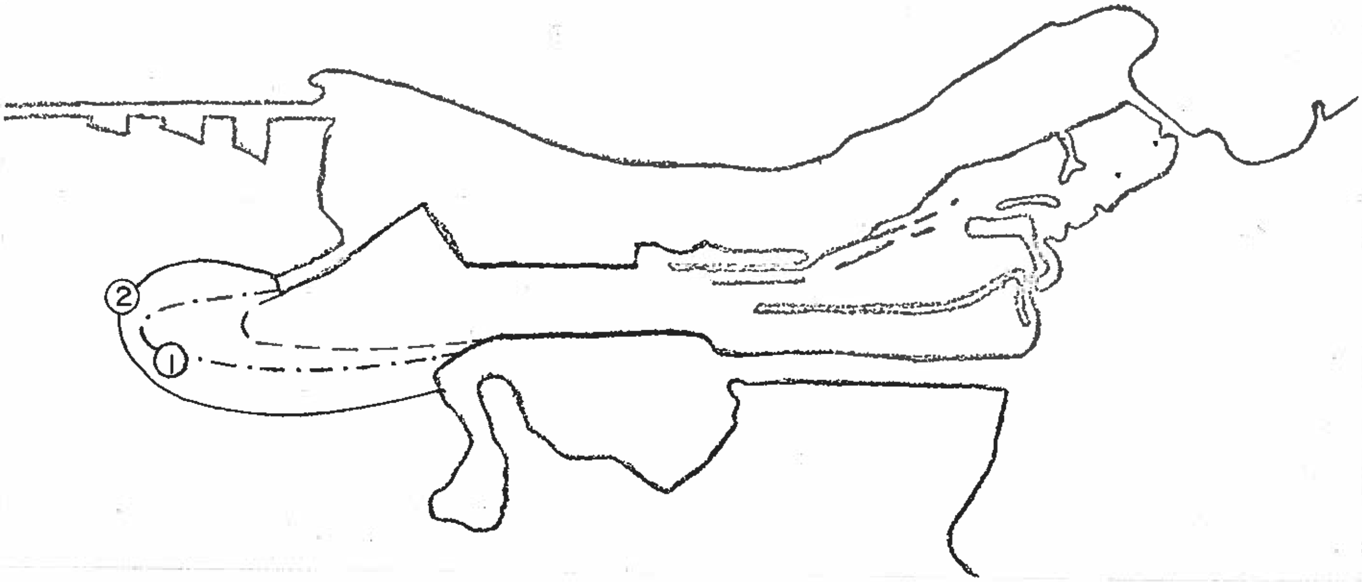

Figure 19. Approximate westernmost limits of temperatures at least .3°C (.5°F) above ambient under most extreme conditions. See the text for further discussion. The dashed line represents the observed pattern for present power plant operations (refer to Figure 16). The dashed-dotted line represents the projected pattern for a future plant output of 12.6 m^3/sec (approx. 200,000 gpm); and the solid line represents the projected pattern for 25.2 m^3/sec (approx. 400,000 gpm). The circled numbers indicate the locations of signal buoys.

A similar calculation has been carried out using the assumption that future plant outfall volume will be 544,000 m^3 per 6-hr tidal cycle (equivalent to approximately 400,000 gpm). The maximum surface area of the harbor likely to be affected under such conditions is 790,000 m^2, or an increase of 88% over the maximum area presently affected. Again the maximum area likely to be affected is plotted in Figure 19.

We must emphasize again that our calculations are very crude, and we hope to be able to refine them. However, because we have assumed the worst possible case, we think that our projections of harbor areas likely to be affected by the thermal plume are maximal and likely to be observed only under extreme conditions. Much smaller areas are likely to be affected by the thermal plume under more usual conditions.

In these calculations we have not separated thermal effects in the harbor due to the outflow of plant effluent from effects due to the outflow of tidal-flat water heated by the sun. We believe that such effects cannot be separated, since the two types of water are well mixed in the harbor. However, outflow of water from the tidal flats during a falling tide greatly exceeds plant output at the present time. Hence, for a falling tide on the afternoon of a sunny day, solar heating may have more of an indirect effect on the harbor than heating from the power plants. On a cloudy day tidal flat water dilutes the heating effect of plant effluent in the Commercial Port area. If the eventual output from existing and future generating facilities reaches 25.2 m^3/sec (400,000 gpm), then plant effluent could represent a greater source of input into the harbor than tidal exchange for a 6-hr falling-tide period when there are spring tides (544,000 m^3 plant output vs. 385,000 m^3 tidal outflow). Under such conditions a large proportion of water flooding Tidal Flats C and D on a rising tide would probably come from the plant outfalls rather than from the Commercial Port area.

Most areas of the tidal flats, as well as the mouth of Piti Channel, probably drop to ambient temperature levels at least once a day. In the case of the tidal flats this occurs at night, since raised temperatures are caused primarily by solar heating rather than plant effluent. The mouth of Piti Channel and the eastern portion of the dredged area of Commercial Port drop to ambient harbor temperatures during periods of rising and high tides when tidal inflow overcomes outflow from Piti Power Plant. After the Cabras Island installation goes into operation we expect the mouth of Piti Channel and the adjacent area at Commercial Port to have a permanent temperature regime higher than ambient harbor temperature. We cannot quantify this projected effect at this time, and our judgement is strictly qualitative.

We do not have sufficient knowledge at this time to predict the biological effects in the harbor caused by the expected new temperature regime. However, we note that warmer water will continue to form a lens on the surface and will not extend to the deeper waters of the harbor nor directly affect benthic organisms. Hence, it is only surface planktonic communities that are likely to be affected. We further note the inherent variability in such communities and believe that we must be extremely careful in ascribing future changes in them to plant effects without a great deal more knowledge than is currently available.

Dissolved oxygen levels in the harbor are presently at saturation levels from surface to bottom, at least in the daytime, although we need to do further sampling. This is fortunate and suggests that the area is presently subjected to no major biological stresses. Tidal and wind-driven circulation also appears to be good and probably enhances vertical mixing. The new power plant should cause no major change in this condition, assuming that its thermal effect is confined to a surface layer of water. However, it must be remembered that if additional biological stresses are imposed on the area in the future there is a possibility of synergistic effects. The thermal load may not be an excessive stress in itself, but in combination with other factors it could contribute to extremely undersirable effects. This would be particularly true if organic material were discharged into the harbor, thereby creating an increased oxygen demand at the same time that higher temperatures were causing lower oxygen solubilities.

Water quality standards for Guam are presently being reviewed and updated, and we do not know what new standards will apply to Outer Apra Harbor. It is possible, but not probable, that future plant operations could cause a violation of temperature standards as they presently apply to the outer harbor. The existing standards specify that temperature in that area should not differ from natural conditions by more than 1.5°F (.8°C). We cannot make exact predictions; but if there is a potential violation, it is likely to affect a relatively small area of the outer harbor (see Fig. 19) and to occur only during a portion of the tidal cycle. This matter will have to be re-examined after the new water quality standards are established. No temperature criteria are in effect for Piti Channel and the Commercial Port area under existing water quality standards, nor do the present standards contain any criteria other than temperature which are likely to be violated by power plant operations. We do not know whether the new standards will include criteria for metallic ions, but such ions may leach from pipes and condensers and lead to a potential problem.

CONCLUSIONS

Adverse thermal effects of the Piti Power Plant are minimal in Piti Channel and adjacent tidal flats. The shallow tidal flats are strongly affected by solar heating, and in the afternoons of sunny days they may have higher temperatures than the effluent cooling water from the power plant. It is doubtful that the present power plant is responsible for heating the water in the general study area to higher temperatures than would be the case because of solar heating alone.

The major influence on temperature fluctuations in Upper Piti Channel and adjacent tidal flats is the daily solar cycle, but this is reinforced by the daily cycle of plant loading. This may be modified by weather. Highest temperatures usually occur in late afternoon and lowest temperatures occur between midnight and dawn. At the mouth of Piti Channel and in the Commercial Port area, highest temperatures occur on a falling and low tide and lowest temperatures on a rising tide. Most of the study area is thus a fluctuating-temperature system, with temperatures dropping to ambient levels for a portion of each day. Daily temperature patterns, as modified by weather, mask any possible seasonal patterns.

Effluent from the Piti Power Plant sometimes causes fish kills in Piti Channel. These may be due to chlorine. Chemical effluent from the plant is probably of greater ecological concern than the thermal effects. It is likely that an increased number of fish kills can be expected in Piti Channel after the new Cabras Island Plant goes into operation.

The maximum current velocity in Lower Piti Channel is likely to increase from approximately .6 m/sec (2 ft/sec) at present to about .85 m/sec (2.8 ft/sec) after Cabras Island Units 1 and 2 go into operation. There may be no reversal of current direction (i.e., an easterly flow) on rising tides in Lower Piti Channel after the new units go into operation. Piti Channel, in effect, will simply become more of a conduit for conducting effluent water from the plant outfalls to the Commercial Port area.

The present tidal flow of water into the harbor from Piti Channel and adjacent flats is approximately four times as great as the flow from the power plant during a falling-tide period. These two types of water are mixed in the Commercial Port area and are indistinquishable there. It is likely that there would be thermal effects in the harbor because of tidal outflow even if there were no plant operations. If total plant output increases to 25 m^3/sec (about 400,000 gpm) in the future, then plant output on a falling tide will be approximately equal to outflow from the tidal flats.

The Commercial Port area presently serves as a cooling lagoon for part of the tidal cycle but also drops to ambient temperatures for a portion of each tidal cycle. With additional future effluent from plant outfalls, the area will have ambient harbor temperatures for a shorter portion of each tidal cycle but will probably still retain its fluctuating-temperature pattern. Warmer water forms a layer approximately 1 m thick on top of the cooler harbor water and thus loses heat to the atmosphere.

Although we have studied only the marine environment, we believe that the most serious environmental problem associated with future operations of the Cabras Island Power Plant is likely to be air pollution rather than marine pollution.

RECOMMENDATIONS

1. Construct the cooling water outfalls for the new power plant in such a way as to maximize turbulence in the immediate outfall locality and prevent effluent water from being forced directly downstream in Piti Channel. This will allow some heat exchange with the atmosphere before the direct downstream flow begins. It may be necessary to construct a series of baffles or artificial shoals at the outfall location or to enlarge the outfall lagoon adjacent to the power plant. In any case, Guam Power Authority should be prepared to modify the outfall structures if this proves necessary after operation of the new plant begins.

2. Alterations on the tidal flats, except in the immediate vicinity of the construction site, should be avoided. Effluent water should be directed into Piti Channel rather than onto the tidal flats.

3. Guam Power Authority should be prepared to modify the existing Piti Channel after plant operations begin if current velocities in the lower stretches of the channel create a safety hazard for fishermen or boaters.

4. Guam Power Authority should be prepared to make any changes necessary after plant operations begin to insure that heated water entering the dredged area at Commercial Port spreads as a layer on the surface and is not mixed into the deeper part of the water column. The objective should be to maximize contact with the atmosphere and to avoid using the deeper portions of the water column for permanent heat storage. To the extent practical, it is also desirable to maintain a thermal stratification in Lower Piti Channel rather than having complete vertical mixing.

5. Carefully evaluate the use of any chemicals in the plant which will appear in the effluent water. This especially applies to chlorine. Do not use any chemicals in plant operations without a compelling reason for doing so, and then use them only in the minimum amounts necessary and only when necessary. There should be continual evaluation and re-examination by competent chemists, biologists and engineers of the routine use of chemicals in plant operations. Operations personnel should keep up-to-date on new developments. Guam Power Authority should be prepared to modify its operations in the future as new developments come about, even though this may involve some change-over expenses.

6. Keep up-to-date on Federal and local water quality standards, and maintain communication with the U. S. and Guam Environmental Protection Agencies to insure that all environmental protection laws are understood and met.

7. Future storage of fuel and chemicals both inside and outside the plant should be carefully planned, conducted, and monitored so as to avoid spillage and leakage of toxic substances into the environment.

Table 3. (Continued)

Date and Time	Weather	Stations 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
18 Aug. 72 Morning	Sunny	27.4	27.8	32.8	30.8	30.6	30.6	30.6	-	-	30.2	30.4	-	-	-	-	-
18 Aug. 72 Midday	Rainy	28.4	-	-	-	-	31.2	30.8	31.0	31.0	-	-	30.3	30.4	29.4	-	29.0
21 Aug. 72 Morning	Overcast	27.4	-	33.0	30.8	30.6	30.2	30.4	-	30.4	-	-	-	-	30.2	29.4	28.6
21 Aug. 72 Midday	Overcast	29.4	-	-	-	-	31.0	31.0	31.0	31.2	-	31.0	-	-	-	-	-
22 Aug. 72 Morning	Scattered clouds	-	-	-	-	-	-	31.8	-	-	-	-	-	-	30.6	-	29.8
22 Aug. 72 Midday	Scattered clouds	-	-	-	-	-	-	32.0	-	-	-	-	-	-	30.2	29.6	29.5
22 Aug. 72 Afternoon	Scattered clouds	-	-	-	-	-	-	34.1	-	-	-	-	-	-	30.8	30.2	30.0
24 Aug. 72 Late afternoon	Cloudy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24 Aug. 72 Midnight	Cloudy	-	-	-	33.0	32.8	32.8	-	30.8	31.0	-	-	-	-	-	-	-
7 Sept. 72 Morning	Sunny	-	-	-	-	-	-	32.0	-	-	-	-	-	-	31.5	31.4	29.4
7 Sept. 72 Midday	Sunny	-	-	-	-	-	-	33.6	-	-	-	-	-	-	32.9	32.4	31.1
14 Sept. 72 Morning	Scattered clouds	-	-	-	-	-	-	30.8	-	-	-	-	-	-	31.1	31.0	30.3
21 Nov. 72 Morning		-	-	32.2	31.5	30.8	30.7	28.9	-	29.4	29.6	-	-	-	-	28.1	28.0
21 Nov. 72 Early evening	Partly cloudy	-	-	-	-	-	32.5	31.3	31.9	32.0	-	-	-	-	28.1	27.9	28.0

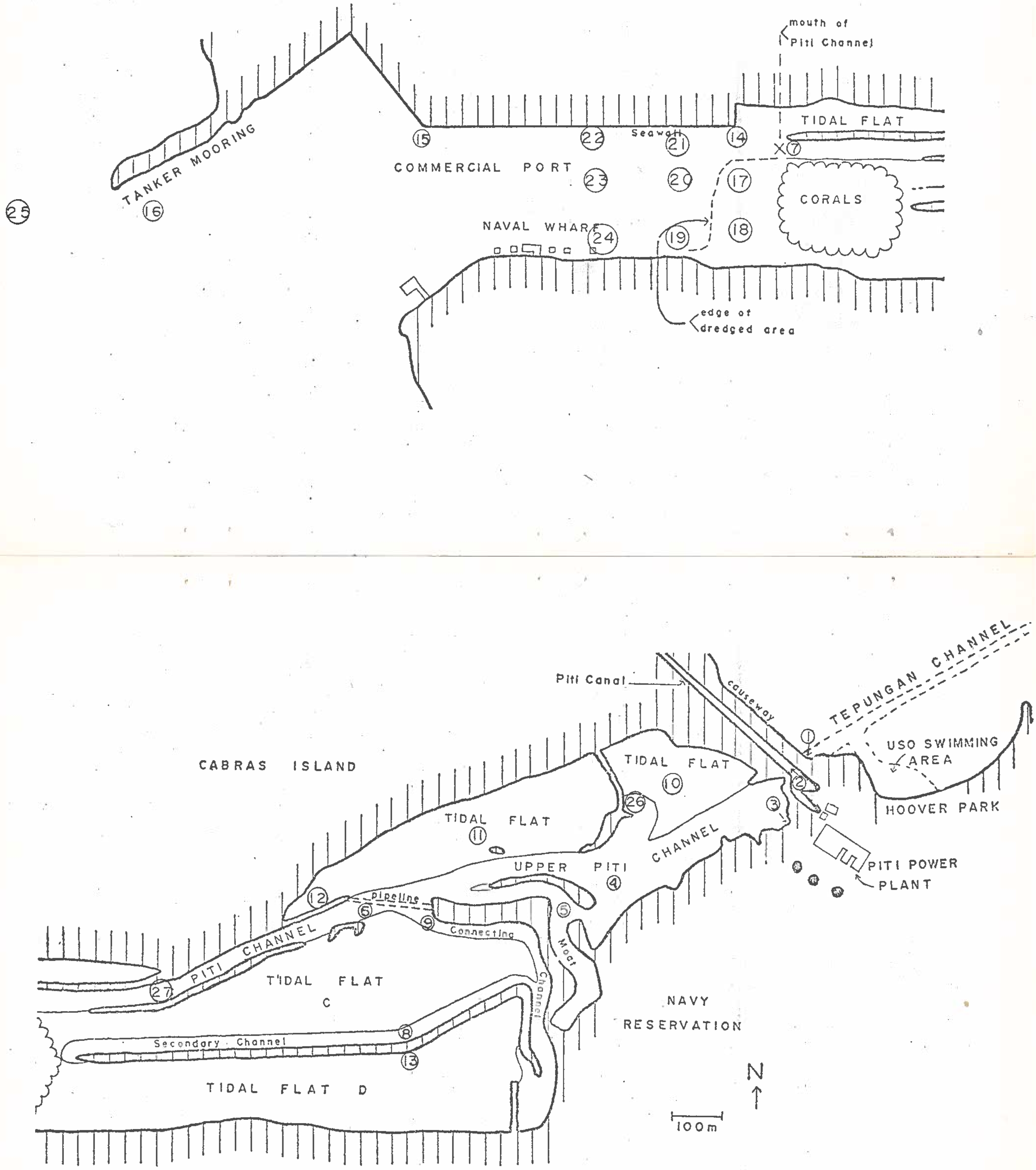

Figure 9. Locations of stations discussed in the text and in Table 3. Station 28 is at Signal Buoy 1 in the outer harbor (see Fig. 19), and Station 29 is at a mooring buoy near the mouth of the harbor.