LIMITED CURRENT AND BATHYMETRIC SURVEYS AT THE MARINE OUTFALL IN LELU HARBOR

AND

RECONNAISSANCE SURVEYS OF EFFLUENT DISPOSAL SITES AT MALEM AND UTWE, KOSRAE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A sanitary and wastewater disposal facilities plan was prepared by World Health Organization (WHO) for Kosrae State (Videnov and Ludwig, 1983). This facilities plan designed village level sanitary systems. It based inovative designs on the concept of individual family core units with septic tank effluent discharge into leaching fields and, in the case of Lelu village, a marine outfall. There were concerns about specific environmental and engineering aspects of this facilities plan expressed by local, national and federal environmental protection agencies. Systems designed for Lelu, Malem and Utwe villages (Figure 1) were of particular concern in regards to effluent disposal. The plan called for a common septic tank effluent collection system and submarine outfall for Lelu with discharge into Lelu harbor. The plan for Malem called for collection of septic tank effluents from household core units into gravity flow pipe lines. This effluent was to be discharged into an adjacent mangrove area using agricultural slotted pipelines. At Utwe village, septic tank effluent would be discharged into three leaching fields, which would be reclaimed from both fringing reef and mangrove swamp adjacent to the community.

OBJECTIVES

The proposed objective of this study was to determine marine water currents within Lelu Harbor and near the reef at Malem. However, a verbal agreement was made with the contracting agency to expand or modify the scope of work and objective, if deemed necessary, after making an on-site investigation in Kosrae.

As a result of preliminary observations made at the beginning of the field survey, the objective was modified: 1) to quantify marine water circulation patterns in Lelu Harbor, 2) to measure harbor floor topography in order to better assess placement and plume dispersion characteristics of a submarine effluent outfall, 3) and to determine the feasibility of using a marine outfall at Malem village by measuring near shore water currents and conducting bathymetric surveys. Diverse field conditions made it impossible to perform field work outside the reef at Malem. Consequently, reconnaissance surveys were used to determine the feasibility of constructing a sewage outfall and assessing other alternatives for sewage disposal. A fourth objective, not originally a part of the study, was to survey mangrove swamp adjacent to Utwe village in relation to anticipated impacts. This Utwe survey was requested by the Kosrae State Environmental Protection Board (EPB) in a January 1984 board meeting.

METHODS

Surveys were conducted in January and April, 1984, at Lelu Harbor, Malem and Utwe shorelines (Figure 1). In January at Lelu Harbor, surface and subsurface (5m and 10m depths) water currents were measured and a detailed bathymetric survey was made of the outer harbor. Reconnaissance

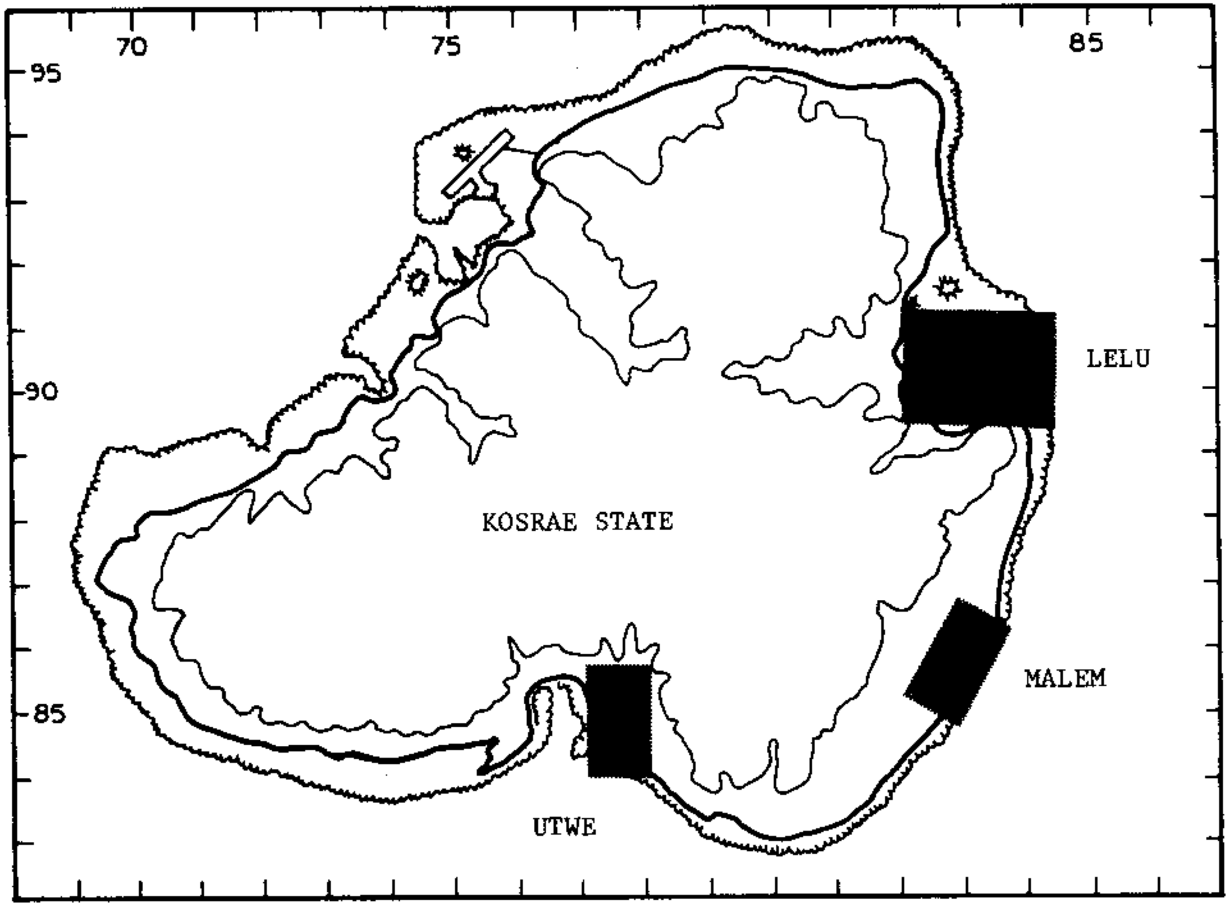


Figure 1. Study areas in Kosrae. Water current and bathymetric surveys were made at Lelu harbor and reconnaissance surveys were made at Malem and Utwe Villages.

level surveys were conducted along the coastline and at proposed effluent disposal leaching field sites near Malem and Utwe communities.

Current studies were made in Lelu Harbor using drift drogues. Drift drogues consisted of a 1-m tall sheet steel vane with a cross shape (as seen in transverse section) suspended from a buoy by a length of line. The length of line was varied to suspend the vanes at three depths: in a surface water layer of 1-2m, a subsurface layer of 5-6m and a subsurface layer of 10-11m. The vane weight and lift of the buoy were adjusted to reduce the above-water exposure of the buoys to a height of 10-15 cm. Drogue tracking was accomplished by using a hand bearing compass. Six triangulation points (harbor marker bouys A to F) were selected within the harbor (Figure 2). Drift drogues were released at 6 locations with 2 drogues, a 1-m and a 5-m vane depth, usually released at each location (Figure 2). Three compass readings on triangulation points were taken as each drogue set was released. Intermittent triangulation readings were taken as the drogues drifted and at recovery of the drogues. Tidal conditions, wind direction and speed were also recorded. Water movement was measured for strong rising and falling tide conditions.

In July 1984, the United States Coast Guard conducted maintenance on the Lelu harbor buoys and buoy B (Figure 2) was removed.

The bathymetric survey of Lelu harbor was made using a recording fathometer (depth range to 300 m or 1000 feet) and transducer. The transducer was clamped off the stern of the boat and was deeper than the keel. Transect lines were selected with mapable beginning and ending points, harbor buoy markers. The boat ran along these transects by following a fixed compass reading at a uniform speed. The fathometer produced strip chart recordings of the bottom topography along transects. Timing marks were made on the strip charts at 30 seconds or 1 minute intervals. These timing marks were used to establish distance traveled along transect and correct for variation in boat speed. The total transect length was taken from the mapped transect ends.

RESULTS AND DISCUSSIONS

Malem

The proposed discharge of effluent into a mangrove system at Malem village was based on the ability of a typical mangrove system, which has tidal flushing, to remove pollutants. According to Videnov and Ludwig (1983) this mangrove disposal would provide high quality effluent and not pose a public health problem. However, the proposed discharge sites which Videnov and Ludwig (1983) designate as mangrove swamps are wetlands (Figure 3). Wetlands do not function environmentally the same as mangrove swamps in "polishing" effluent discharges. This wetland area around Malem has limited water exchange with the marine system. Although it does rise and fall with tidal change, it generally has diffuse water movement and is prone to stagnation. Additionally, it floods (up to 1m) in heavy rain

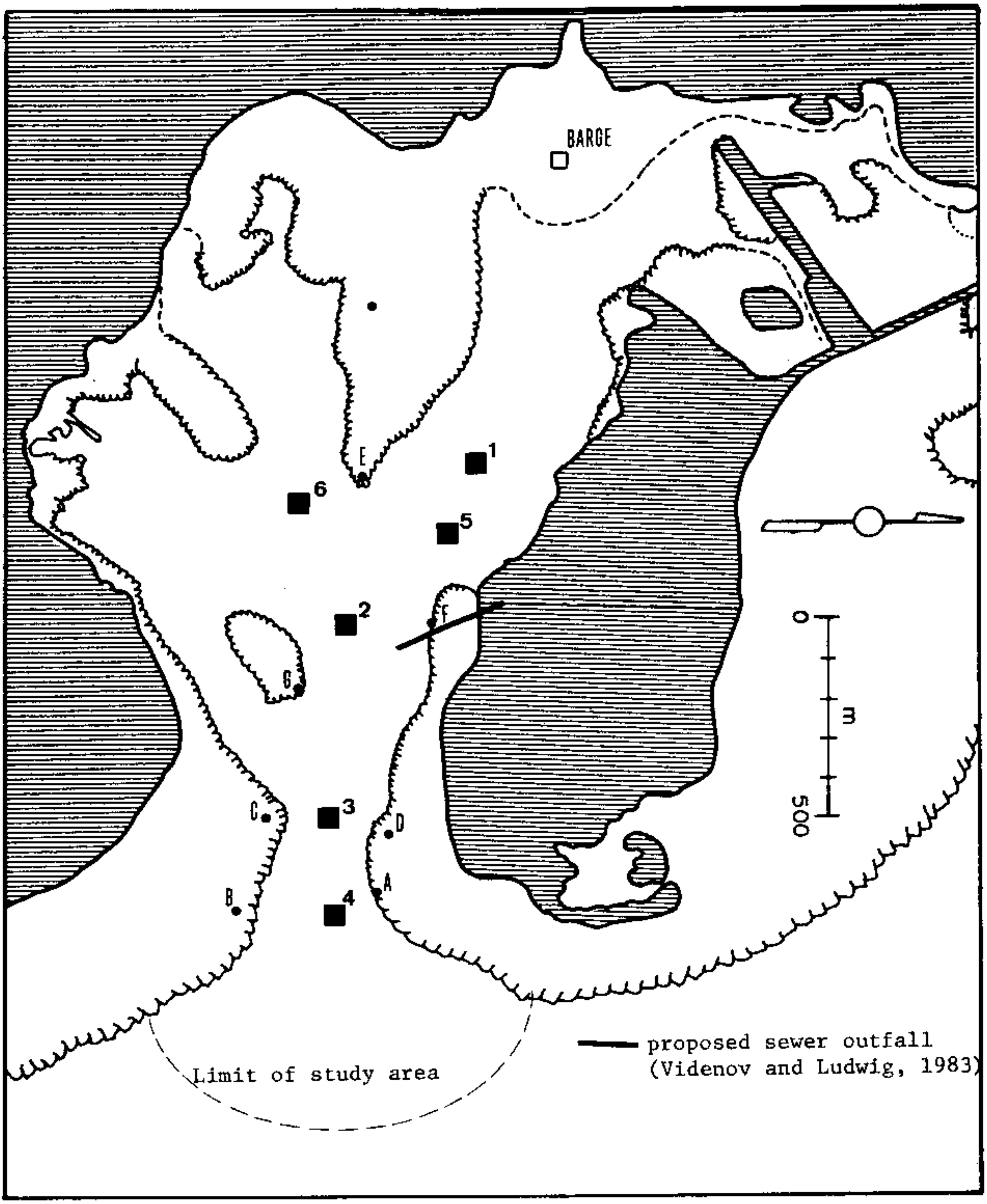


Figure 2. Lelu Harbor with drogue release areas (numbered squares), harbor bouys (letters A to G) and limit of current and bathymetric survey.

periods. Therefore, it was felt by local, national and federal environmental agencies that the effluent disposal design for Malem would need to be altered. Other alternatives proposed for wastewater disposal were: 1) ocean outfall, 2) oxidation ponds, and 3) leaching fields adjacent to core units.

A reconnaissance level survey was made of the Malem coastline and reef-flat in January, 1984. The generally physiography of the reef-flat and steepness of beach deposits characterizes this coastline as a high energy environment. This is defined as a coastal area where wave action is consistently very strong. The reef-flat commonly exposes at low tide. There are large boulders on the reef-flat, which are frequently moved by wave action. In January, a large turbidity plume, caused by heavy rains discharging from a small stream, was observed. This facilitated in qualifying offshore current movement (Figure 3). There was a strong longshore current which moved the plume offshore. The high surf caused the turbid water to be moved back onto the reef-flat south of Malem. It can be anticipated that an effluent discharge plume would be subject to frequent back washing onto the reef-flat. Since Malem coastline is a high energy environment, a sewer outfall placed over the reef would be subject to breakage at the reef margin in storm periods. Therefore, a marine outfall for Malem is not a very feasible alternative.

In January, two days were spent at Malem conducting reconnaissance surveys along the coastal lowlands. Several informal discussions were made with Malem people who wished to express their opinions on effluent disposal. Based on these surveys, it was proposed to the Kosrae EPB that oxidation ponds should be considered for Malem. Several possible sites were selected for consideration.

A public hearing was held in Malem Village in March by the Kosrae EPB. The use of oxidation ponds for sewage disposal was discussed and accepted by the village. At that time, there was some problem with site location. These problems were generally related to fears of some land owners in regards to oxidation pond impact on their land. Therefore, in April I spent a day resurveying sites,including an area where a land owner had tentatively agreed to allow ponds to be place on his land (Figure 3). This proposed pond site is a Nypa palm wetland. Pond effluent could be discharged into an adjacent small stream. This stream currently receives a large amount of waste water from several houses and a small piggery. The stream discharges onto the adjacent reef-flat. There will be minimal damage to wetland with the construction of ponds and probably no decrease in water quality of coastal receiving waters.

Utwe

A general survey was made of coastal areas and mangrove swamp which borders the coastal zone in the vicinity of Utwe community (Figure 4).

There is currently a dredge operation in Taf harbor, which is providing material for road construction (Figure 4). This dredging is

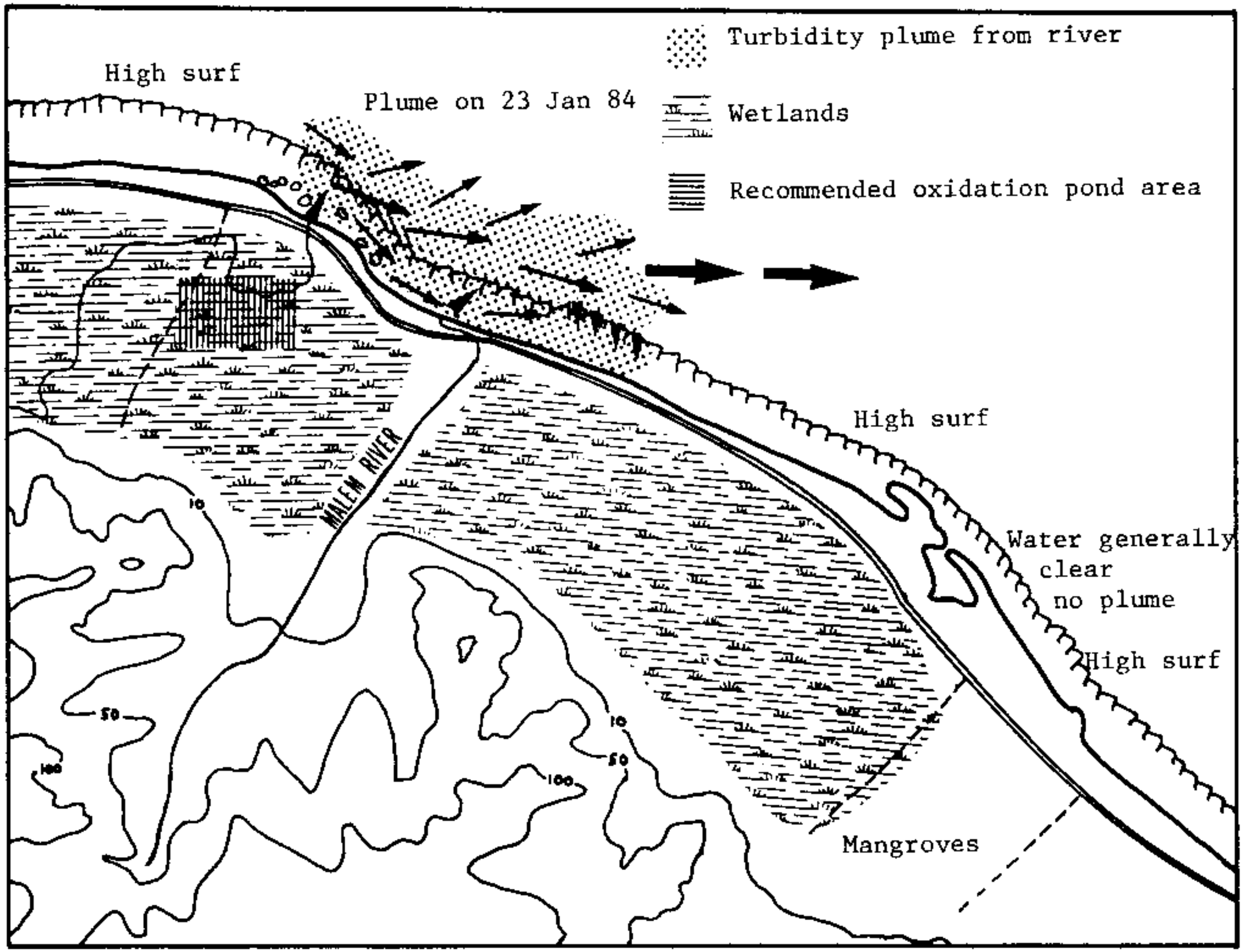


Figure 3. Malem coastline and nearshore environments. A recommended location is shown for oxidation ponds. A small stream is shown near this area which could be used for oxidation pond effluent discharge.

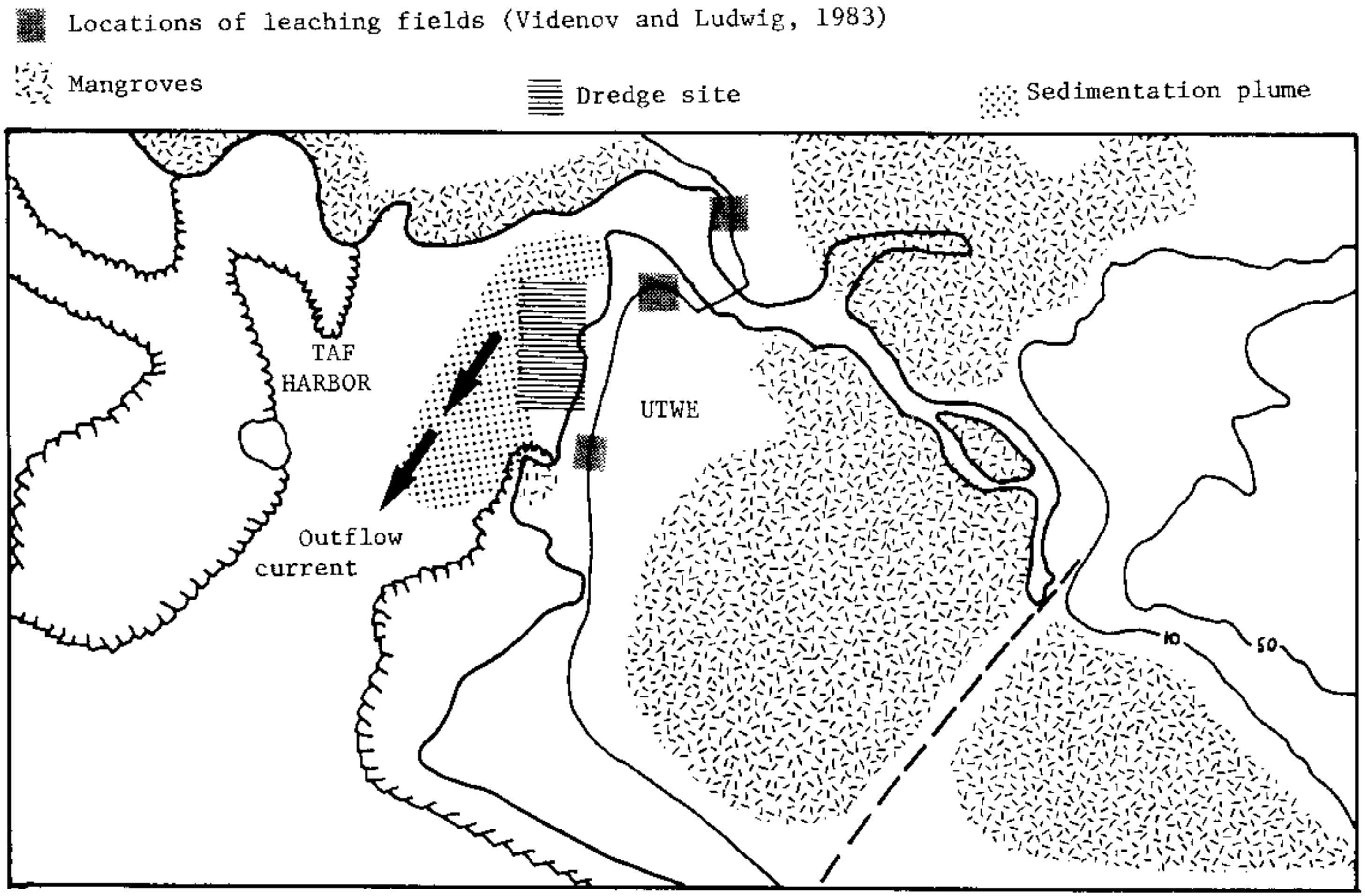


Figure 4. Utwe village coastline and dredge site. Mangrove swamp around village (blank area on map) shows extensive human induced changes.

being done by bucket crane using a moving ramp technique. This type of dredging operation produces turbidity plumes and siltation on adjacent reef systems. A turbidity plume was observed along the northern side of the harbor, extending toward the harbor mouth. This turbid water was washed onto the north side reef-flat and into a sparse mangrove zone adjacent to shore. The mangrove swamp surrounding Utwe village shows extensive man-induced alternations. There is considerable artifical filling, clear cutting of adjacent mangrove swamp and it contains a large quantity of debris and refuse.

The leaching field development as proposed for group core units (Videnov and Ludwig, 1983) will have minimal impact on the existing natural mangrove ecosystem. These leaching fields should provide a viable means of effluent disposal with minimal environmental impact at the proposed construction sites. This system can only help to improve sanitary conditions of mangrove swamp adjacent to Utwe.

Lelu Harbor

The proposed Lelu marine outfall was designed and recommended for placement in the eastern portion of the harbor about 500m west of the entrance (Figure 2). Environmental agencies were concerned about the placement of a marine outfall in the harbor area. There were only limited data available for marine water circulation patterns in the harbor. Additionally, there were no available bathymetric surveys which defined the harbor floor topography. Since there was this noteable lack of data available to characterize the anticipated effluent discharge plumes, both residents of Lelu and the local environmental health office were concerned about pollution (primarily bacteriological) of Lelu shoreline by sewage. Finally, the facilities plan did not adequantly deal with plume dispersion under various tidal conditions.

A limited water current survey was conducted on 21 and 22 January 1984 to ascertain current changes under strong rising and falling tides. This allows a first approximation of the circulation system for near surface waters between -1m to -10m. Preliminary results show current flow both into and out of the harbor to be dependent on flood or ebb tide. There is a complex circulation pattern in the harbor which was generally characterized by the current study.

The current flow patterns in the harbor were measured twice under strong falling tide and strong rising tide conditions with an east wind (Figures 5 (falling), 6 (rising), 7 (falling), and 8 (rising). The current flow direction, distance and speed as recorded by drift drogue movement is presented in Tables 1, 2, 3 and 4, which correspond with Figures 5 to 8, respectively.

In January there were strong winds (10-15 knots) outside the harbor and the surf was breaking 1.2 to 1.8 m (4 to 6 feet) with a few 2.4 m (8 foot) breakers. Swell was 1 to 1.2 m (3 to 4 feet). These conditions

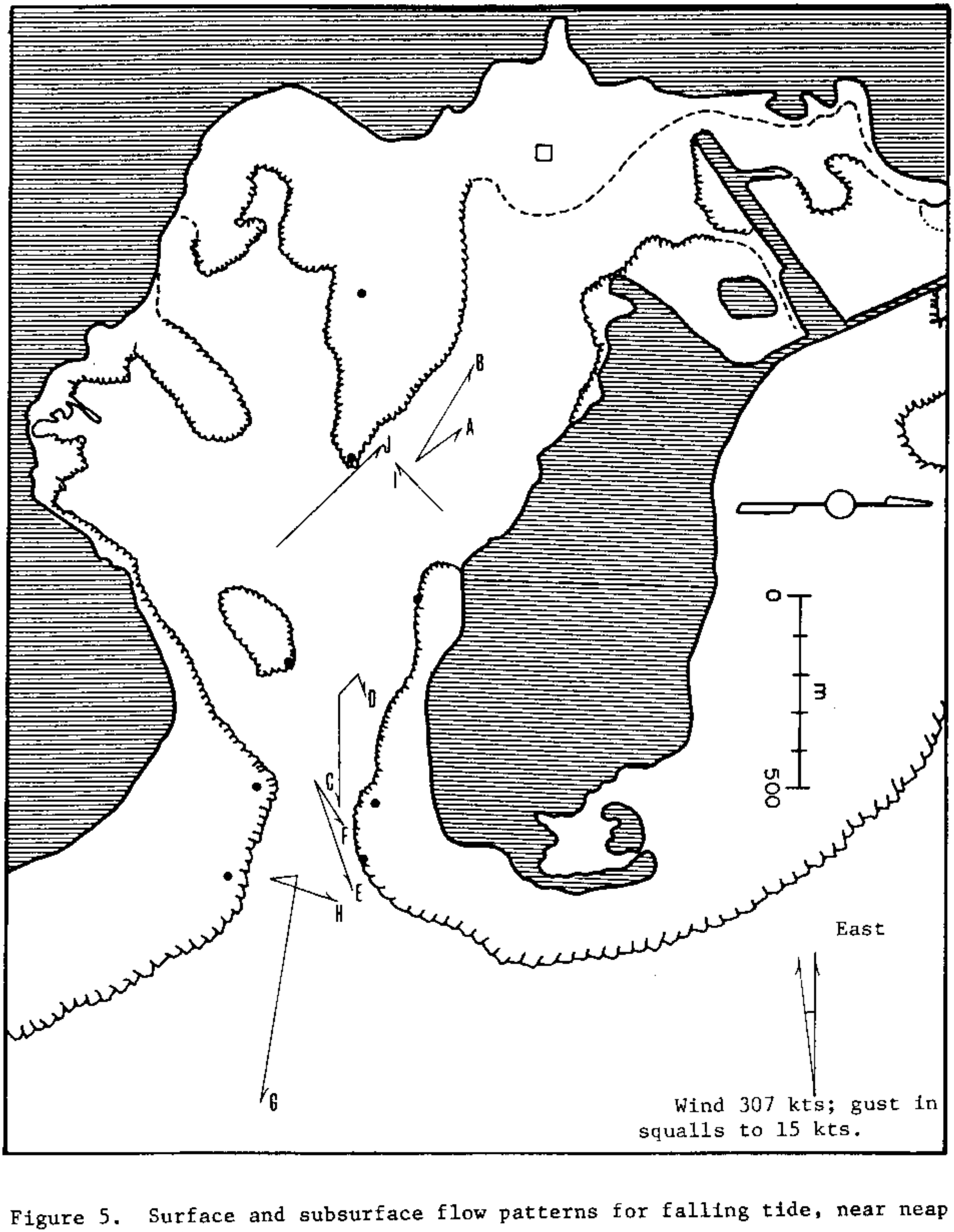


Figure 5. Surface and subsurface flow patterns for falling tide, near neap tide.

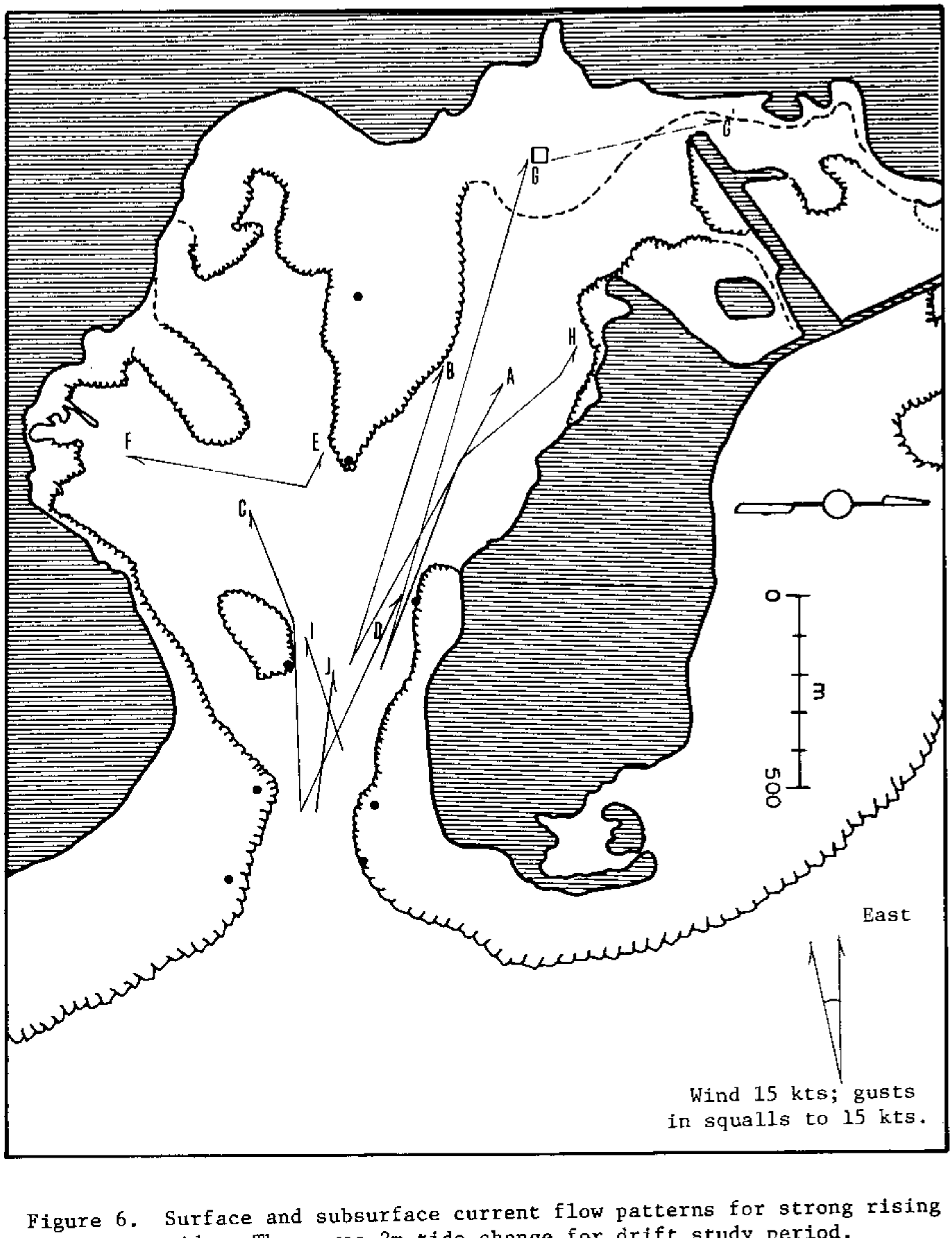
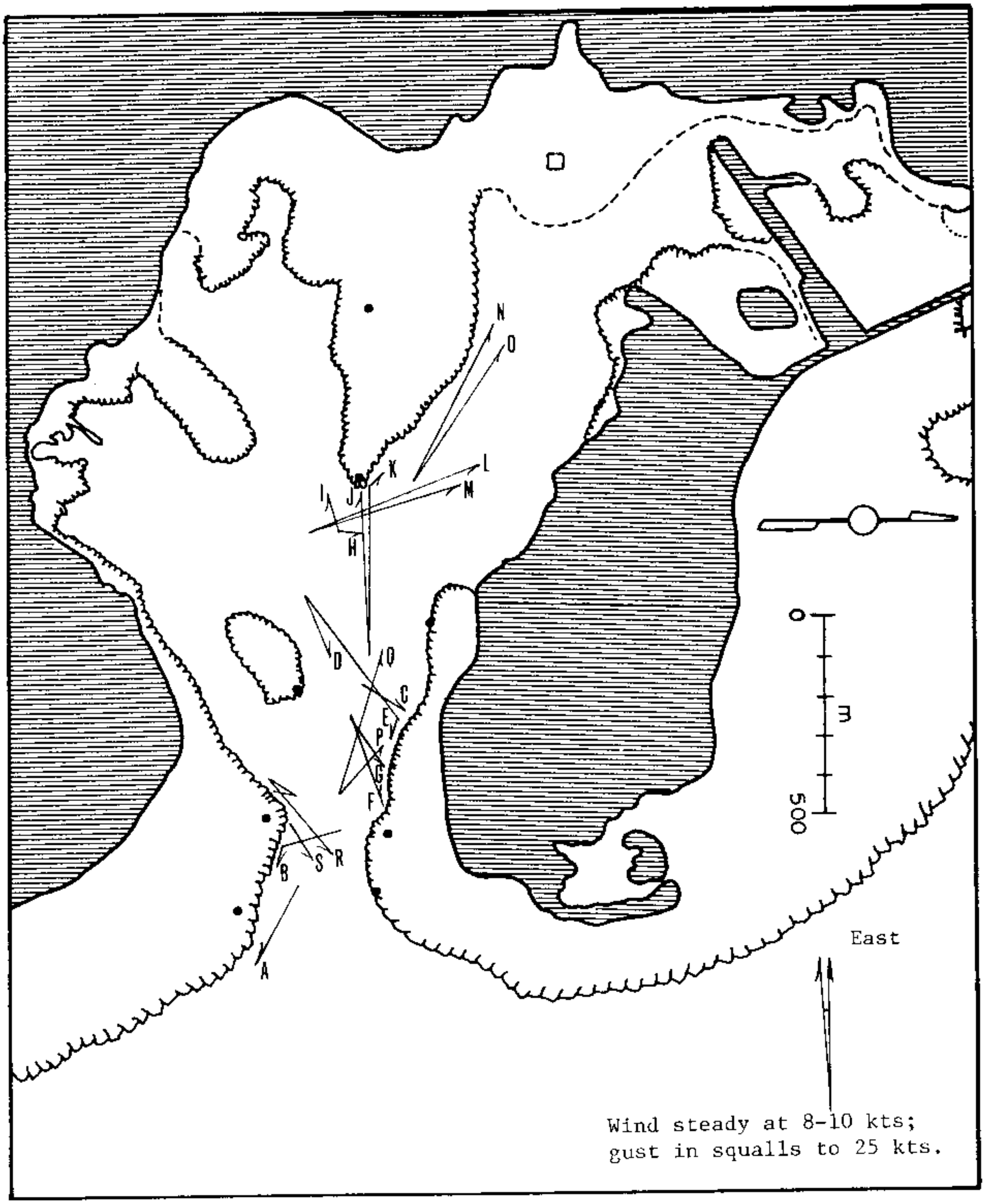
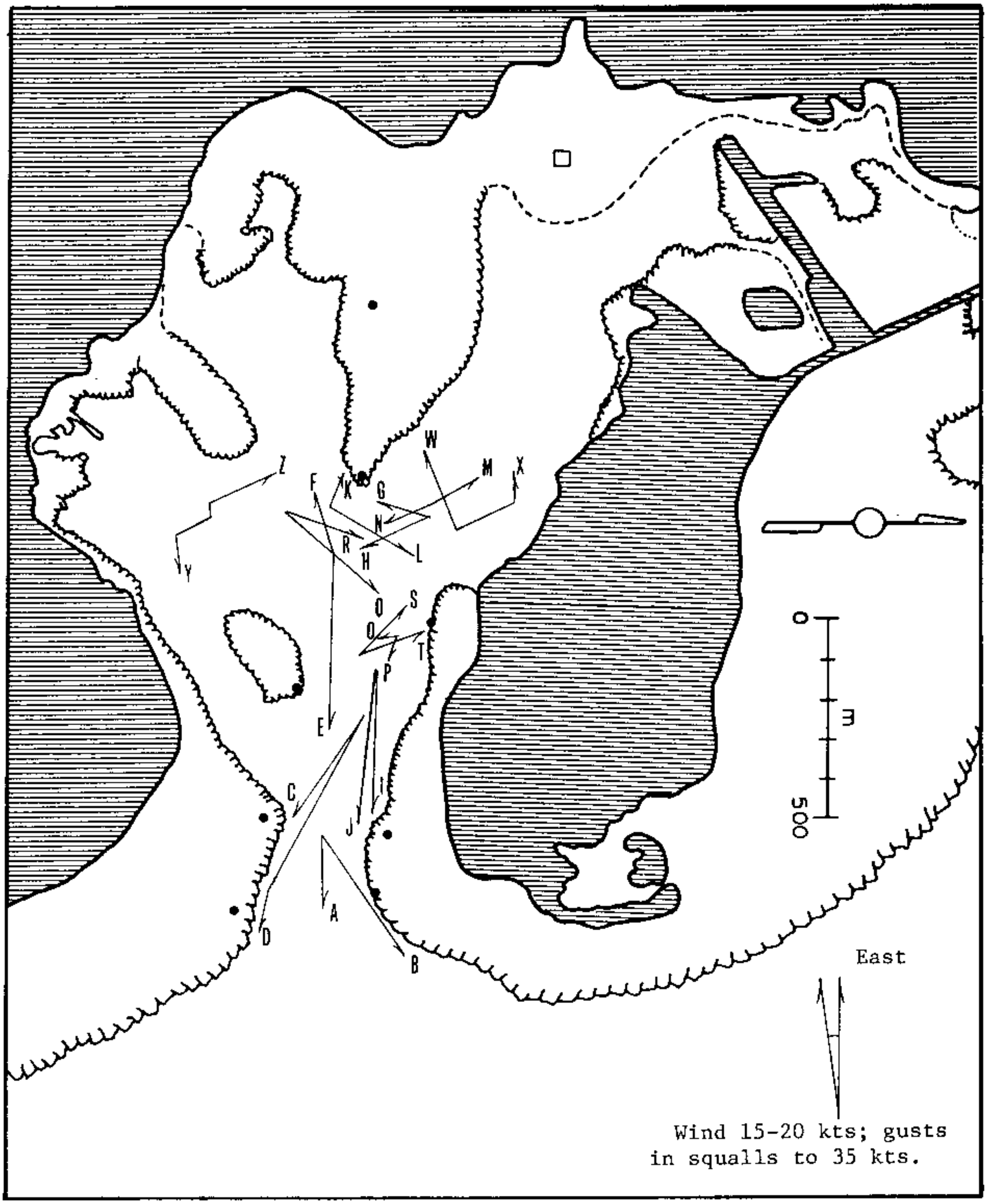


Figure 6. Surface and subsurface current flow patterns for strong rising tide. There was 2m tide change for drift study period.



Wind steady at 8-10 kts;
gust in squalls to 25 kts.

Figure 7. Surface and subsurface current flow patterns for strong falling tide.



Wind 15-20 kts; gusts in squalls to 35 kts.

Figure 8. Surface and subsurface current flow patterns for strong rising tide.

Table 1. Current flow direction and speed for low tide with a moderate dropping tide toward neap tide, 21 January 84. See Figure 5 for drift patterns.

Drogue Release Point	Vane Depth(m)	Time In (hr)	Run Time (min)	Drift Distance (m)	Flow Direction (degree)	Drift Speed (m/sec)	Tide Change
1-A	1	1044	131	151	323	0.019	low tide
1-B	5	1044	126	286	300	0.030	dropping
2-C	1	1050	112	279	88	0.041	
2-D	5	1050	140	151	360*	0.018	
3-E	1	1055	43	301	69	0.117	
3-F	5	1055	105	151	57	0.024	
4-G	1	1100	43	633	98	0.220	
4-H	5	1100	140	241	24	0.029	
5-I	1	1205	105	151	225	0.024	neap @
6-J	1	1207	96	377	316	0.065	1200

* change flow direction in drift period.

Table 2. Current flow direction and speed for strong rising tide, 21 January 84. See Figure 6 for drift patterns.

Drogue Release Point	Vane Depth(m)	Time In (hr)	Run Time (min)	Drift Distance (m)	Flow Direction (degree)	Drift Speed (m/sec)	Tide Change
2-A	1	1310	205	814	292	0.060	strong rising tide
2-B	5	1310	160	783	286	0.082	
3-C	1	1320	140	828	262*	0.099	
3-D	5	1320	145	693	295	0.080	
6-E	1	1400	80	113	306	0.024	
6-F	5	1400	76	155	192	0.034	
2-G	1	1445	80	1356	198	0.283	
2-H	5	1445	95	995	213*	0.174	
3-I	1	1320	90	316	254	0.059	high tide @ 1700 w/ 2m change
3-J	5	1320	100	377	276	0.063	

* changed flow direction in drift period.

hindered work in the harbor mouth. In April, there were even stronger winds (15 to 20 knots with gusts to 28 knots); the surf was breaking 1.8 to 2.4 m (6 to 8) feet with a 1.2 to 1.5 m (4 to 5) feet swell and heavy wind chop. The general weather conditions, primarily wind direction and speed, and tidal changes for the January current study are presented in Table 5.

Current data were replotted, separating surface and subsurface water flow for both rising and falling tides. Surface water flow for falling tide shows an outward flow at the harbor mouth which negates east wind influence, while the west harbor surface water mass is wind driven (Figure 9). Current flow speed at the harbor mouth, particularly along the northern reef-flat, was substantial higher compared with a mid harbor surface water mass. Subsurface flow (at -5m) in falling tide showed a similar pattern to surface water (Figure 10). There was a strong outflow of water adjacent to the northern reef-flat. This subsurface flow generally moved southward after exiting the harbor. There was an inflow of subsurface water toward the western end of the harbor which also had a high flow speed. This flow speed was partly influenced by the strong east winds. Surface water mass during a rising tide showed a complex mixture of current and wind-driven flow patterns with high flow speeds (Figure 11). Water mass near the harbor entrance was current controlled and generally flowed outward. This water mass moved toward the northwest. The western harbor had a complex flow pattern controlled by deeper currents and surface winds. Toward neap tide this surface water mass moved with a very high flow speed toward the western mangrove system. Subsurface flow with a strong rising tide and strong east winds showed a net movement of water into the harbor (Figure 12). Current flow directions at similar times, were different (flow direction and speed) on the north and south sides of the harbor entrance. Inflowing subsurface water moved along the northern reef-flat, while outflow occured along the southern reef-flat. This inflowing and outflowing system produced a large eddy complex in the south harbor. This south harbor subsurface water generally had lower flow speeds. In this area, surface and subsurface flow directions were as much as 180 degrees different. A few drift drogues were modified to measure a deeper subsurface water mass (-10m). This deeper water mass should have been below the zone of surface wind influence. Since there were difficulties with maintaining neutral bouyancy of surface floats, only 4 runs were made to measure deeper water flow (Figure 13). However, these drifts do provide some general flow characteristics. There is distinct layering of water masses in different portions of the harbor. In a rising tide along the northern harbor entrance, three water masses were observed which moved in different directions with different speeds (Figures 11 to 13). Surface water flowed out of the harbor, subsurface water at -5m showed strong inflow, and subsurface water at -10m showed strong outflow. There appeared to be a strong inflow of water deeper in the harbor entrance which flowed upward toward the central harbor and influenced current flow patterns in the western and southern portions of the harbor.

Based on these preliminary current studies, placement of an effluent marine outfall would be most effective toward the harbor entrance. The proposed site in the WHO facilities plan (Videnov and Ludwig, 1983) would

Table 5. Weather and tidal conditions for drift drogue study period.

	Time	Weather and Tidal Conditions
	1040	Wind East, 90 to 100 degrees; 3-7 kts.
21 January	1045	low tide; still dropping; reef flat beginning to expose.
	1130-1200	at low tide; neap period; flats exposed 0.2m.
	1140	Squall with wind gusts to 15 kts.
	1200	Wind east, 90 degrees, 5 kts.
	1200-1230	tide beginning to rapidly rise.
	1300	Wind east, 95 degrees, 3-6 kts.
	1330	Squall with wind gusts to 15 kts.
	1400	Wind east, 90 to 105 degrees, 3-8 kts.
	1420	Squall with wind gusts to 18 kts.
	1500-1700	Wind east, steady 90 degrees, 5 kts.
	1700	very high tide with 2m change since 1200.
22 January	0700	Wind east, steady at 90 degrees, 8-10 kts; sea rough with 2m (5-6 feet) breakers at harbor mouth; 1.5m (4-5 feet) swell in harbor toward entrance with 2 to 2.5m (6-7 feet) larger breaker set on northern reef flat side of harbor mouth; tide was high at about 0400-0500; strong dropping tide.
	0800	Wind east, steady, 8 kts.
	0900-1000	Squall, east wind at 90 to 105 degrees, 20 kt wind with gusts to 25 kts; heavy rain.
	1100	Wind east, steady 10 kts; reef flats beginning to expose.
	1140-1230	Squall with thunderstorm, east wind, 20 kts, gusts to 35-40 kts; generated 1m (3 to 4 feet) chop in harbor; heavy rains.
	1230	low tide with reef flats still exposed 0.2m.
	1300	Tide beginning to rapidly rise.
	1300-1430	Wind east, steady, 10 kts.
	1430-1500	Squall, east wind at 95 degrees, 20 kts with gusts to 25 kts; heavy rains.
	1510-1530	heavy debris drift lines. no wind; inner harbor calm; 2-3m (6-9 feet) breakers in harbor entrance.
	1530-1600	Wind East at 90 degrees, 1 to 3 kts; large squall line and thunderstorm approaching.

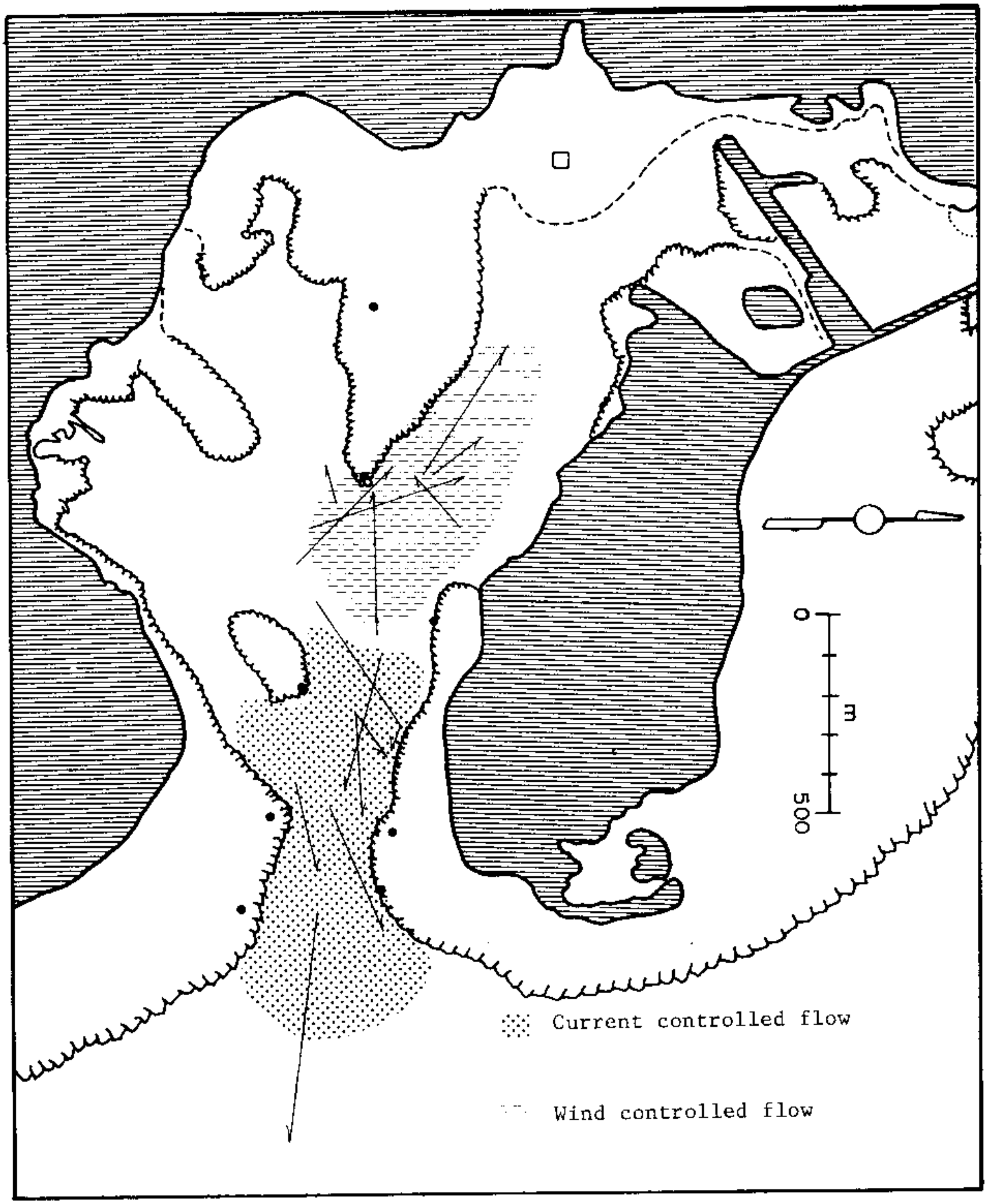


Figure 9. Water flow pattern of surface water with falling tide and east winds.

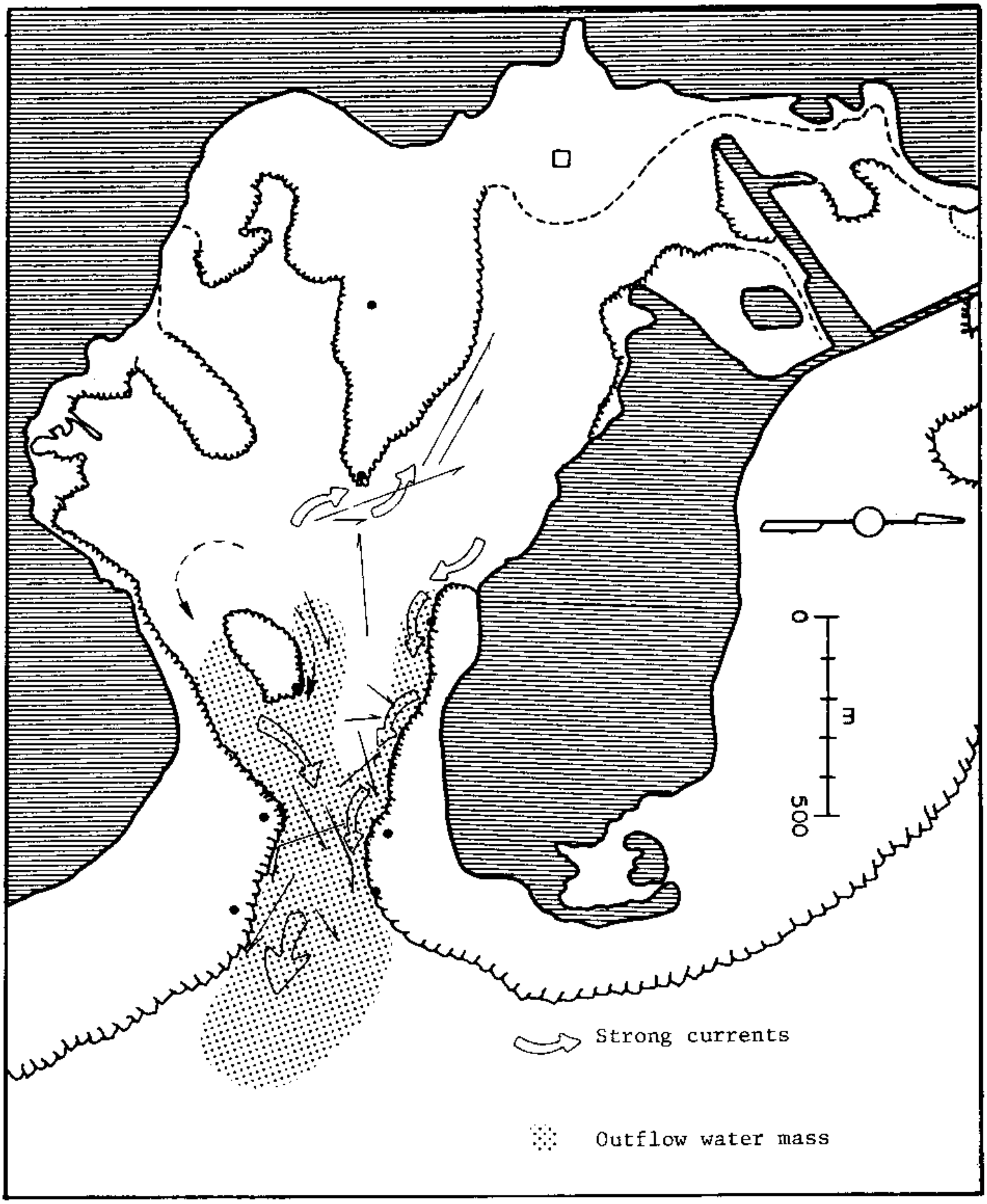


Figure 10. Generalized flow pattern of water mass at depth of 5m with strong falling tide.

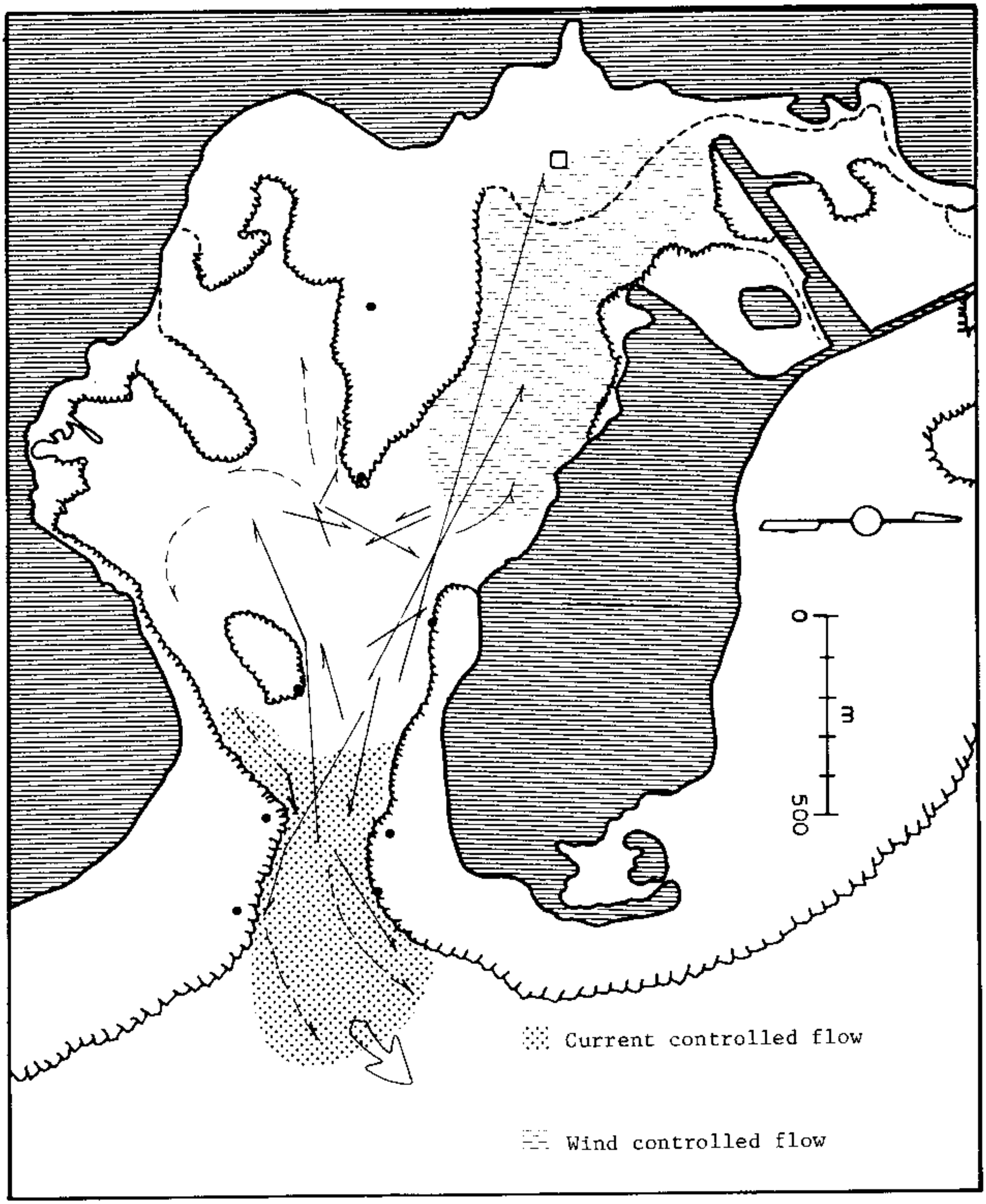


Figure 11. Water flow pattern of surface waters with rising tide and east winds. Back harbor water flow is influenced by a mixture of wind and current, while the harbor mouth is dominated by currents.

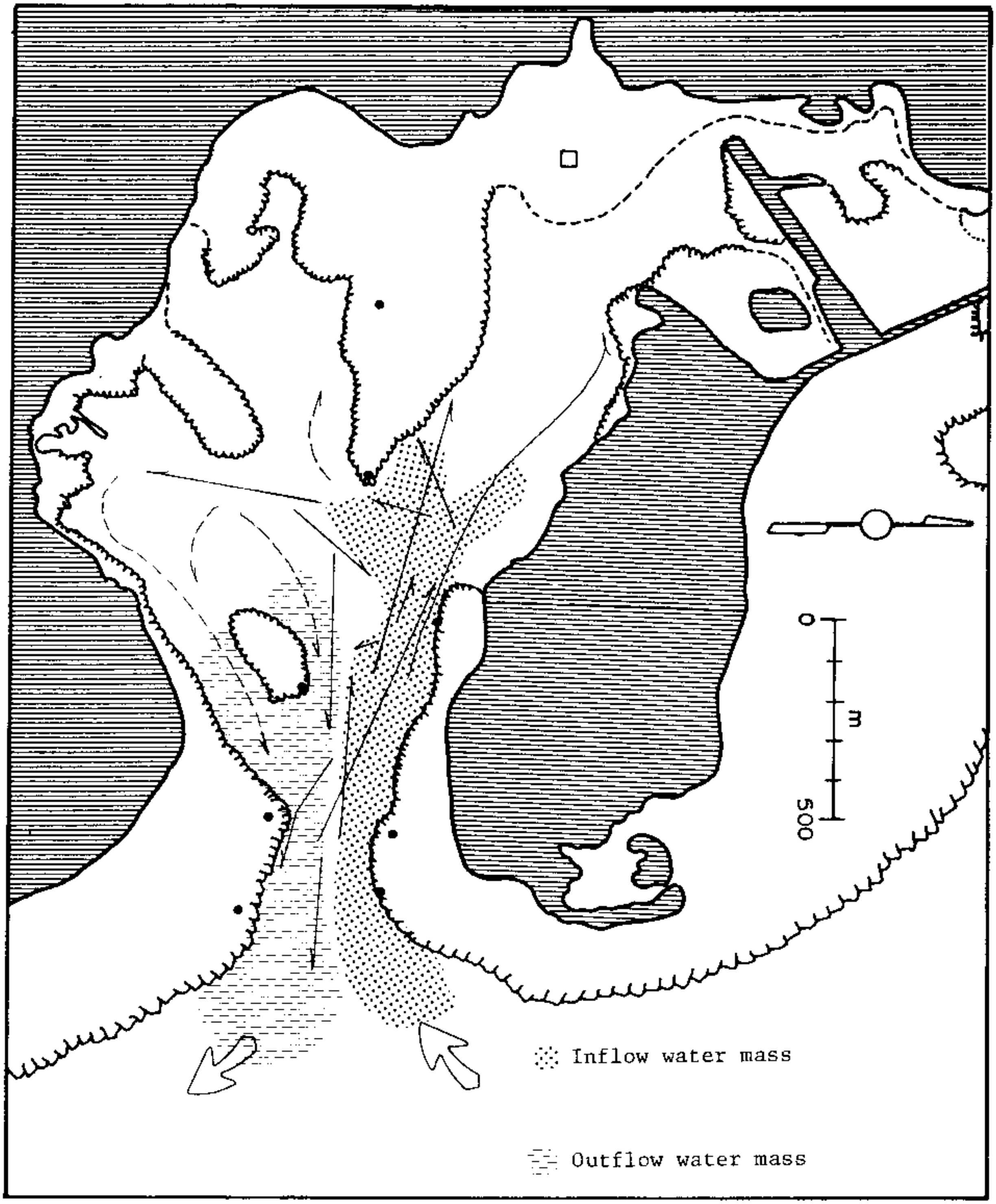


Figure 12. Generalized flow pattern for water mass at depth of 5m with strong rising tide.

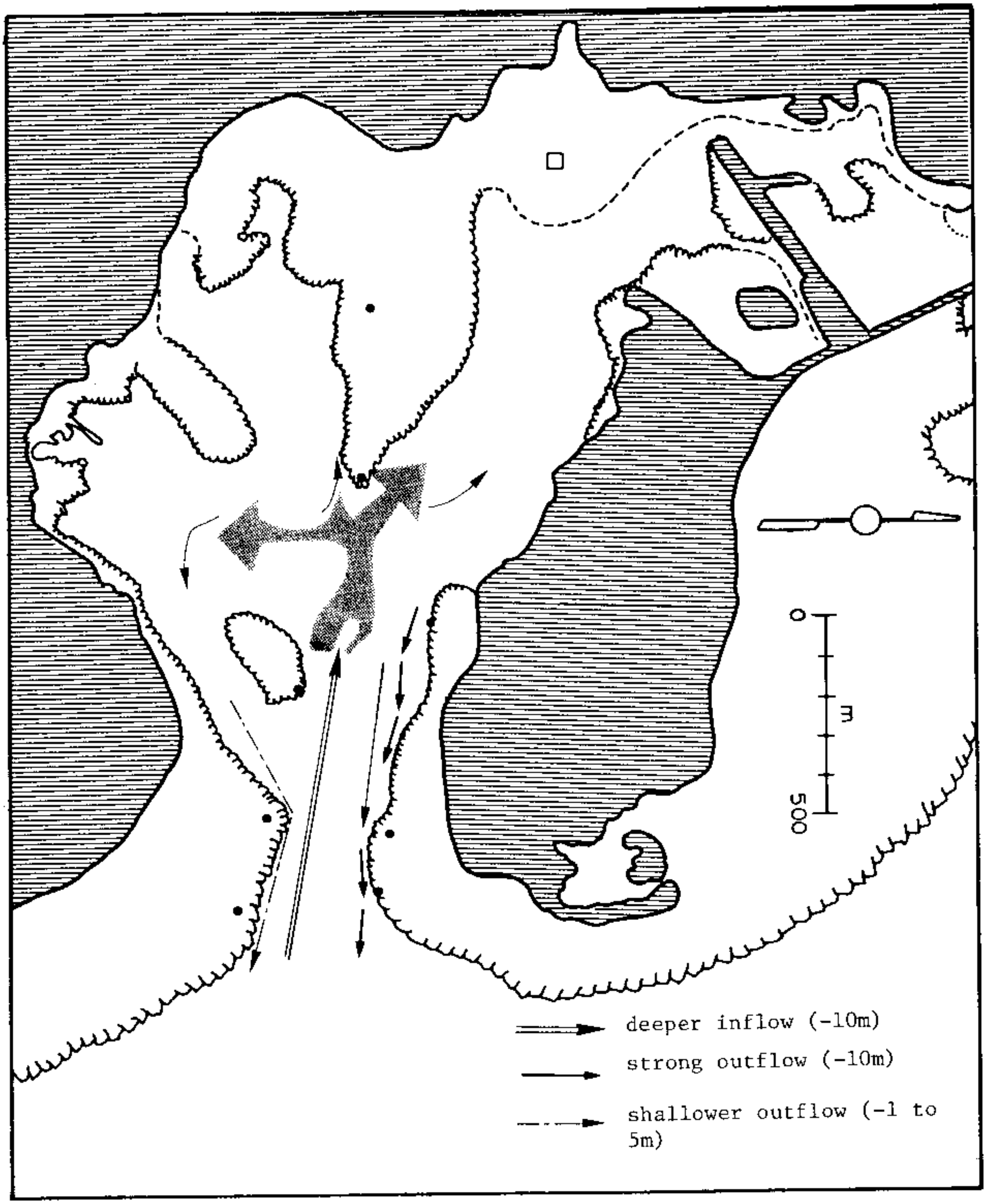


Figure 13. Generalized flow pattern for water mass at depth of 10m with a strong rising tide.

place the outfall in an area where water flow moves both inward and outward with periodic flow onto the northern reef-flat. These flow patterns would cause the effluent plume, at times, to wash along the Lelu shoreline.

In order to better assess the location for a marine outfall in Lelu Harbor, a bathymetric survey was made along selected transects (Figure 14). Fathometer traces were made along transects with emphasis placed on the harbor entrance. A total of 10 transects was made in the harbor. These traces are presented in Figures 15 (traces 1, 2 and 3), 16 (traces 4, 5 and 6), 17 (traces 7 and 8), and 18 (Traces 9 and 10). The harbor is a drowned river valley which has a channel along the northern side (Figure 16). The harbor entrance has steep walls which narrow toward the base (Figure 15: T-30). This restricted entrance greatly influences water flow into and out of the harbor and accounts for the strong flow speeds. The submarine slope seaward of the harbor entrance drops off very rapidly with depths in excess of 300m just 350m east of A bouy (Figure 17: T-7). Depths (in feet and meters) along transects in the harbor entrance and along transect 1 are presented in Table 6. Data from this table were used to contour harbor floor topography at the harbor entrance (Figure 19). This topographic map can be used to help determine placement of a marine outfall.

RECOMMENDATIONS

Lelu Marine Outfall

Based on preliminary current flow patterns and harbor topography, a recommended area for a marine outfall in Lelu Harbor is shown in Figure 20. Placement of an effluent diffuser in this area would maximize dispersion of the plume and minimize environmental impact along the Lelu shoreline. The diffuser should be placed as close to the harbor entrance as possible, but not further seaward than D-Bouy (Figure 2).

Malem

The use of a marine outfall for effluent disposal in Malem is not a very feasible alternative. A pipe line over the reef margin would be prone to breakage. It is recommended that oxidation ponds be built for effluent disposal. The ponds should be built in the wetland area north of Malem (Figure 3). Discharge from these ponds would enter a small stream which currently empties from the wetland. Monitoring of effluent water quality in the stream would be necessary and can be done by the local environmental health office.

Utwe

The leaching field development designed for Utwe community will have minimal enviromental impact on adjacent mangrove systems and coastal areas. These leaching fields should provide a viable means of effluent disposal.

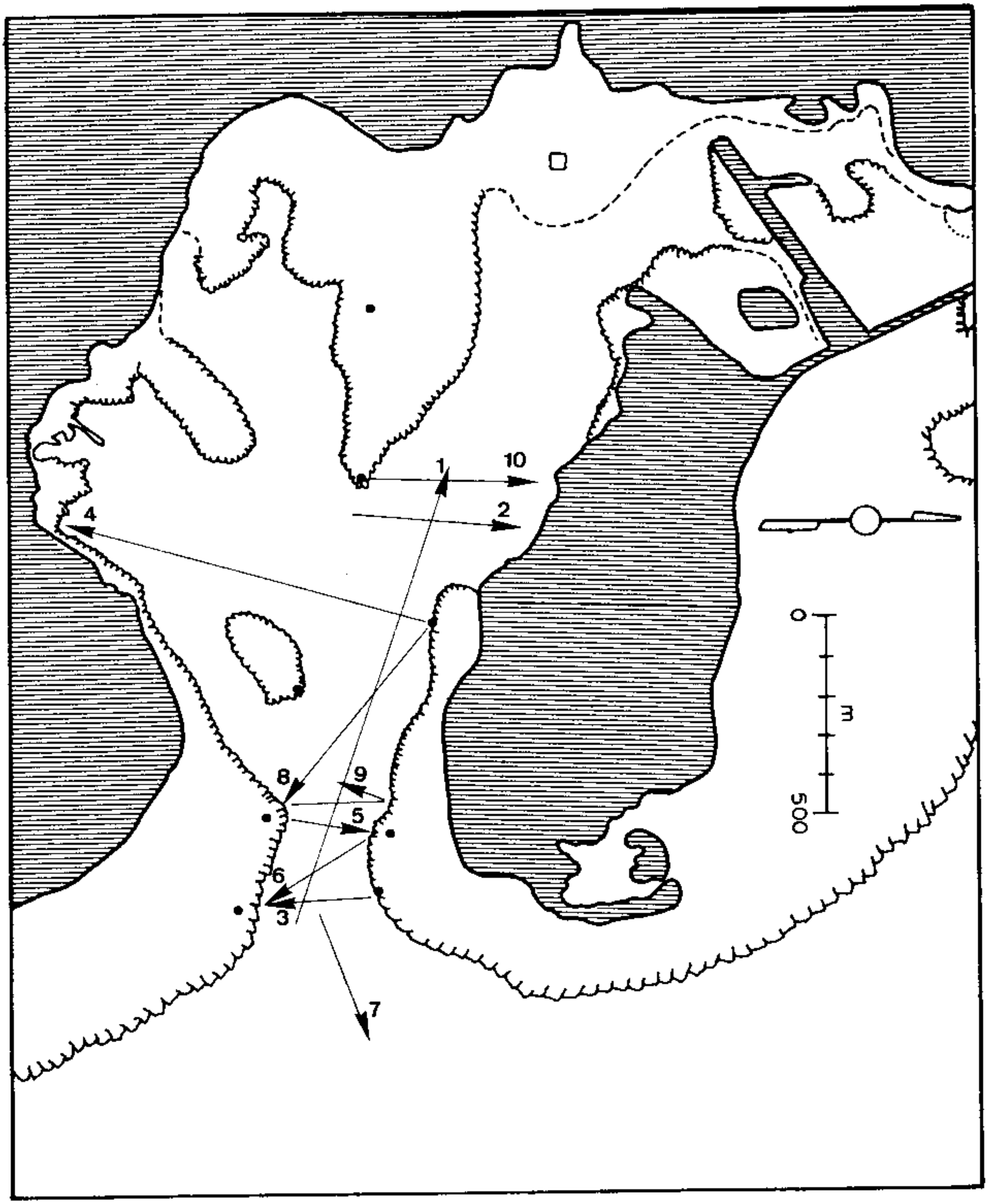


Figure 14. Transect traces for fathometer runs in Lelu Harbor. The arrow on transect denotes direction of travel.

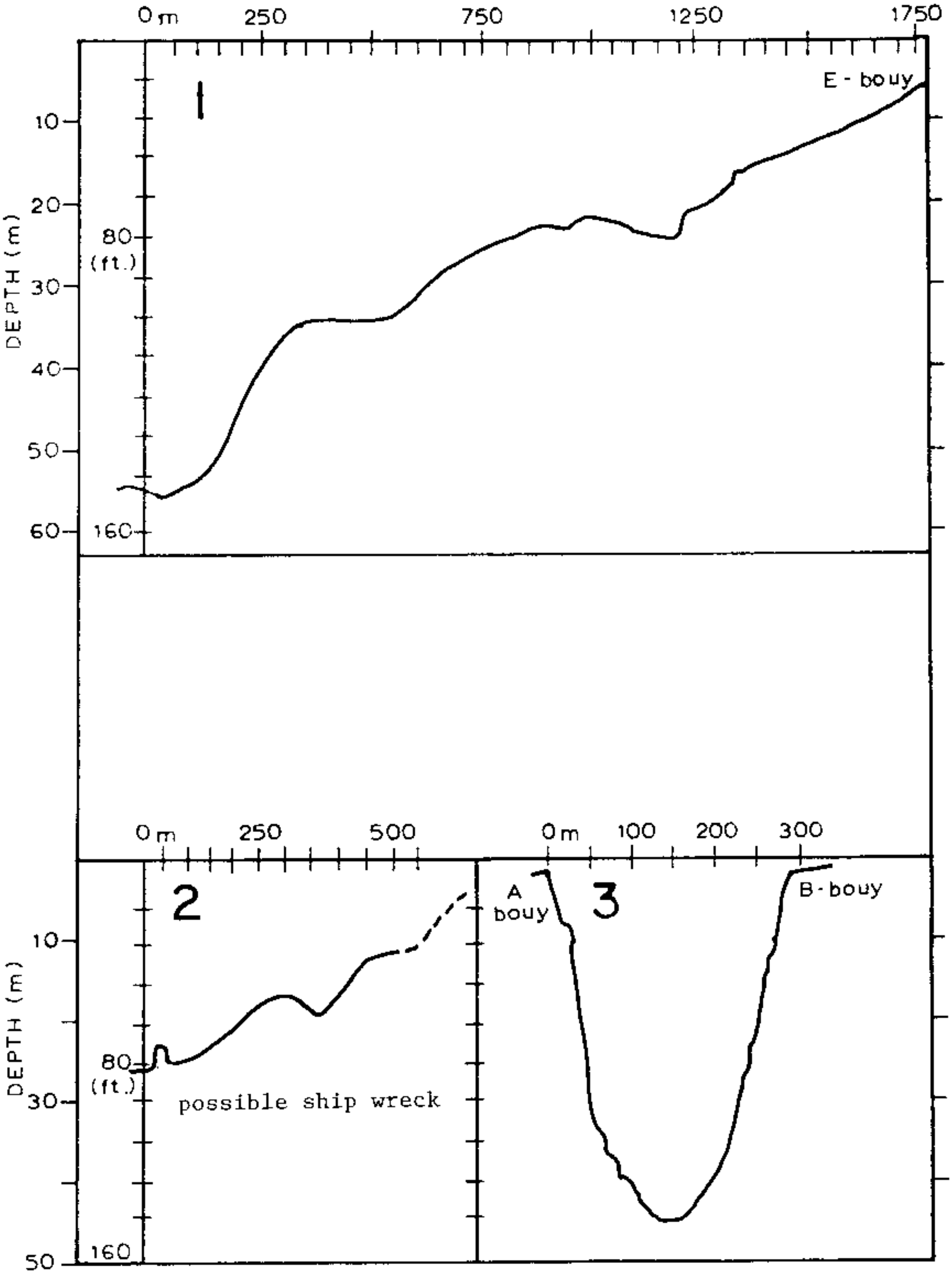


Figure 15. Bathymetric contours of transects 1, 2 and 3. See Figure 14 for location and direction of transects.

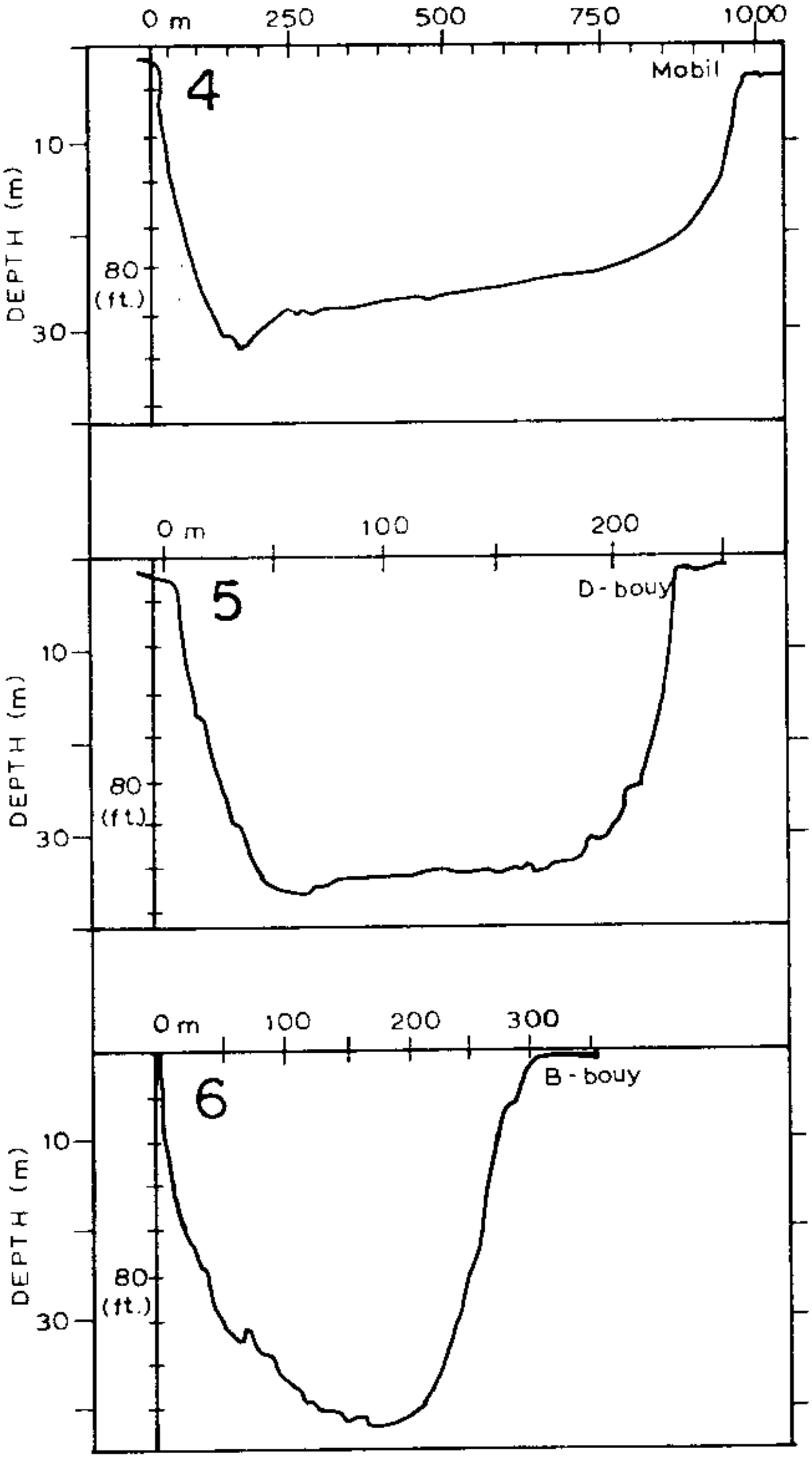
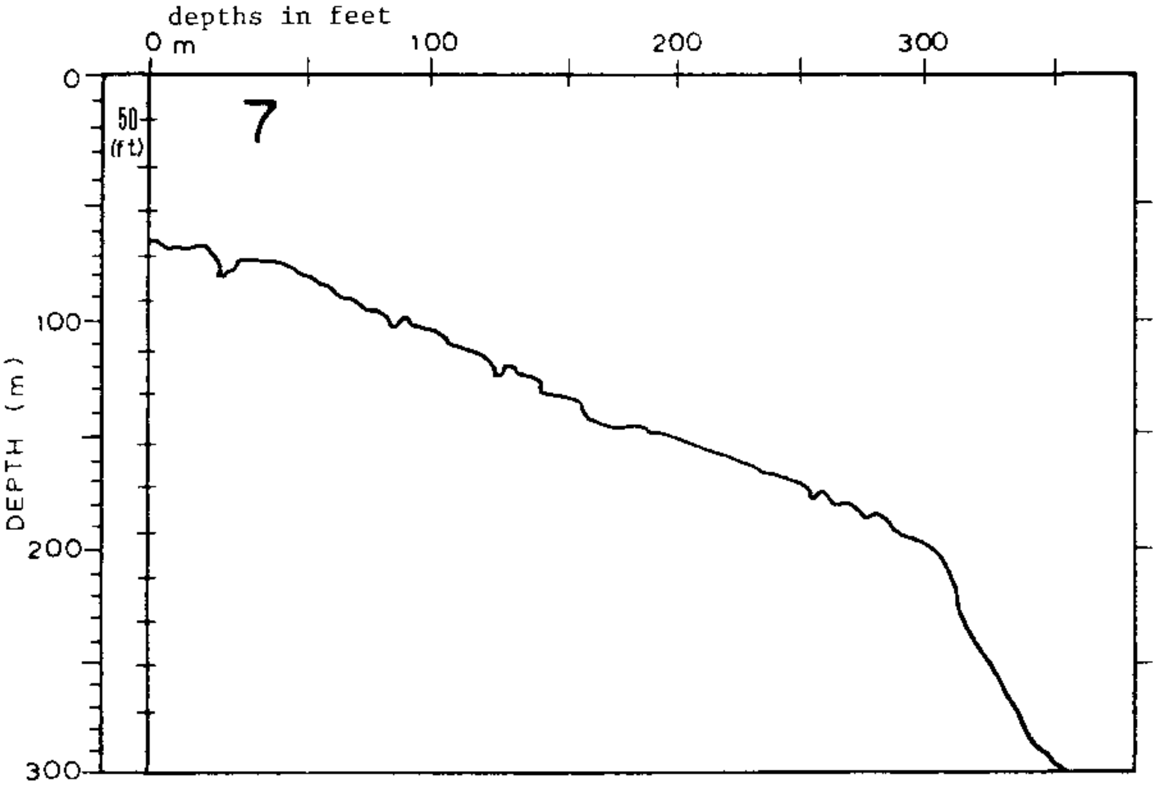


Figure 16. Bathymetric contours of transects 4, 5 and 6. See Figure 14 for location and direction of transects.



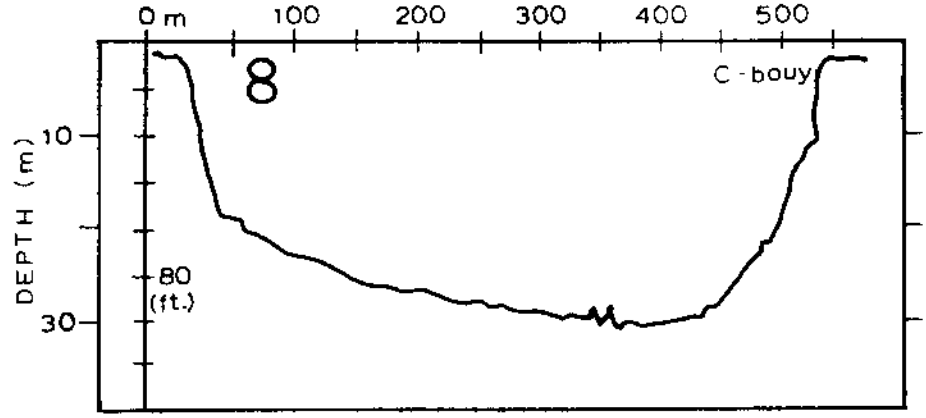


Figure 17. Bathymetric contours of transects 7 and 8. See Figure 14 for location and direction of transects.

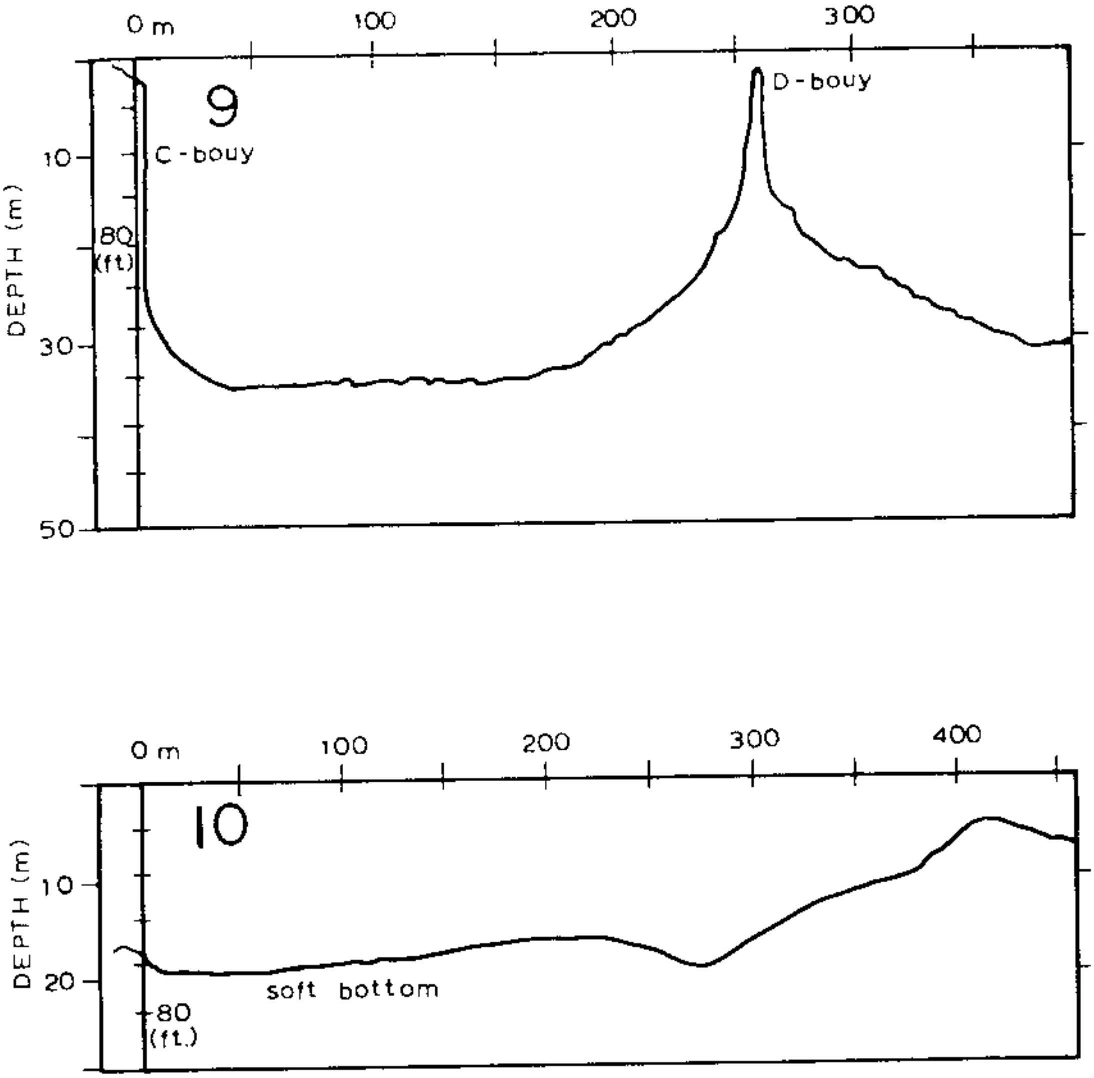


Figure 18. Bathymetric contours of transects 9 and 10. See Figure 14 for location and direction of transects.

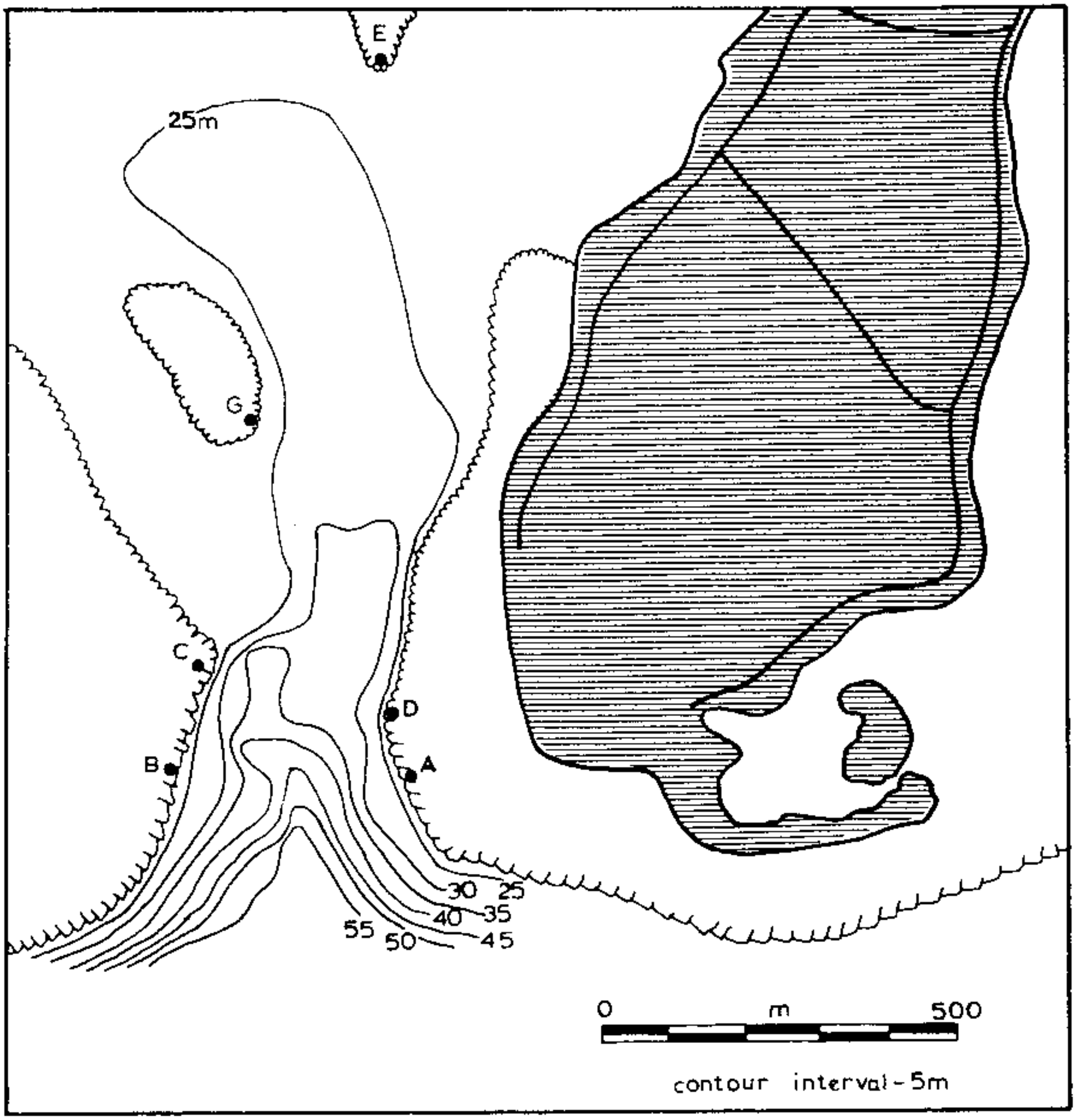


Figure 19. Contour map of harbor entrance.

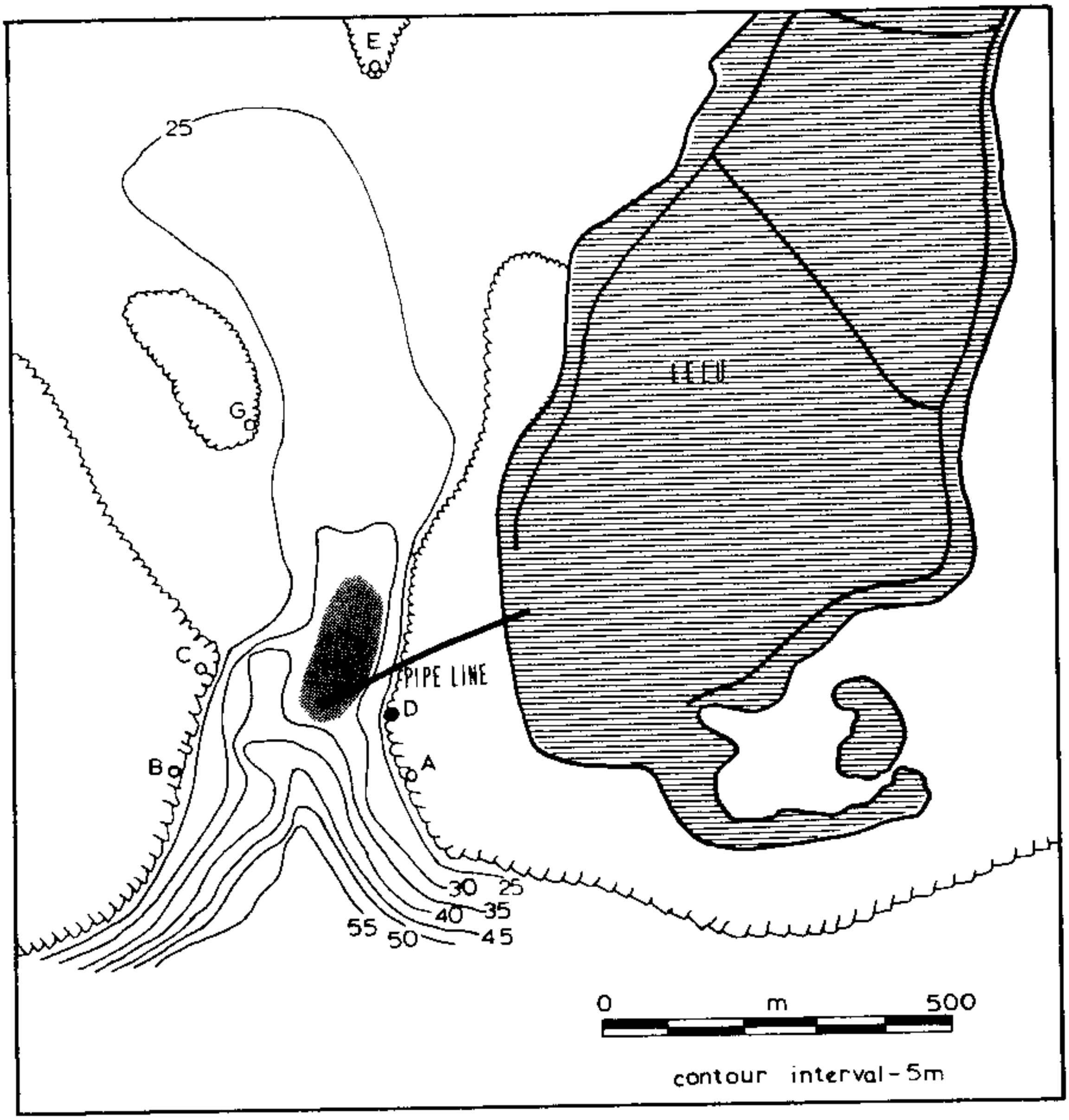


Figure 20. Recommended area for outfall discharge (cross-hatched area).

Table 6. Selected depths along transects at harbor entrance and along transect 1.

Transect 1			Transect 5			Transect 8		
Distance	Depth		Distance	Depth		Distance	Depth	
(m)	(m)	(ft)	(m)	(m)	(ft)	(m)	(m)	(ft)
0	57	187	0	1	3	0	2	5
50	56	184	25	27	88	50	19	61
100	54	184	50	35	115	100	23	75
150	50	165	75	36	117	150	26	85
200	45	120	100	34	112	200	27	88
250	41	133	125	34	112	250	28	93
300	37	120	150	34	112	300	29	96
350	35	115	175	33	109	350	30	99
400	35	115	200	30	99	400	30	99
450	35	115	225	1	4	450	27	88
500	35	115				500	23	75
750	25	83				550	2	6
1000	22	72						
1250	21	69						
1500	13	43						
1750	6	19						

Transect 3			Transect 6			Transect 9		
Distance	Depth		Distance	Depth		Distance	Depth	
(m)	(m)	(ft)	(m)	(m)	(ft)	(m)	(m)	(ft)
0	1	3	0	1	3	0	2	8
50	28	93	25	21	69	25	34	112
100	41	133	50	31	101	50	36	117
150	46	149	75	33	109	75	35	115
200	39	128	100	36	117	100	35	115
250	18	59	125	39	128	125	36	117
300	1	4	150	41	133	150	35	115
			175	42	139	175	33	109
			200	41	133	200	31	101
			225	34	112	225	30	99
			250	24	80	250	14	45
			260	7	24	270	2	8

LITERATURE CITED

Videnov, T. and R. G. Ludwig. 1983. Kosrae, plan design proposal for sanitary and wastewater disposal facilities. World Health Organization, Suva, Fiji.