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BATE BAY POLLUTION STUDY: vol. 7
Stormwater drains and beach water quality / S. Jane Hall

DATE DUE	BORROWER
~~-7 AUG 1994~~	Andrew Coulbridge - S/R X5248
~~19/9/94~~	Russell Hopkins Lidcombe.
~~15/9/94~~	~~R. Lee (Phillip)~~
	~~Lynne Robinson x 5266~~
~~10 NOV 1994~~	
~~8/3/95~~	~~Annabelle Andrews EER~~ Recalled 9/3/95
17 APR 1995	Scott Hudson Gordon

(PTO)

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17. [illegible] 1936 M. Parmentier

Environmental Management and Investigations
Australian Water Technologies
Water Board
(Sydney - Illawarra - Blue Mountains)

PO Box A53
Sydney South 2000
Tel. (02) 339 9299
Fax. (02) 332 3158

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Bate Bay Pollution Study
Volume 6
The Bate Bay Scour Hole

S. Jane Hall

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EXECUTIVE SUMMARY

During November and December 1991, a series of pollution events occurred along the Cronulla beaches in Bate Bay. In the northern section of Bate Bay is a depression in the sea floor which may have contributed to the pollution events. Debris accumulated in the base of the hole during certain oceanographic conditions may be removed under different oceanographic conditions. This feature is thought to be an active scour hole rather than a relic depression that has not been filled.

The scour hole was investigated on several occasions using a camera mounted on a Remotely Operated Vehicle (ROV). An accumulation of unattached kelp and other organic material was recorded at the base of the hole. The material was mostly estuarine and marine plant debris and anthropogenic litter. Probable sources of this material were discharges from the Port Hacking estuary, stormwater drains, urban runoff and nearby rocky reefs. The area and volume occupied by the debris varied between sampling occasions suggesting that material was accumulated in the hole under certain conditions and flushed from it under other conditions.

High levels of faecal bacteria were recorded from water sampled in and around the scour hole. No site or occasion sampled recorded consistantly higher levels of faecal bacteria than any other site nor occasion sampled. Sediments sampled from the base of the hole also contained high levels of faecal bacteria. Possible sources of this faecal material were the discharges from the Cronulla STP outfall at Potter Point, the small unsewered community at Boat Harbour and urban runoff from stormwater drains discharging into Bate Bay and the catchments of nearby estuaries (Port Hacking and Botany Bay).

Elevated bacterial levels recorded in the hole mostly did not exceed the levels of bacteria recorded on the Cronulla beaches.

The oceanographic conditions which scoured the hole and flushed out the accumulated material were unlikely to provide the transport mechanisms necessary to deposit this material onto the Cronulla beaches.

The scour hole is unlikely to be a major source of pollution onto the Cronulla beaches.

CONTENTS

1. INTRODUCTION.

1.1. BACKGROUND.

A series of pollution events occurred along the Cronulla beaches during November and December 1991. The pollution comprised of high faecal bacteria levels and visible pollution of sewage and stormwater origin (Beachwatch, 1992a & b). These events received considerable media attention and raised the community awareness of pollution in the Cronulla area. Of particular concern was the possibility that the pollution may have come from the recently commissioned deepwater sewage effluent outfall at Malabar.

There are several possible sources of pollution on the Cronulla beaches. In addition to the deepwater ocean outfalls, other sources in the area include the Cronulla sewage outfall at Potter Point, local stormwater drains, a small, local, unsewered community at Boat Harbour, the Port Hacking and Botany Bay estuaries, marine debris and ship discharges.

A depression in the sea bed in the northern part of Bate Bay may contribute to the distribution of pollution in the area. The hole is believed to be an area of active scouring and not a relic depression. The scour hole may function as a secondary source of pollution. It may accumulate material (marine debris, anthropogenic litter or pollutants) under certain current and weather conditions, and when conditions change (perhaps during storms), this accumulated material may be discharged from the scour hole and carried to the beaches.

Two scenarios of weather and oceanographic conditions have been speculated to cause the accumulation and removal of material from the hole. These are :

1. During a rainfall event, stormwater debris would be carried into the Port Hacking estuary. In an ebb tide this material would be transported with estuarine debris (*Posidonia* and *Zostera*) to the mouth of the estuary. In a light or moderate southeasterly wind with low to moderate wave conditions this material may be transported north along the Cronulla Beach shoreline. Other stormwater material could be picked up from discharge from some of the 24 stormwater drains along the Cronulla peninsula (see Riddle, 1993). This material could be transported to the northern end of Bate Bay and eventually deposit in the scour hole.

2. In a period of good weather with light northeasterly winds, wind driven effluent may be transported from Potter Point towards Merries Reef and by wave action over the reef into the scour hole. This scenario may have further implications. For example, in an ebb tide, pollutants discharged from Botany Bay and private outfalls on the Kurnell penisula may be transported towards the Bate Bay scour hole.

Both scenarios could occur without intervening scour events. This would result in the accumulation of material from diverse sources.

This report examines the Bate Bay scour hole as a possible source of pollution on the Cronulla beaches. Other reports in the Bate Bay Pollution Study examine the physical transport of material from known discharge points in the region, the levels of contaminants in sediments and mussels from Bate Bay and near known discharge points, the effect of stormwater on beachwater quality, and the conditions historically associated with pollution events in Bate Bay.

1.2. THE SCOUR HOLE.

Seabed information charts of the Bate Bay region (Public Works Department, 1989) show a deep, steep-sided hole in the northern section of Bate Bay, between the northern end of Cronulla Beach and Merries Reef (Figure 1.). The surrounding seafloor is at 15m depth and slopes steeply into the hole where the depth is around 30m at the centre. The substrate in this area is described as finegrained, fawn coloured sand with 30% shell. Rocky reef occurs near the eastern and east-southeastern edge of the scour hole.

Little information exists on the mechanism of formation of the hole. It may be a relict feature but is more likely to be erosional. Scouring and overdeepening of the bay bed has probably occurred from storm-induced bottom currents behind Merries Reef (Roy and Crawford, 1979).

Evidence from sediment cores also suggest that the feature is maintained through active erosion. Non-shelly sand (probable Pleistocene sand) has been identified in the bottom 3cm of a 93cm core from the scour hole (P. Roy, pers.comm.). The environmentally corrected date of the 75-90cm interval of the core was 1445 +/- 90 years before present. This is older than may be expected from such a short core, which suggests that more sediment may have originally overlain this section of the core, but has been removed. Scouring may have removed much of the sediment originally overlying this dated 75-90cm interval of the core. This suggests that the hole is probably a scour feature.

Similar scour features occur elsewhere in the Sydney region, between Lion Island and Middle Head in Broken Bay, behind Maitland Reef north of Broken Bay and behind Jibbon Bombora near the mouth of Port Hacking.

1.3. OBJECTIVES.

The objective of this report was to determine whether pollutant material accumulates in the Bate Bay scour hole and if so, did this material periodically empty from the scour hole and could it subsequently deposit upon the Cronulla Beaches.

Pollutant material as defined by Beachwatch (1989) includes debris of sewage origin (greaseballs, condoms, sanitary napkins, cotton buds and plastic remnants), as well as debris of stormwater origin (street litter such as paper and plastics, twigs and leaves). Non-visible pollutants include high levels of faecal bacteria.

The scour hole was studied in two series of investigations. Sampling for the first series occurred between April to July 1992. This pilot study tested many of the techniques used for the later study and established that material did accumulate at the base of the hole. Sampling for the main study occurred between November 1992 to January 1993.

The aims of this study were to :-

* assess whether the area covered and volume of debris accumulated at the base of the scour hole had changed over the study period,

* determine likely sources of material in the scour hole by identification and consideration of possible transport mechanisms,

* assess the water quality in the scour hole,

* characterize the water in the scour hole using temperature, salinity, pH and conductivity,

* assess whether a visual indicator (such as the presence of debris or water clarity) could be identified for faecal bacterial contamination.

The bacterial indicator organisms (faecal coliforms, faecal streptococci and *Clostridium perfringens*) are not normal inhabitants of fresh or marine waters. They are usually associated with human faeces or sewage effluent, and their presence is usually an indication of contamination by sewage or stormwater. Faecal coliforms indicate the presence of fresh faecal material. *Clostridium perfringens* is a more persistent faecal indicator than most other faecal bacteria and it's presence may indicate the previous occurrance of faecal material in an area.

This report describes some of the physical and microbiological features of the subtidal scour hole located in the northern section of Bate Bay, and determines whether it could be a source of pollution.

2. METHODS.

2.1. SURVEY BY REMOTELY OPERATED VEHICLE (ROV).

The base of the scour hole was photographically surveyed by ROV towed in a grid pattern over the northern section of Bate Bay. The topography of the scour hole and the position of debris at the base of the scour hole was mapped by integrating video footage with depth soundings and accurate position fixing using either a Trisponder Position Fixing System or Global Positioning System (GPS). The pilot study was undertaken on April 29, June 1 and July 1, 1992.

The ROV was towed over a finer grid pattern during a second series of surveys on November 5 and 9, November 23 and 24, December 18 and 19, 1992 and January 12 and 13, 1993. The visible features within the scour hole were summarised from each survey (Table 2). The maximum dimensions of the accumulated debris was measured by ROV survey and shown as East-West by North-South. The area covered by the accumulated debris was calculated by plotting the perimeter of the accumulated material. The density of the plant debris was estimated as a percentage of the bottom water layer in which it was suspended. The volume of the plant material suspended at the bottom of the scour hole was calculated from the approximate density (estimated from the video footage) of the plant material suspended in the water layer at the base of the hole, and the area covered by and the depth of the accumulated debris in this bottom water layer.

A three dimensional representation of the scour hole was generated using depth soundings taken on November 23, 1992 (Figure 3).

The organic and anthropogenic components were identified from visual assessment of the video footage (Table 2). The degree of decomposition of the organic components was also assessed from the video footage.

Water samples were taken from locations within and around the scour hole usually on the day after each video survey. In addition, temperature, salinity and pH were measured using a submersible data logger (SDL) (Figures 9-11). The temperature and salinity profiles indicated some of the physical processes in the water column, the dissolved oxygen and pH indicated some of the biological processes. The calibration of the SDL sensors may not have been accurate, hence the profiles were interpreted in terms of overall trends rather than absolute figures.

2.2. WATER SAMPLE ANALYSIS.

During the pilot study on July 1, 1992, one water sample was collected from the subsurface (0.5m depth) and from the bottom (0.5m above the sea bed) at three locations.

Two sampling locations were in the scour hole, one in and above the accumulated debris and the other to one side and just out of the accumulated debris. The third location was south-east of the scour hole, towards Merries Reef (Figure 2). This location was chosen because it was between the scour hole and the outfall of the Cronulla sewage treatment plant at Potter Point.

Water samples were tested for faecal coliforms and faecal streptococci.

In the second series of surveys, the three locations previously sampled were resampled and a 4th location between Merries Reef and Potter Point was included. Bottom, subsurface and some intermediate depths were sampled at each location (Figure 2). During each day of sampling, every location was visited on three occasions. On each occasion, three independent replicate samples were collected from each depth. Sampling took place on four dates. Table 1 shows the experimental design, and the locations and depths sampled.

Table 1. Experimental design for the water sampling program of the second series of investigations for each occasion of sampling.

Location	Depth (m)	Location Number	Number of Sites	Number of Replicates
In debris in scour hole	0	1	3	3
	11	2	3	3
	19	3	3	3
	28	4	3	3
	29.5	5	3	3
Out of debris in scour hole	0	6	3	3
	29.5	7	3	3
Inshore of Merries Reef	0	8	3	3
	15	9	3	3
Offshore of Merries Reef	0	10	3	3
	15	11	3	3

Levels of faecal coliforms measured during the second series of investigations were analysed by analysis of variance (ANOVA) and Tukey multiple comparison tests (TMC), after testing for homogeneity of variance and log transforming the results. The levels of faecal streptococci were not included in the analyses because of failure of the laboratory to provide results from sampling from December 18, 1992.

The results were analysed in two formats, one to determine whether a difference in faecal coliform levels occurred between locations or between sampling dates, the other to determine whether a difference occurred between subsurface and bottom depths or between those locations within the hole and those outside of the hole.

2.3. SEDIMENT ANALYSIS AND IDENTIFICATION OF ORGANIC DEBRIS.

Three sediment cores of 3cm diameter and 6cm depth, and 1 water sample were collected by SCUBA divers on January 28, 1993. Samples were analysed for levels of faecal coliforms and *C. perfringens* and the results given as colony forming units (cfu) per 10 grams of sediment analysed and cfu per 100ml for the water analysis (Table 4). Organic debris was collected from the base of the scour hole for identification.

3. RESULTS.

3.1. GENERAL TOPOGRAPHY.

The substrate in the area surrounding the scour hole was usually clean sand with little or no debris or strong ripple marks. Water depth was about 15m and water clarity usually good with visibilty around 15-20m.

A three dimensional representation of the scour hole is shown from a south-west view, through the shallow gradient of the western end of the hole (Figure 3). All other sides of the hole are steep. This figure represents 900m in length (east-west dimensions) and 550m in width (north-south dimensions) of the scour hole, with an exaggerated vertical (depth) axis. The base of the scour hole gradually increased in depth to a maximum of 30.3m depth near the eastern edge. The sides of the scour hole were bounded by rock at the eastern and east-southeast edges, and elsewhere the substrate was sand.

Water clarity in the scour hole declined with increasing depth. Layers of poor water clarity were mostly about 1m thick and occurred at different depths on some occasions of surveying (Table 2).

A dense accumulation of unattached kelp, other plant debris and some anthropogenic litter was usually found at the base of the scour hole. The video footage indicated that the organic material was in various stages of decomposition. The volume and composition of material in the accumulation and the area covered by it varied between sampling dates.

3.2. VISIBLE FEATURES WITHIN THE SCOUR HOLE.

Accumulated organic material was suspended in a distinct layer of very poor water clarity about 1m thick at the base of the scour hole. As the ROV descended into the water layer at the base of the hole, the visibility abruptly decreased from several metres in the clearer water above to almost zero in the water layer at the base of the lens.

The area covered by the accumulated material in the scour hole varied considerably between each day of sampling (Table 2, Figs. 4-8). There was no complete survey on June 1, 1992 although some footage recorded kelp lying in rows at one location on the sea bed before the ROV failed. No large area of accumulated material was recorded at the base of the scour hole on January 12, 1993, although some kelp was present in small disjunct patches. On all other occasions the composition of the accumulated material was mostly kelp. The condition of the kelp varied between each day of sampling from fresh to very decomposed.

Table 2. Features within the Scour Hole - Results of the ROV surveys.

	Series 1-Pilot Study			Series 2			
	29/4/92	1/6/92 *	1/7/92	5/11/92	23/11/92	18/12/92	12/1/93
Max. dimensions of lens (m) (E-W x N-S)	400 x 90	-	200 x 50	650 x 60	700 x 110	950 x 220	0
Area of lens (m^2)	18000	-	5000	31250	46200	99500	0
Density of plant debris in bottom water layer (%)	10	-	5	5	5	5	-
Volume of suspended plant debris(m^3)	1800	-	250	1562	2310	4975	-
Organic components	kelp *Posidonia ZosteraSargassum*	kelp in rows	kelp	kelp	kelp	kelp	kelp in small patches
Anthropogenic components	paper, plastics	none seen	none seen	none seen	none seen	paper,plastics	-
Visible condition of plant debris	very decomposed	-	decomposed	Nct decomposed	not decomposed	not decomposed	-
Depth of layer of poor water clarity (m)	28	0	28	25 & 28	28	21 & 28	24 & 27

* ROV failure

3.3. WATER SAMPLE ANALYSIS.

High levels of bacteria were recorded at the base of the scour hole on July 1, 1992 (Table 3). Elevated levels of faecal coliforms were recorded at 11m depth in the scour hole and at bottom and subsurface depths offshore of Merries Reef on November 9, 1992. High faecal coliform levels were also recorded at the 11m depth in the hole on January 13, 1993. High faecal coliform levels were recorded from the bottom samples offshore of Merries Reef on November 23, 1992 and from the bottom samples inshore of Merries Reef on December 18, 1992.

The faecal coliform counts were variable (Table 3). The variances were heterogenous and could not be stabilized by a variety of transformations. However, log transformed results were still analysed by ANOVA and by Tukey multiple comparison tests. Due to the significant heterogeneity in the data these results should be interpreted with caution.

There was a significant interaction between location and time (Appendix Table 1). This suggests that the variability in faecal coliform counts amongst locations was not consistant over time, i.e. that no one location showed consistantly higher or lower bacterial counts than other locations over time.

On November 9, 1992, the faecal coliform levels at the 11m location over kelp were similar to the levels at the 15m location offshore of Merries Reef and both were higher than at other sites inshore of Merries Reef (Tukey multiple comparison tests). Faecal coliform levels at the locations offshore of Merries Reef were higher than the levels recorded inshore of the reef. On November 23, 1992, the levels recorded at the 15m location offshore of Merries Reef were significantly higher than the levels at all other locations. On December 18, 1992, the levels at the 15m location inshore of Merries Reef were significantly higher than the levels recorded at all other locations. On January 13, 1993 the 11m depth in the hole over kelp had significantly higher faecal coliform levels than the other locations. Overall, higher levels of faecal coliforms were recorded at more locations on November 9, 1992 than at any other sampling date.

There was significant interaction between location and time (Appendix Table 2) but not between depth and site (within location). This suggests that the variability in faecal coliform counts between locations was not consistent over time, but between depths was consistant over locations. No one location either within the hole nor near to the hole showed consistantly higher or lower bacterial counts than other locations over the period sampled. More locations showed higher bacterial counts from the bottom samples than from the subsurface samples.

Table 3. Levels of faecal coliforms (FC) and faecal streptococci (FS) (cfu/100ml) in water samples from locations in and near the scour hole in northern Bate Bay. Results from single samples (Series 1) or mean with range in parentheses (n=9) (Series 2).

Location	Depth (m)	Location Number	Series 1		Series 2						
			1/7/92		9/11/92		23/11/92		18/12/92	13/1/93	
			FC	FS	FC	FS	FC	FS	FC	FC	FS
Over Debris in Hole	0	1	4	2	9 (0-16)	3 (0-8)	0 (0)	0 (0-1)	1 (1-2)	1 (0-2)	1 (0-4)
	11	2	-	-	61 (8-160)	6 (4-27)	1 (0-2)	0 (0-3)	1 (1-2)	121 (2-360)	12 (1-32)
	19	3	-	-	16 (0-49)	2 (0-6)	4 (0-10)	1 (0-1)	3 (1-16)	1 (0-1)	1 (0-1)
	28	4	160	36	10 (0-26)	2 (0-6)	4 (1-9)	1 (0-4)	1 (1-2)	1 (0-2)	2 (0-4)
	29.5	5	170	62	9 (1-26)	3 (0-10)	4 (1-7)	0 (0-1)	2 (1-6)	1 (0-2)	2 (0-6)
Not Over Debris in Hole	0	6	-	-	11 (0-56)	5 (0-22)	0 (0)	1 (0-3)	1 (1)	1 (0-2)	1 (0-1)
	29.5	7	170	44	5 (0-9)	1 (0-5)	5 (1-9)	1 (0-4)	2 (1-6)	1 (0-1)	1 (1-2)
Inshore of Merries Reef	0	8	2	22	2 (0-6)	0 (0-1)	0 (0)	0 (0)	1 (1)	1 (0-5)	0 (0-2)
	15	9	14	2	2 (0-3)	0 (0)	1 (0-3)	1 (0-1)	106 (40-300)	4 (0-12)	0 (0-2)
Offshore of Merries Reef	0	10	-	-	59 (0-210)	61 (0-200)	1 (0-1)	0 (0-1)	18 (1-68)	15 (1-63)	7 (0-24)
	15	11	-	-	61 (21-89)	9 (3-15)	126 (39-170)	28 (14-28)	3 (1-6)	4 (1-12)	0 (0-1)

3.4. SEDIMENT ANALYSIS AND IDENTIFICATION OF ORGANIC DEBRIS

Water clarity within the scour hole near the sea bed was less than that at mid water and subsurface. At subsurface depth the visibility was 15m, at the 14-27m depth range visibility was 10-6m, at 28.5m depth the visibility was abruptly reduced to 1m and 0.5m above the sea bed (29.5m) visibility was zero. The upper layers of sediment within the scour hole were composed of a very fine black silt suggesting that conditions may have been anoxic.

The sediments in the scour hole recorded very high levels of *C. perfringens* (Table 4), the levels of faecal coliforms were less.

Table 4. Levels of *C. perfringens* and faecal coliforms in sediment and water samples from the base of the scour hole.

Bacterial Indicator	Sediment Samples (cfu/10gm)			Water Sample (cfu/100ml)
	1	2	3	
C. perfringens	34,000	52,000	7,100 *	370
Faecal coliforms	<200	<200	<200	6

* Core split in collection bag.

The loose organic material which was collected from the base of the scour hole on January 28, 1993 was composed of about nine taxa of seagrass and algae (Table 5). No plants were found attached to the substrate in the scour hole indicating that the seagrass and algae had been detached from their usual growing site. Plants varied in condition from fresh to very decomposed. Decomposed material had usually lost its original colour and shape and was grey in colour, recent material had retained its original colour and shape.

Table 5. Identification of organic material from the base of the scour hole.

Taxa	Condition, colour	Usual habitat
Ecklonia	Very decomposed	Reef, open marine
Sargassum	Very decomposed	Reef or sand, marine
Posidonia or *Zostera*	Very decomposed, * balled	Sand, marine or estuarine
Zonaria	fresh, green	Reef, marine
Grateloupia filicina	fresh, brown	Reef, marine
Caulerpa ?filiformis	fresh, green	Reef or sand, marine
Dictyota dichotama	fresh, red	Reef, marine
Delisea pulchra	fresh, red	Reef, marine
Hydroids	fresh	Hard substrate

* Strands of *Posidonia* and *Zostera* were found in balls, probably caused by movement along the sea floor.

3.5. PHYSICAL CHARACTERISTICS OF THE WATER COLUMN.

Salinity was uniform at all locations on all sampling dates, therefore only the temperature profiles are shown to represent the density of the water column at each location (Figures 9-11).

Temperature profiles over the scour hole and inshore of Merries Reef on November 23, 1992 were all similar (Figure 9). The temperature decreased from 19°C at the surface to 15°C at 9-10m water depth at the base of the thermocline. Offshore of Merries Reef, the temperature decreased from 19°C at the surface to 17°C at 14m depth.

On December 18, 1992 (Figure 10) the water temperature was constant at about 20°C from the surface to about 18m. In the scour hole the water temperature abruptly dropped from 20°C at 18m to 17°C at 22-23m, and remained constant from 23m to the sea bed. At the locations inshore and offshore of Merries Reef, the water temperature was constant from surface to sea bed indicating that the upper mixed layer extended throughout the water column.

On January 13, 1993 (Figure 11) temperature profiles were similar on either side of Merries Reef. The water temperature was constant at 20°C from the surface to about 11m indicating a well mixed upper surface layer. Over the scour hole the temperature dropped from 20°C at 11m to 15°C at 22-23m. From 23m to the sea bed the temperature was constant at 15°C which also indicated that the water was well mixed.

4. DISCUSSION

4.1. THE ACCUMULATED DEBRIS.

4.1.1. Composition and Sources.

Accumulated material of marine and anthropogenic origin was present at the base of the Bate Bay scour hole. The area covered by this material increased and decreased during the study period. The composition of the material indicated that it originated from sources external to the scour hole. Tracing the source of this material may indicate some of the oceanographic transport mechanisms in Bate Bay.

Kelp was the most common material in the scour hole. Nearby possible sources of kelp are Merries Reef (0.75-1.0km east of the hole) and the rocky reefs east and south of Merries Reef (e.g. near Boat Harbour, Potter Point, Cape Baily, Glaisher Point, Port Hacking Head and Jibbon Bombora). Strong wave action during storms detaches kelp from the substrate.

Posidonia and *Zostera* were also present in the hole. These seagrasses usually live in shallow, low-energy areas such as in Port Hacking (4km southwest of the scour hole), or Botany Bay (8km northeast of the hole). In an ebb tide, detached seagrasses could be transported northwards from the Port Hacking estuary by a northward flowing current which was observed along the Royal National Park, north of the Port Hacking Point and along the Cronulla peninsula (Large *et al*, 1994). After rain, stormwater debris from the Port Hacking catchment could also be transported to the hole by this current.

The condition of the organic material ranged from fresh to very decomposed, and indicated the period of time since the material had been removed from its growing site and probably also the period of time that this material had accumulated in the hole. The specimens of small reef growing algae collected during the dive into the scour hole (Table 8) were not decomposed. This may suggest that these algae were likely to have recently accumulated there. The larger, reef growing specimens of kelp and *Sargassum* and the seagrasses *Posidonia* and *Zostera* were very decomposed which may suggest a longer period of accumulation in the hole. Further work could show whether all the debris accumulated in the base of the hole is removed during all periods of scouring.

The decomposed organic material probably contributed to the layer of poor water quality at the base of the scour hole.

The anthropogenic material recorded in the scour hole (paper and plastics) may have been from boat discharge or of stormwater origin. Nearby possible sources of material of stormwater origin include the stormwater drains at Cronulla and Shelly Beach (3.5km southwest of the scour hole), runoff from the small community at Boat Harbour (2km east of the scour hole) and from the Port Hacking estuary and Botany Bay.

4.1.2. Area and Volume of the Accumulated Material.

The area covered by the accumulated material differed between surveys and this may have been due to material either accumulating or being removed from this area at the base of the scour hole, material being concentrated or dispersed within the scour hole, or material being held in another area at the base of the hole.

Between December 18, 1992 and January 12, 1993 the area covered by the accumulated material decreased from 99500m^2 to a very patchy cover of almost zero. This material must have been removed and not merely redistributed within the scour hole, and this is likely to have occurred during a scouring period. The volume of suspended plant material removed from the base of the hole cannot be accurately quantified because of the very approximate estimates of the density of the plant material suspended at the base of the scour hole. The estimates of the volume are provided as a guide to the amount of plant material which may have been be deposited onto the Cronulla beaches under certain oceanographic conditions. However, as shown later, the currents which cause flushing of material from the scour hole are more likely to transport subsurface material offshore than onshore onto the Cronulla beaches.

The increases and decreases in area covered by the accumulated material indicates that the scour hole undergoes accumulating and scouring phases. Accumulation may occur over weeks or months, with the organic debris in the lens undergoing some decomposition over this period. Scouring may occur over a shorter period of time. Accumulation probably occurs during periods of weak circulation currents within the hole, scouring probably occurs during periods of strong circulation current in the hole generated by significant wave action across Merries Reef (AWACS, 1993).

Weak currents have been recorded in the scour hole and were associated with an ebb tide at Port Hacking and a weak anti-clockwise current in the bay (AWACS, 1993). This could be another transport mechanism to transport seagrasses from the closest potential source of seagrasses in Port Hacking, to the northern section of the bay where they accumulated in the hole.

Wave action has two possible roles in the accumulation and distribution of plant material in the scour hole. Strong wave surge during storms can detach seagrasses and algae from the substrate. In addition, strong waves cause wave induced transport over Merries Reef which can generate strong anti-clockwise currents inshore of Merries Reef (AWACS, 1993). Stong currents have been recorded at the base of the hole (AWACS, 1993) and would scour the hole flushing out accumulated material.

The strong anti-clockwise currents observed above the scour hole combined with a northward flow along the Cronulla Peninsula generated a counter rotating circulation within Bate Bay (Large *et al*, 1994). Under these conditions, material scoured from the hole may be transported to the Cronulla beaches but is more likely to remain subsurface and eventually be transported offshore.

It has been suggested (AWACS, 1993) that the strongest currents will be generated when an outgoing tide coincides with storms from the south-east causing waves over 2.5m in height over Merries Reef.

The observations were not consistant with these scenarios. Between December 18, 1992 and January 13, 1993 when material was removed from the hole, there were no major storms from the south-east that recorded a significant wave-height over 2.5m (Figures 13 and 14). However between November 5, 1992 and December 19, 1993 when material was accumulating in the scour hole, there were a number of occasions when these scenarios occurred, and the hole should have been flushed out (Figures 12 and 13). Scouring from the hole may only occur with additional conditions to those proposed in the scenario.

On December 18, 1992, prior to the major scour event in the hole, there was an upper mixed layer to 18m depth, below the lip of the hole, a thermocline of 3°C from 18-22m depth and a well mixed layer occurring from 22m to 29m at the base of the hole. It is suggested that if the upper mixed layer extended to the base of the hole causing full depth mixing, the destratification of the water column in the hole would allow easier transfer of wave energy over the reef and into strong current generation at the base of the hole. It is suggested that destratification or full depth mixing within the scour hole may be another criterion required in the scenario proposed to cause scouring and flushing of material from the hole.

4.2. WATER QUALITY.

No single locality recorded higher faecal coliform levels than the other localities nor were higher bacteria counts recorded at all localities at any one sampling time compared to other sampling times. High bacterial levels were not associated with any single physical characteristic measured within the water column, nor were they always associated with the base of the scour hole, the debris accumulated there, nor layers of poor water clarity.

Elevated levels of faecal coliforms occurred at the base of the scour hole on July 1, 1992. On November 9, 1992, levels were significantly higher at the 11m locality in the hole and at the 15m locality outside Merries Reef than at other locations.

On November 23, 1992, high levels of bacteria were recorded near the maximum depth sampled (15m) offshore of Merries Reef. The SDL data for that day indicates that this coincides with the base of the thermocline.

On December 18, 1992, high levels of bacteria were recorded near the maximum depth sampled (15m) inshore of Merries Reef. This was at the base of a well-mixed upper surface layer.

High counts of bacteria were recorded at 11m depth within the hole on January 13, 1993. This depth coincides with the top of the thermocline at the base of the well-mixed upper surface level.

None of these elevated levels exceeded the water quality guidelines followed by Beachwatch which state that water is polluted when the faecal coliform level exceeds 300/100ml (geometric mean of 3 samples) or exceeds 2000/100ml in a single sample (Beachwatch, 1991).

The highest faecal coliform levels from the sampling period were recorded on January 13, 1993. These were 360 cfu per 100ml for a single sample and 244 cfu (geometric mean of

3 sites) from the 11m depth above debris in the hole.

There is no evidence of direct transport of effluent to the hole from the nearest possible sources of effluent, the outfall at Potter Point and the small unsewered community at Boat Harbour. On January 12 and 13, 1993, the faecal coliform levels from Boat Harbour and the other Cronulla beaches were low. Additionally, on these days, the faecal bacteria levels recorded from the sites located between the hole and outfall at Potter Point ("inshore" and "offshore of Merries Reef") were low. The elevated levels of faecal bacteria in the hole on January 13, 1993 may be due to an earlier or periodic discharge from Boat Harbour or Potter Point or to a less direct transport route from these sources to the hole.

Generally, dilution and bacterial die-off causes faecal coliform levels to decrease as the distance increases between the sampling site and source. The survival rate of faecal bacteria in ocean discharged effluent is dependent upon a complex series of factors. These include physical processes (dispersion and sedimentation) and loss of viability by solar radiation, osmotic stress, water clarity and predation by natural microbiota (Bell *et al*, 1991). Hence it is difficult to estimate the rate of decay of bacteria in an open system. In an aquatic system, 90% bacterial decay may occur in 2.5 - 8 hours and 70 - 80 hours in darkness (Bell *et al.*, 1991).

Potter Point is the only local source of faecal coliforms with a concentration of faecal coliforms and volume of discharge high enough to impact upon the site of the scour hole. The Potter Point plume has been recorded to extend over the scour hole during suitable oceanographic conditions (Large *et al.*, 1994).

Clostridium perfringens is a more persistant faecal indicator bacteria than faecal coliforms. There are no water quality guidelines for the levels of *C. perfringens* in sediments or water. The *C. perfringens* levels recorded from sediments in the base of the hole are high. High levels have been recorded from sampling of sediments near sludge dump sites (White *et al.*, 1993) and from sediments near deepwater discharge sites (Ashbolt *et al*, 1991). The combination of high levels of *C. perfringens* and low faecal coliforms recorded in sediments at the base of the hole indicates previous exposure to effluent.

In addition to possible periodic input of bacteria from an outside source, the sediments may act as a secondary source of bacteria. High concentrations of faecal bacteria have been recorded in sediments sampled near the de-commissioned cliff-face outfall at Malabar eight months after decommissioning (Ashbolt *et al.*, 1991). They suggest that these elevated levels were maintained as a result of bacterial multiplication equalling die-off processes.

High bacterial levels at the base of the scour hole may be maintained by secondary input of bacteria from the sediment. A continuous input of effluent may not be the sole source of the elevated bacterial levels in the hole. However, input of bacteria from the sediment would be affected by sediment erosion during scouring in the hole. The rate of erosion of sediments at the base of the scour hole has not been quantified.

4.3. CONCLUSION

The changes in the area covered by the accumulated material at the base of the hole indicate that this is a dynamic system which alternates between phases of accumulation and scour. Scouring would flush out accumulated debris and pollutants from the hole.

The composition of material recorded at the base of the scour hole was similar to the pollutant material recorded on the Cronulla beaches. Weed, algae and plastic remnants were recorded as visual pollution indicators on the Cronulla beaches in November and December 1992 (Beachwatch, 1992a & b) and were also recorded in the accumulated debris at the base of the scour hole. Floatable indicators of visual pollution such as greaseballs and cotton tips are unlikely to accumulate in the hole, but have been recorded on the beaches. This suggests that the scour hole may not be a major source of pollution to the beaches.

Elevated bacterial levels recorded on the Cronulla beaches often exceeded the levels of bacteria recorded in the hole during this study. Bacteria in the hole would undergo further die-off during transport to the Cronulla beaches. It is unlikely that the scour hole was the major source of bacterial pollution on the beaches.

The scenarios likely to generate the currents which scour and cause flushing from the hole are unlikely to provide the transport mechanisms necessary to deposit this material onto the Cronulla Beaches. The flushed material is more likely to be transported offshore.

The scour hole is unlikely to be a major source of pollution onto the Cronulla beaches.

4.4. SUMMARY

A steep-sided hole occurs in the northern section of Bate Bay. Evidence suggests that it is a scour feature.

Debris of estuarine, marine and anthropogenic origin, including effluent and stormwater debris, accumulates in the hole. Some of the material recorded in the accumulated material was also recorded as visual indicators of pollution on the Cronulla beaches.

Elevated bacterial levels were recorded at different depths and locations in and around the scour hole. No single locality, depth or sampling occasion showed consistantly higher levels over the sampling period. Elevated bacterial levels in the hole were not associated with any visual indicators of pollution such as debris or poor water clarity.

Accumulated material is scoured from the hole under certain oceanographic conditions. It is unlikely that the material which has been flushed from the hole is a major contributor to the pollution on the Cronulla beaches.

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7. APPENDICES

APPENDIX TABLE 1.

Two Way Analysis of Variance Results for Faecal Coliform Counts at 11 Locations on 4 Sampling Dates.

Source	DF	SS	MS	F	P
Location (Loc)	10	32.16	3.21	27.25	<0.001
Time	3	13.35	4.45	37.71	<0.001
Site (Loc)	22	6.65	0.30	2.86	<0.001
Loc x Time	30	57.84	1.93	16.34	<0.001
Error	352	41.58	0.12		
Total	395	144.93			

APPENDIX TABLE 2.

Three Way Analysis of Variance Results for Faecal Coliform Counts at 4 Locations and 2 Depths on 4 Sampling Dates.

Source	DF	SS	MS	F	P	F vs
Location	3	81.1146	27.0382	0	0	no test
Depth	1	52.3869	52.3869	0	0	no test
Time	3	42.8792	14.2931	9.29	.0003	TxS(L)
S(L)	8	12.4402	1.5550	1.01	.4538	TxS(L)
LxD	3	11.3116	3.7705	0	0	no test
LxT	9	84.7614	9.4179	6.12	.0002	TxS(L)
DxT	3	44.9170	14.9723	12.5	0	DxTxS(L)
DxS(L)	8	12.1651	1.5206	1.27	.3045	DxTxS(L)
TxS(L)	24	36.9085	1.5379	5.56	0	Residual
LxDxT	9	90.6655	10.0739	8.41	0	DxTxS(L)
DxTxS(L)	24	28.7398	1.1975	4.33	0	Residual
Residual	192	53.1141	0.2766			
Total	287	551.4041				

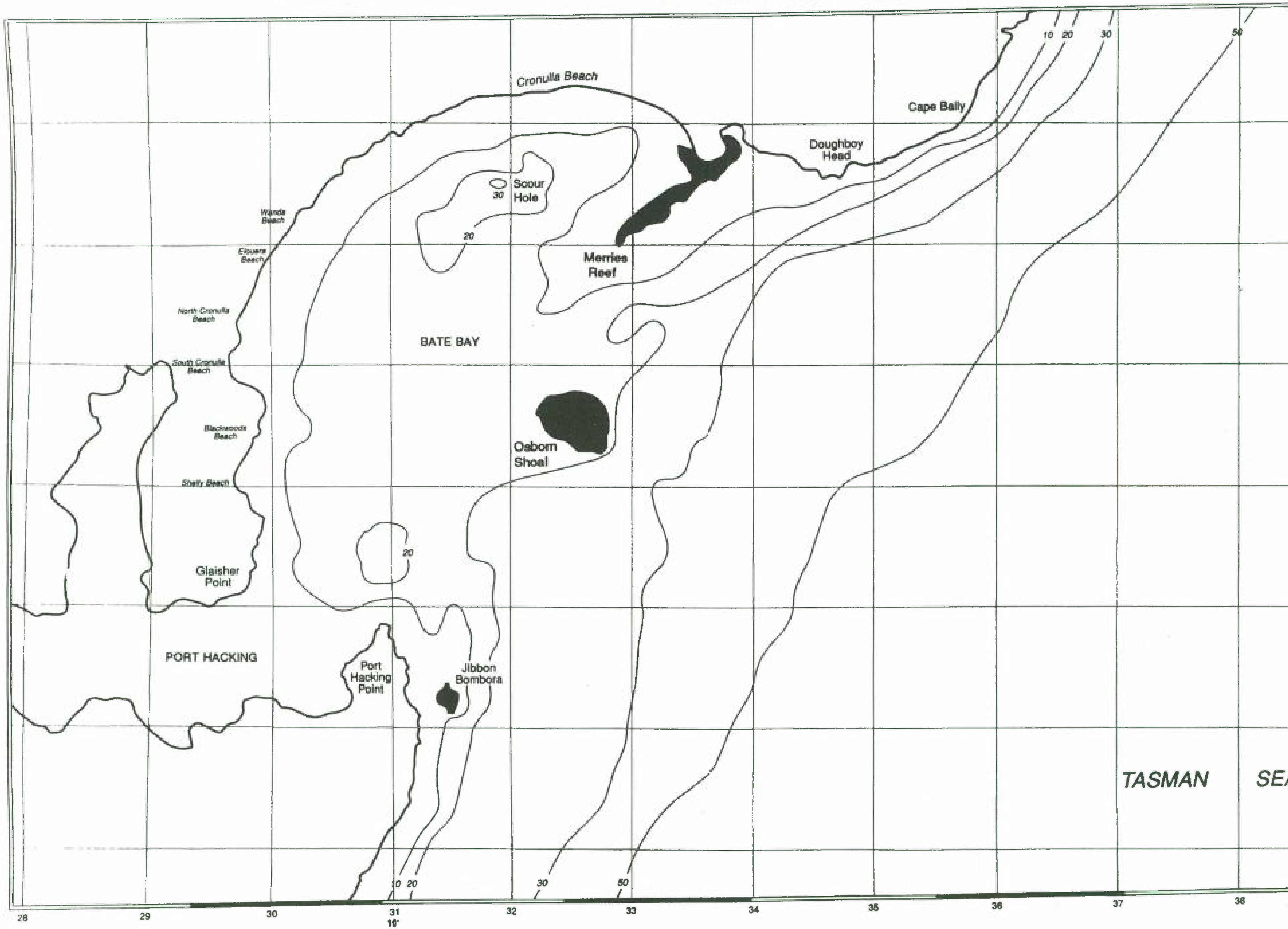

Figure 1. Bate Bay showing the location of the Scour Hole and the Cronulla Beaches (10m, 20m and 30m bathymetric contours shown).

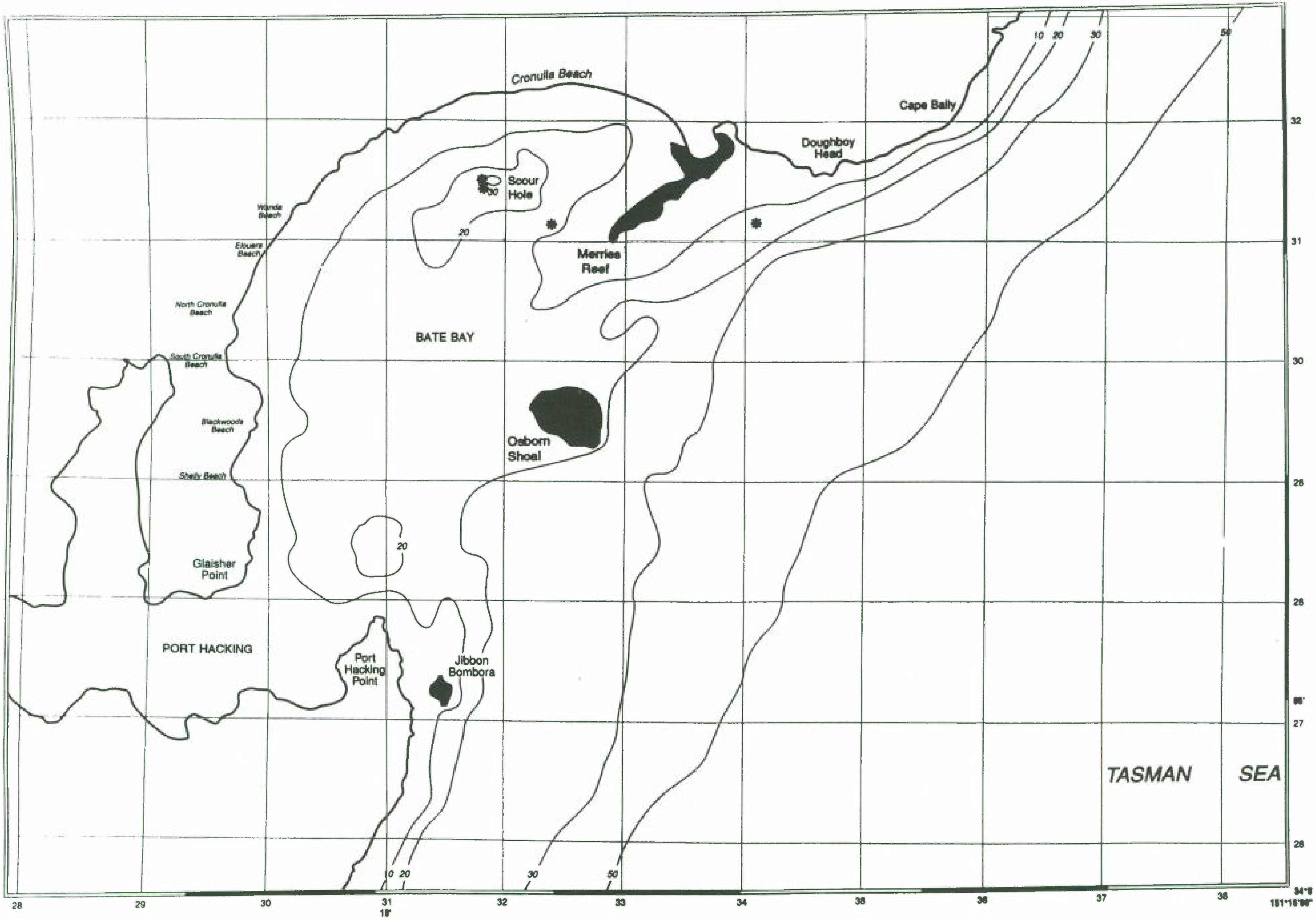

Figure 2. Location of water sample sites.

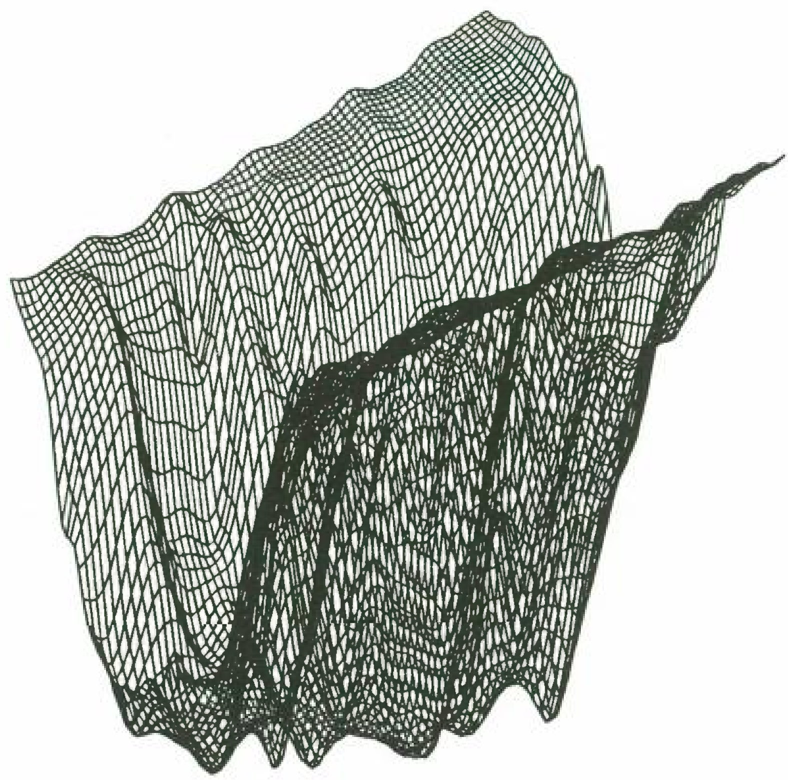

Figure 3. Graphic image of the Scour Hole from a south-west view. Length (east-west dimensions) represents 900m, width (north-south dimensions) represents 550m, depth represents about 30m.

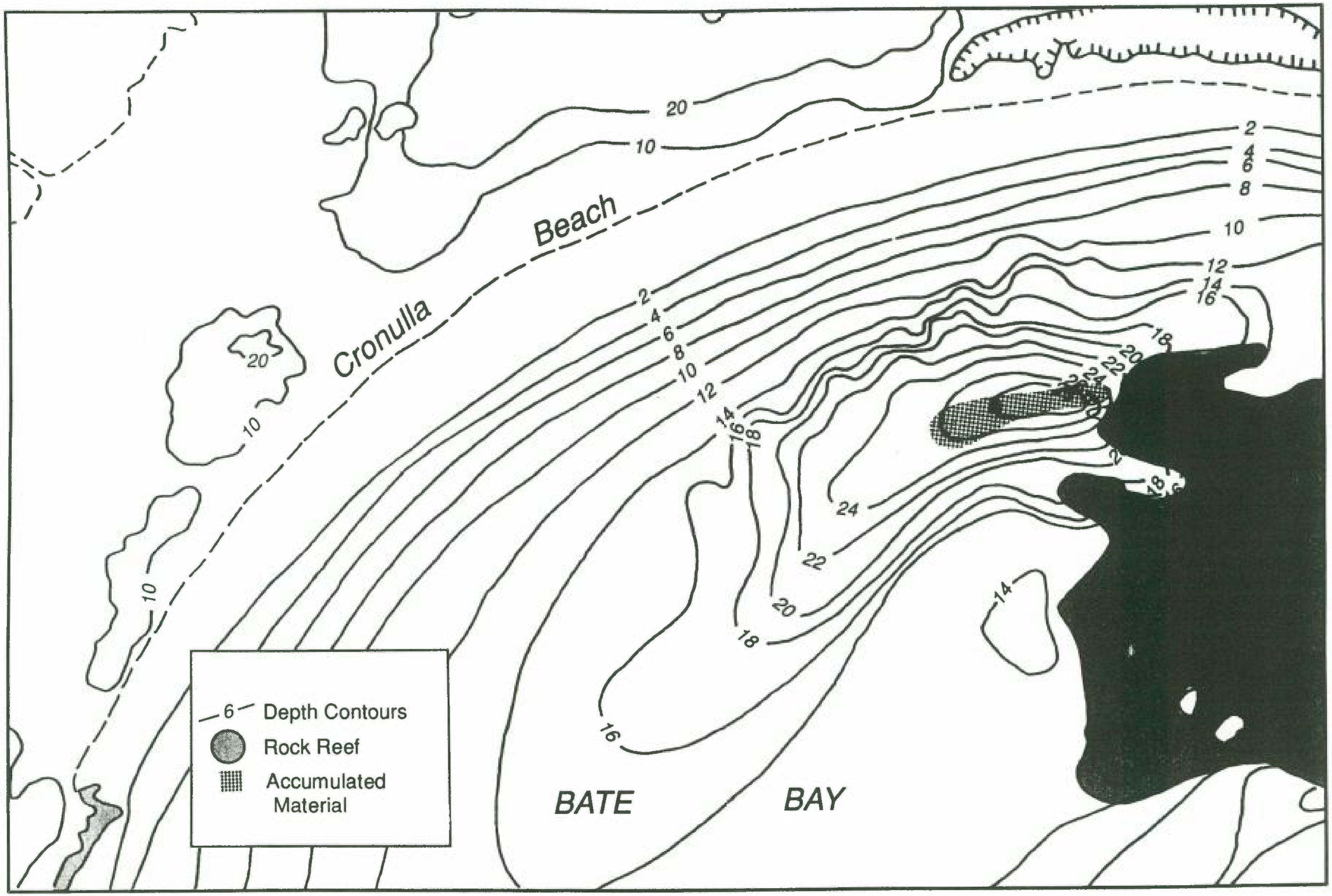

Figure 4. Area covered by the accumulated material on April 4, 1992.

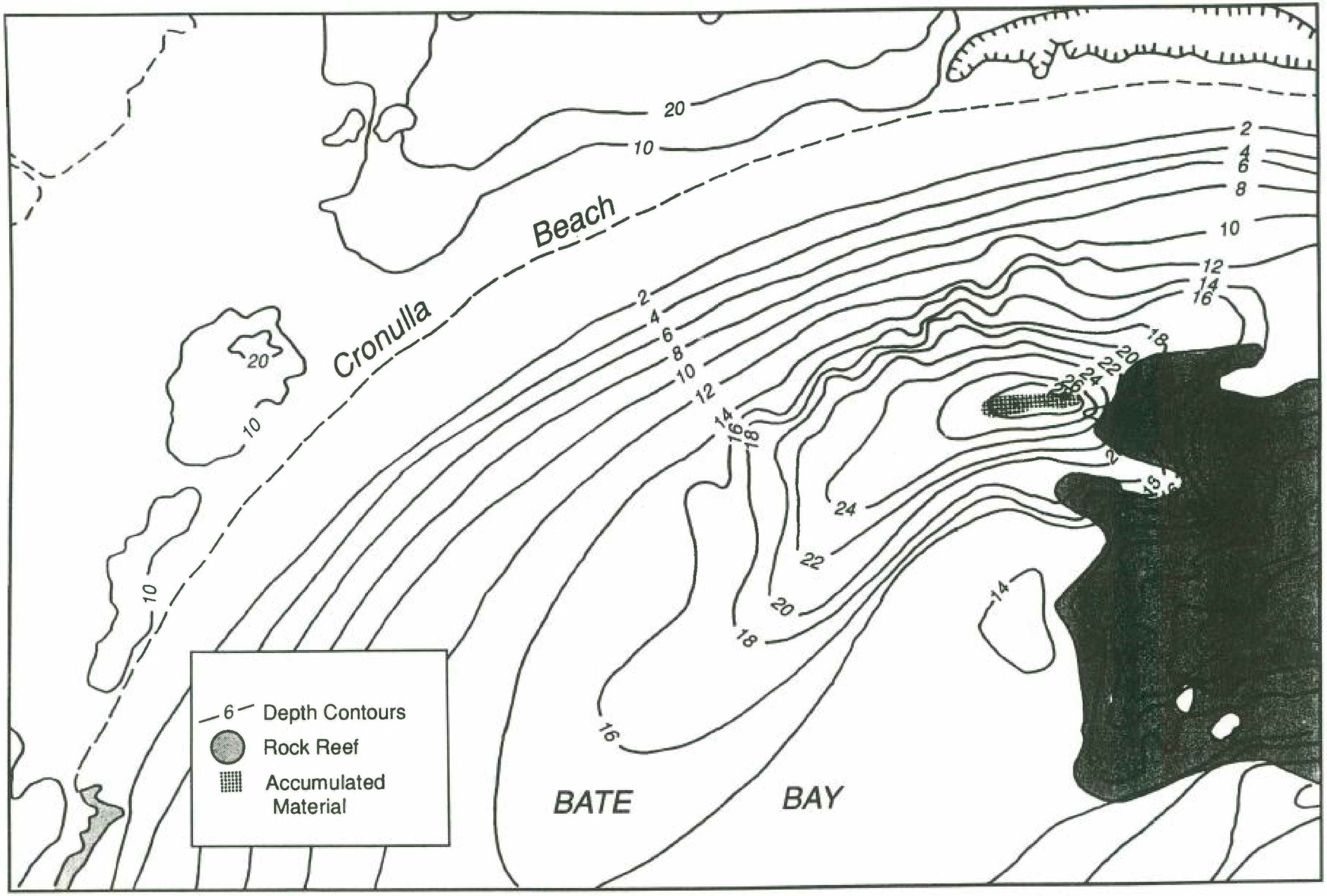

Figure 5. Area covered by the accumulated material on June 1, 1992.

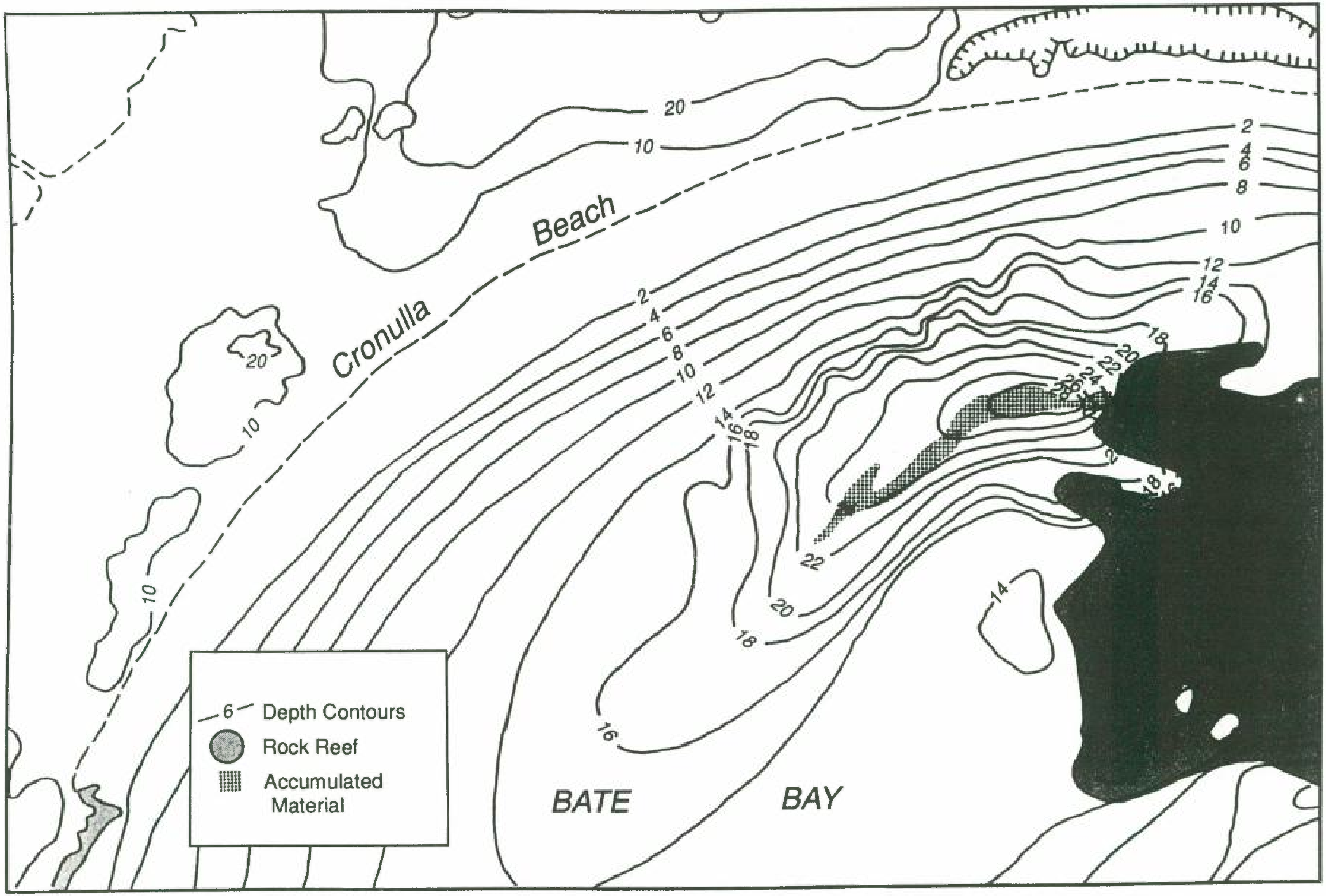

Figure 6. Area covered by the accumulated material on November 5, 1992.

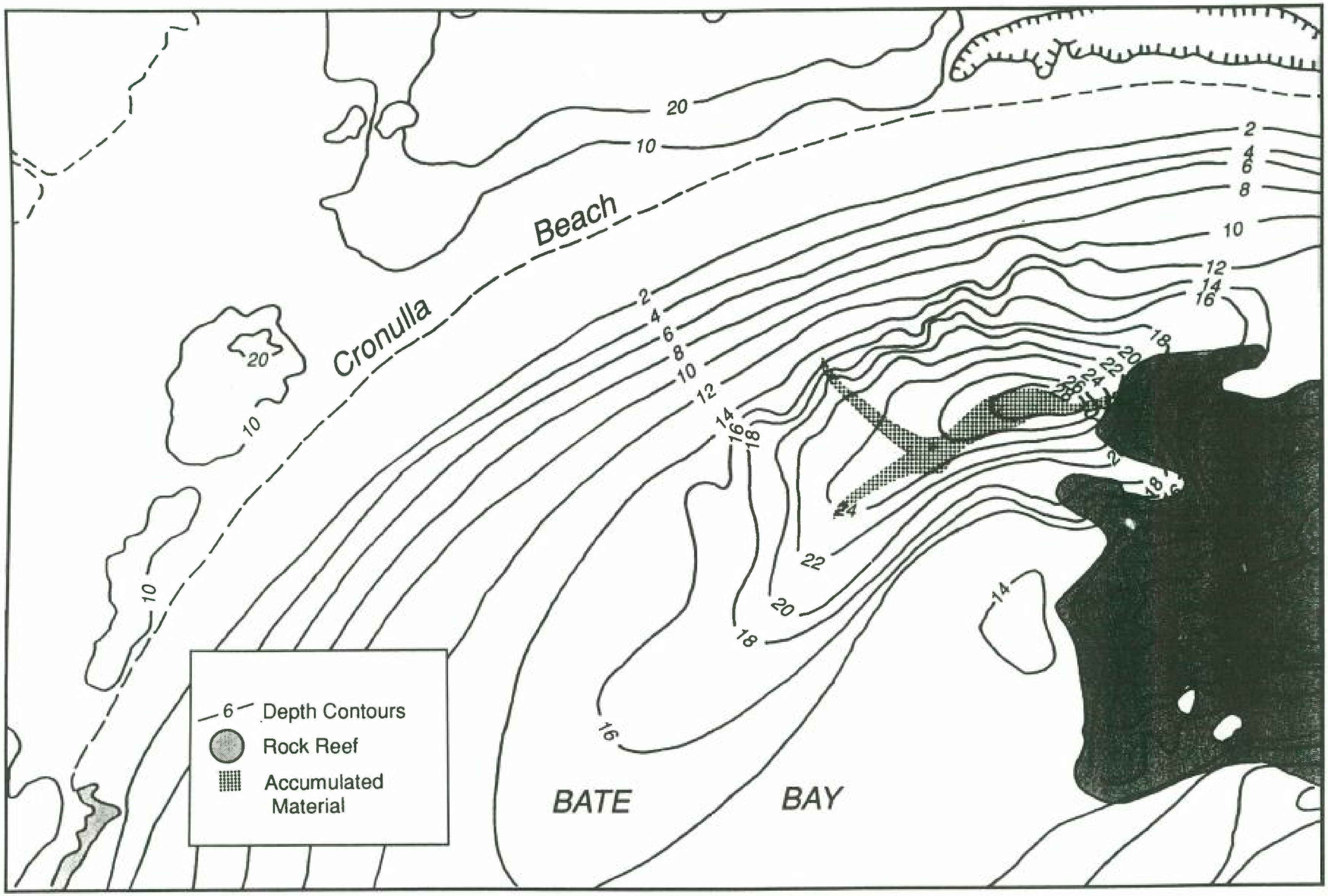

Figure 7. Area covered by the accumulated material on November 24, 1992.

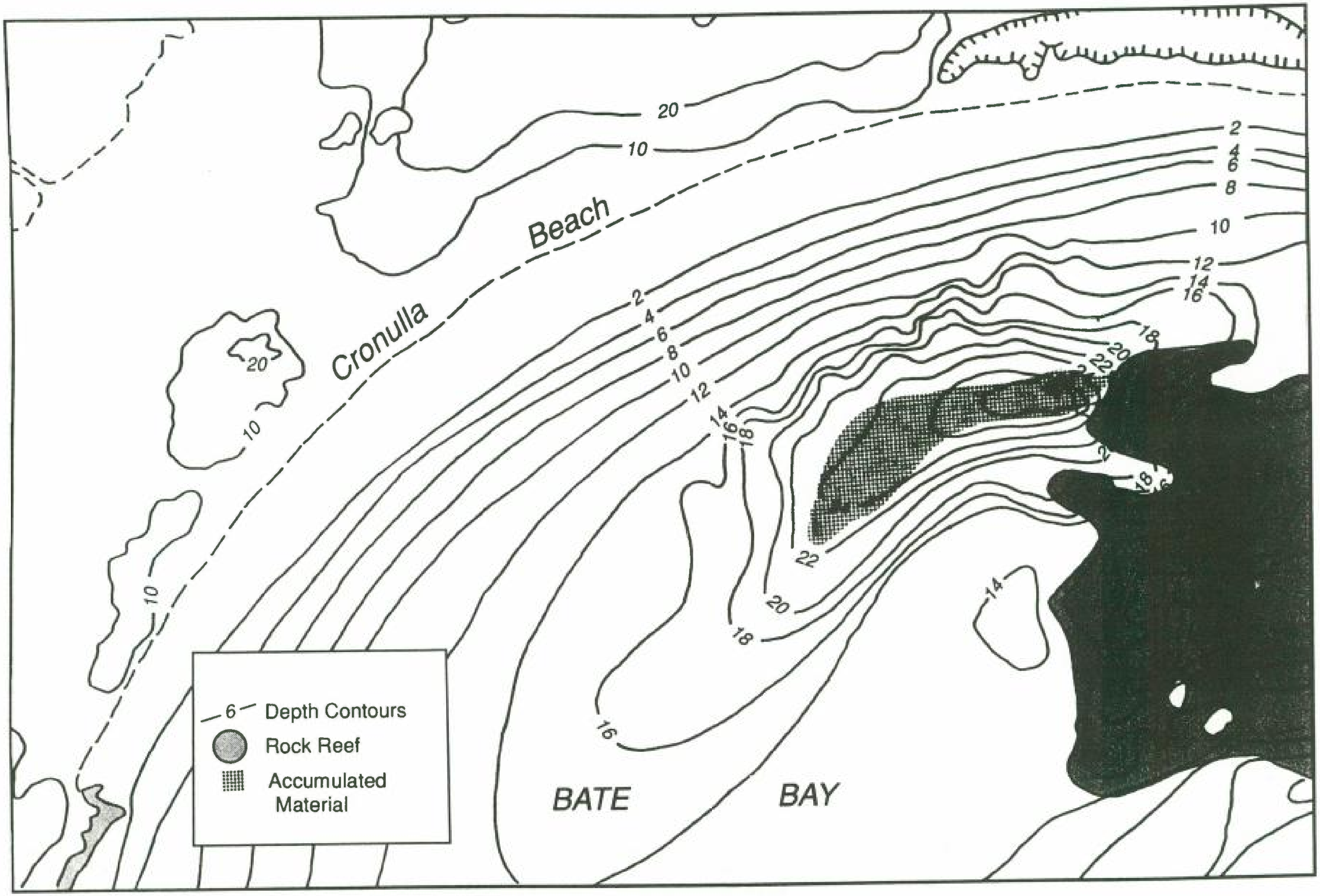

Figure 8. Area covered by the accumulated material on December 19, 1992.

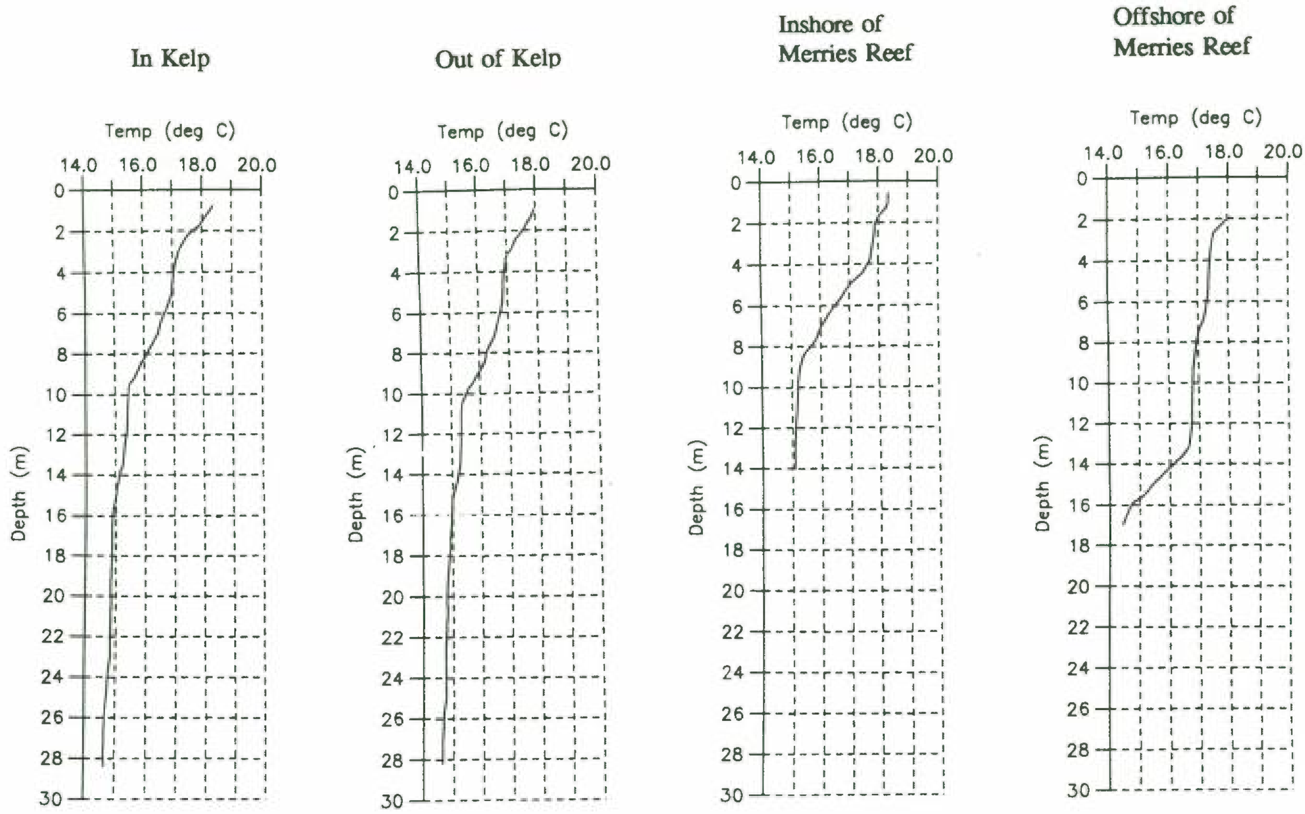

Figure 9. Temperature profiles of the water column on November 23, 1992.

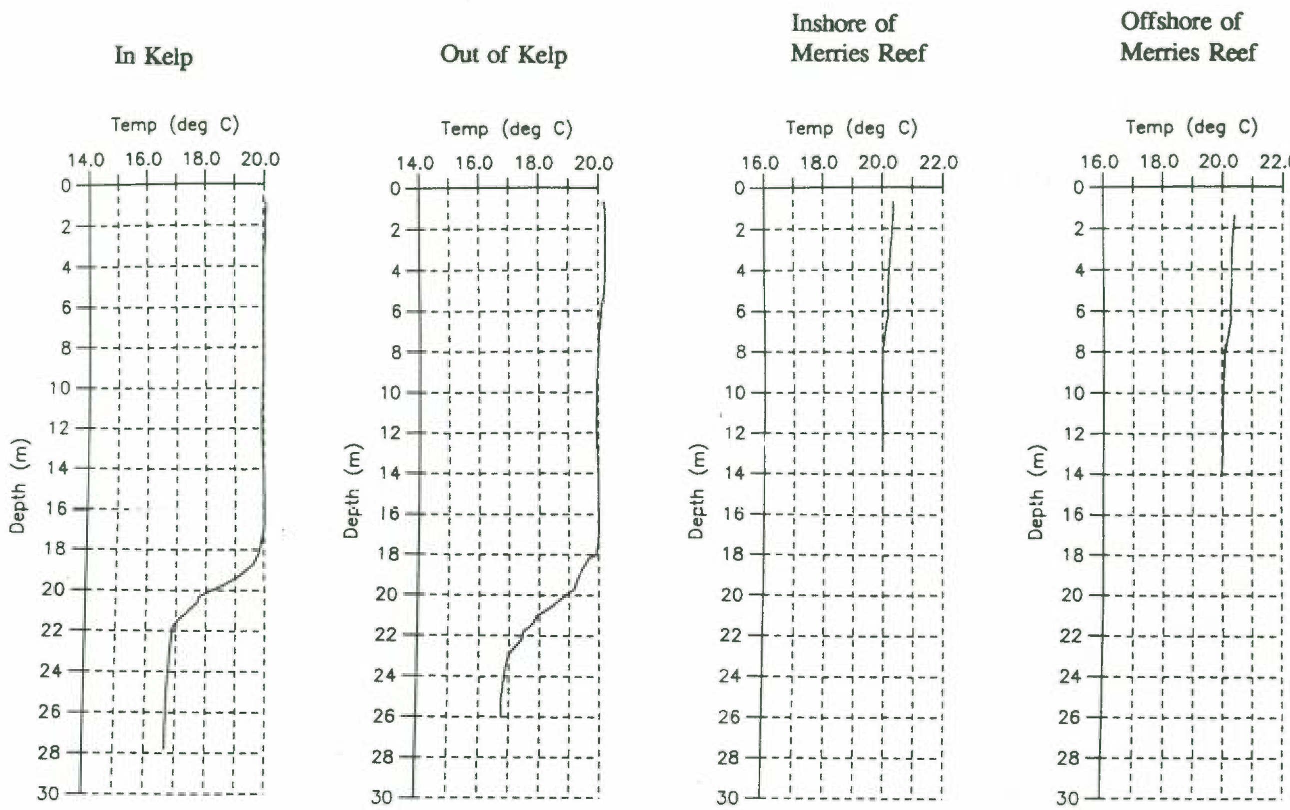

Figure 10. Temperature profiles of the water column on December 18, 1992.

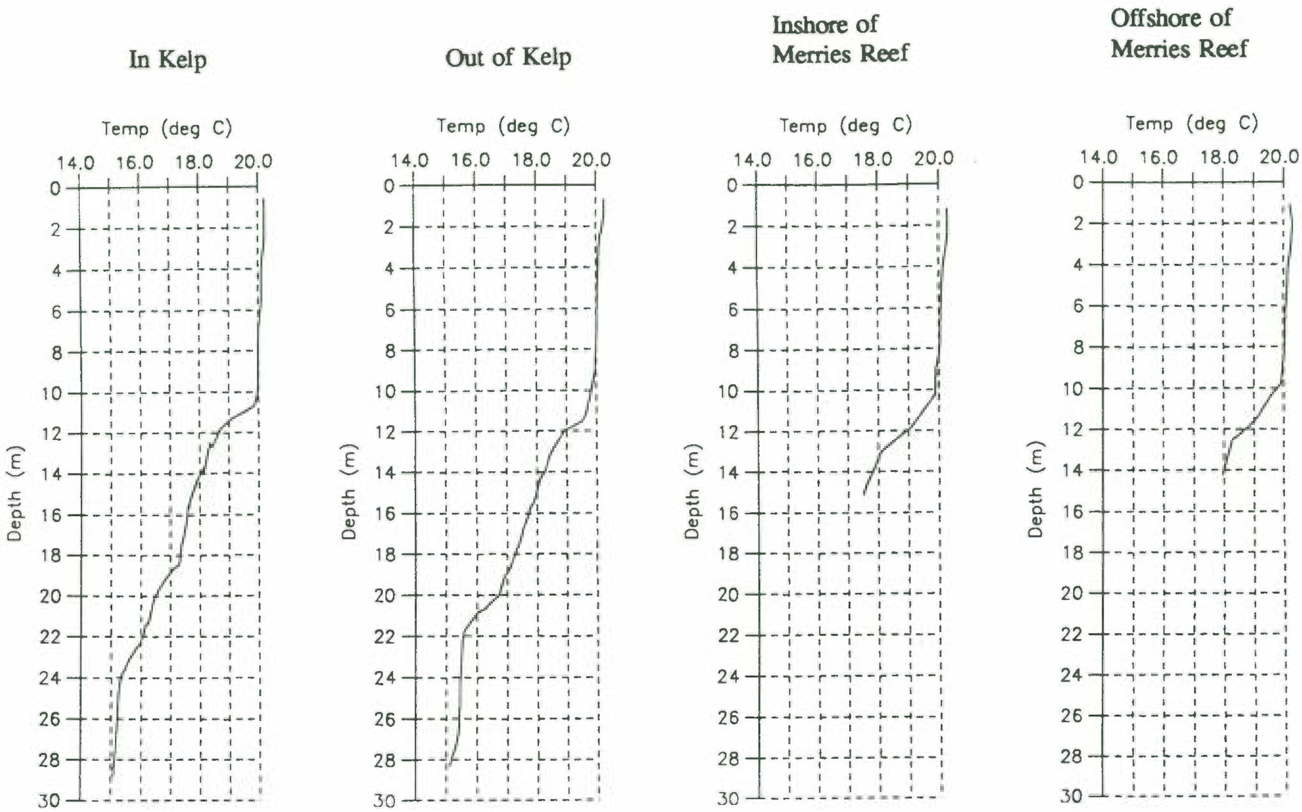

Figure 11. Temperature profiles of the water column on January 13, 1993.

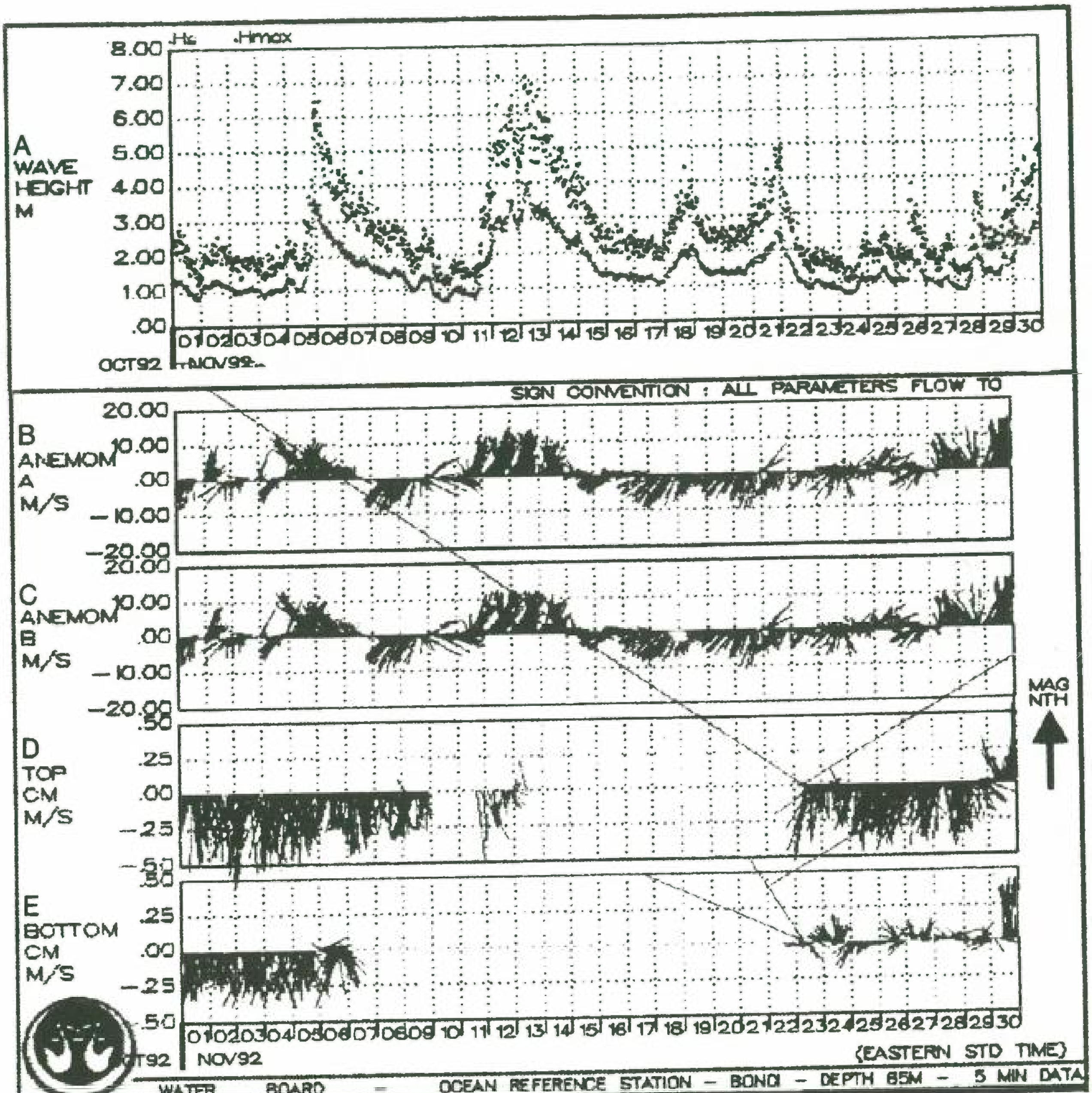

Figure 12. Wave (A), Wind (B and C), Current (D and E) information from the Ocean Reference Station for November, 1992.

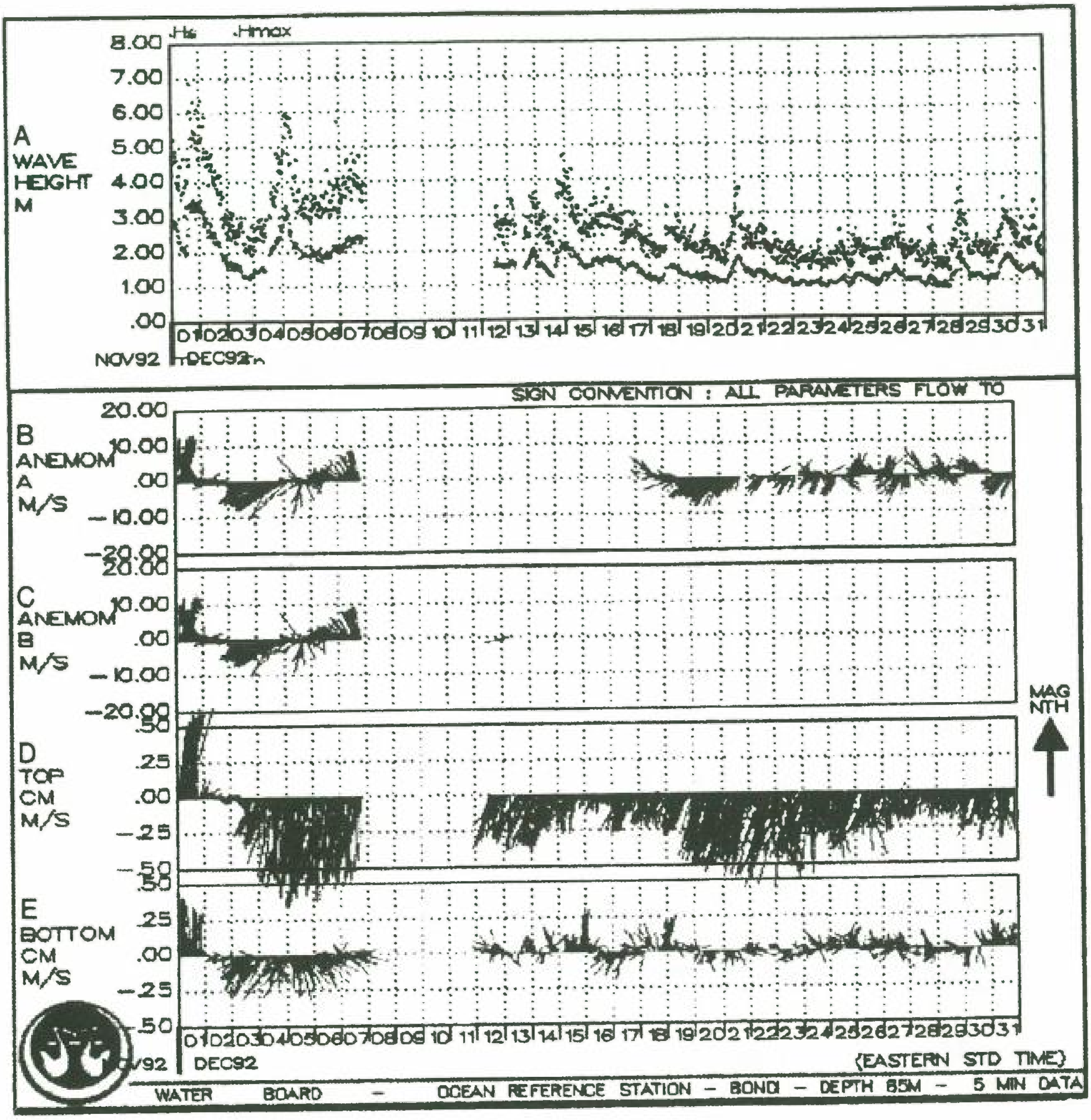

Figure 13. Wave (A), Wind (B and C), Current (D and E) information from the Ocean Reference Station for December, 1992.

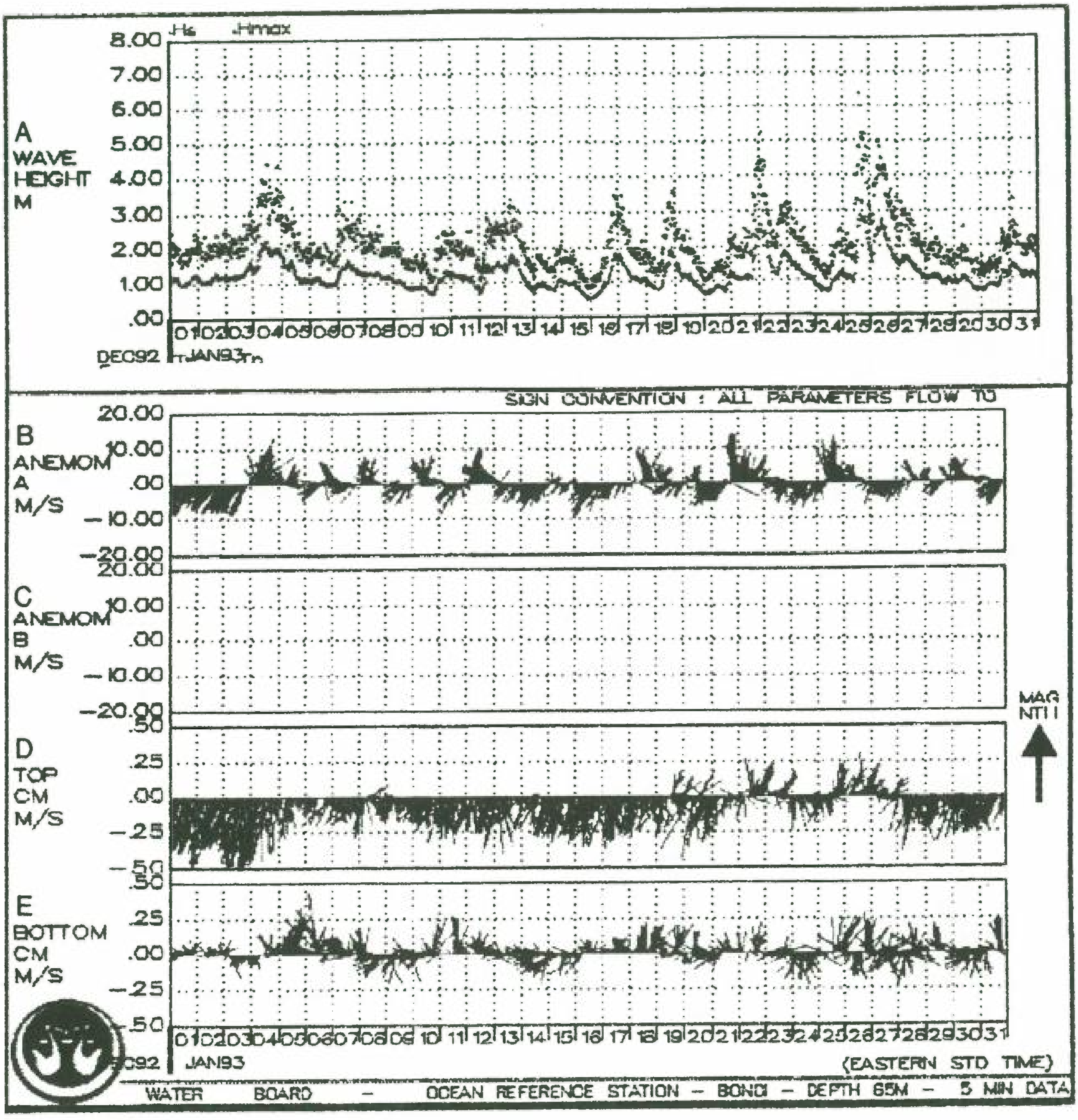

Figure 14. Wave (A), Wind (B and C), Current (D and E) information from the Ocean Reference Station for January, 1993.

AWT ENVIRONMENTAL MANAGEMENT & INVESTIGATIONS

285 CROWN STREET, SURRY HILLS, NSW 2010, AUSTRALIA
MAILING ADDRESS: PO BOX A53, SYDNEY SOUTH, NSW 2000, AUSTRALIA. FAX: (02) 332 3158. TEL: (02) 339 9299