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COASTAL CIRCULATION OFF BOMBAY IN RELATION TO WASTE WATER DISPOSAL

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ABSTRACT

Flow patterns in the coastal waters of Bombay were studied using recording current meters, direct reading current meters, floats and dye in relation to the proposed waste water disposal project of the Municipal Corporation of Greater Bombay from 1976 to 78. The water movements were mainly tide-induced and elliptical in nature, with the major axis more or less parallel to the coast. The currents were mainly towards the northeast at a bearing of approximately at 30° during flood and towards the southwest approximately at 210° during ebbs, with a counterclockwise during spring ebbs occasionally reached 3 km/hour. A strong onshore shift of current vectors during the slack periods. The peak velocities during spring ebbs occasionally reached 3 km/hr. A strong onshore component was noticed in the nearshore waters mainly due to the wind drift and is quite likely that a portion of the effluent material released 3 kms off shore, could, under extreme wind-induced drift, reach the shore in about 6 to 10 hrs.

Key-words : Circulation, waste disposal, currents, Bombay coast.

INTRODUCTION

Bombay is considered to be India's industrial and commercial capital. The present population of Greater Bombay is around 8.3 million crammed into 438 sq km and is likely to reach 13 million by 2,000 AD at the present rate of growth. About 400 million gallons of water are utilized per day for its industrial and domestic use, most of which is discharged back into the environment as waste water causing considerable strain on the environment. Bombay Municipal Corporation (BMC) was struggling to find out ways and means for the disposal of this huge quantity of waste water. Regardless of the water treatment system adopted, it will be necessary to dispose off at least part of the effluent either to the Thana creek or to the Arabian Sea or possibly to both. In this endeavour to evolve an efficient and suitable waste water disposal system the BMC assisted by the World Bank retained the services of Metcalf and Eddy Incor. USA and Environmental Engineering Consultants Bombay to suggest ways and means of disposal. In this connection the National Institute of Oceanography was requested to conduct a detailed oceanographic study around Bombay and this paper deals with the salient features of flow patterns studied as a part of the BMC project.

Area of study

The area of study covered the coastal regions around Bombay, extending from south of Colaba point to the Bassein creek along the Arabian sea,

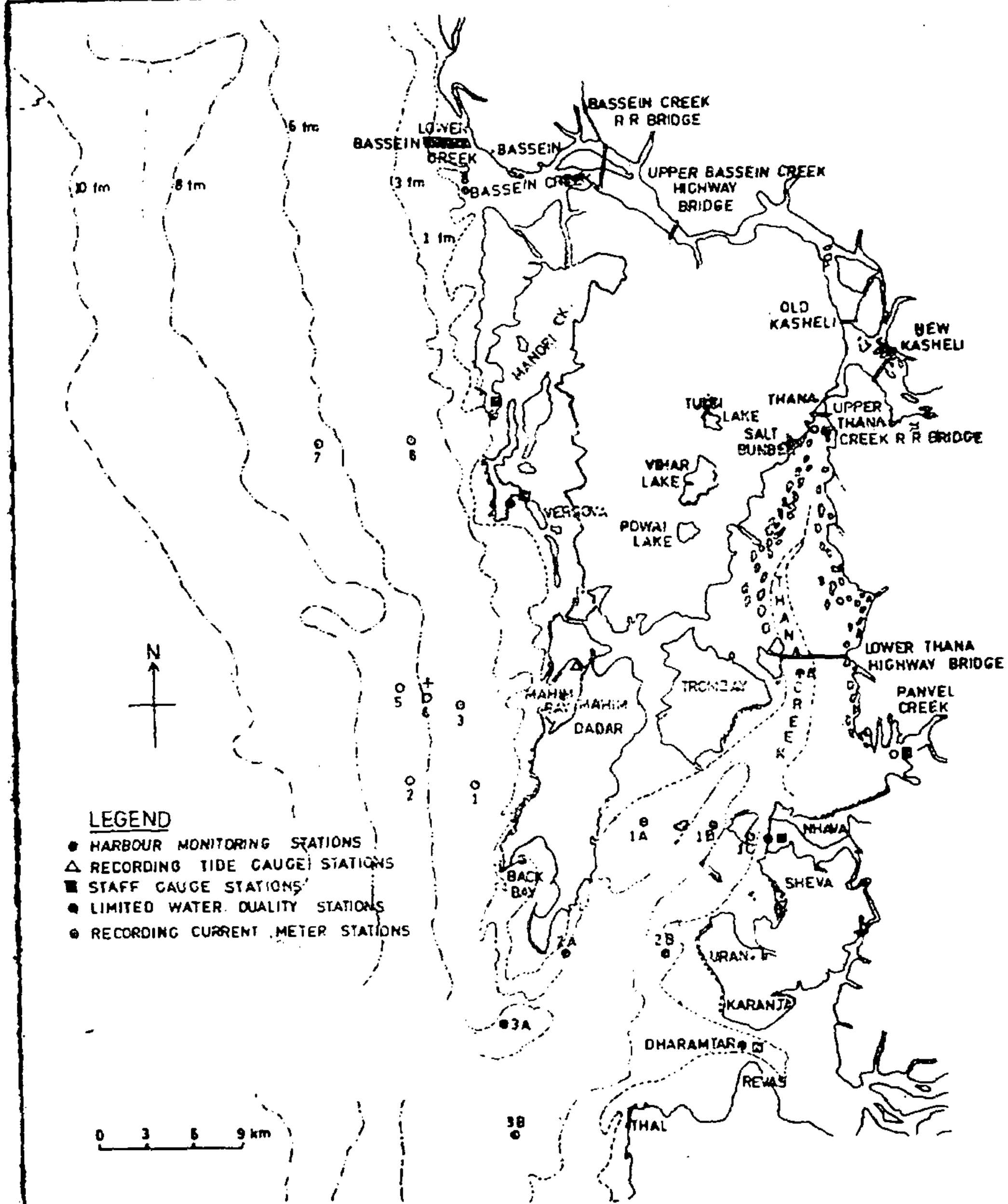

FIG. 1 MAP SHOWING LOCATION OF STATIONS

over 60 km and upto a distance of 12 km offshore (Fig. 1). The sea bed in this region is sloping gently and attains a depth of about 17 m around the 12 km line. The Bathymetric survey indicated a bottom with clay sediments varying in thickness from less than a metre to more than 12 m underlain by rocks. In many places, especially in near shore regions, extensive rocky out crops were also noticed.

The inshore waters comprising the Bombay harbour regions, and the adjoining tidal inlets and creeks were also studied. The Bombay harbour covers an area of approximately 320 sq km and is at the mouth of Thana creek. A few tidal creeks and inlets join the harbour, out of which the Dharamtar, Nhava Sheva and Panvel creeks are the important ones. The Thana creek, which forms the upper reaches of the harbour, is connected with the Ulhas river. Extensive salt pans are operational along the west bank of Thana creek.

MATERIALS AND METHODS

Recording current meters of General Oceanic type were moored at nine points in the area of study during 1976–78 using double anchor mooring system. Very often these current meter installations were seriously affected by the intensive fishing activity with drifting and trawling nets. A few of the recording current meters were rendered useless due to entanglement of current meters in fishing nets. During the springs and neap tides flow patterns were also studied using biplane metallic drogues of size 3′x2′ fitted with flags for convenient tracking and identification. These current crosses were adjusted to register the flow at the required depth using suitable floats, weights and shaft ropes. The floats were suitably adjusted to minimise the effect of wind stress and drag. Battery powered lights were fitted on the drogue mast during night for easy tracking and position fixing. Rhodamine-B dye patches were also used to assess the movement of water bodies. The drogues and dye patches were followed by a boat and locations were fixed at regular intervals and as and when required using sextant and the trajectories plotted for drogue and dye patch movements. The data from the Recording Current meters were reduced to linear values by using calibration charts.

RESULTS AND DISCUSSION

The water movements in the region under study are mainly tide-induced and closely associated with the tidal patterns. The tides experienced in the region are semi diurnal type with an appreciable diurnal element producing unequal tides. The tidal ranges vary considerably through neaps and springs, with the recorded high water maximum and low water minimum being 5.39 m and 0.46 m respectively (Table I) (Anon., 1976). Accordingly the water movements also vary significantly depending on the phase and stages of the tide.

The studies conducted from 1976 November to 1977 September showed a more or less consistant pattern of general circulation, as evident from the offshore current data summary (Table II). The basic flow pattern of the water movements was in general elliptical with the major axis almost parallel to the coast. During the flood the current flow was towards the northeast at a bearing of 30° and during ebb to the southwest at 210°, except during periods of unusual local disturbances which might have affected the general patterns. These results were in good comparison with the earlier studies conducted during 1970–71 (Anon., 1971). During the slack periods when the direction of the flow reversed, counterclockwise water movement had been observed in most of the cases. The low water slack lasted for one to two hours and flood slack lasted for 1½ to 2 hours around the occurrance of high water.

Table I. Tide levels at Apollo Bunder

Tide	Height, metres
Highest recorded high water	5.39
Mean high water — spring	4.42
Mean high water	3.86
Mean high water — neap	3.30
Highest low water	2.74
Local mean sea level and mean sea level of Survey of India levelling	2.50
Lowest high water	2.48
Mean low water — neap	1.86
Mean low water — spring	0.76
Chart Datum	0.00
Lowest recorded low water	–0.46

Table II. Offshore oceanographic data summary, 1977.

Survey starting date	Tide	Tide range meters	Wind direction degree T	Sustained maximum wind velocity, kts.	Alongshore maximum current km/hr	Inshore (1) drift, km/hr
20 Jan	Spring	4.60	270	10–16	F (3); 1.6	0.13
28 Feb	Neap	1.70	315	8–10	E (4); 1.2	–0.09
20 Mar	Spring	3.50	270	N.D.	F ; 1.2	0.02
12 Apr	Neap	2.00	160	5–10	E ; 1.5	0.09
4 May	Spring	4.50	000	5–10	E; Southerly drift	N.D. (2)
26 May	Neap	2.20	270	10–15	E; Southerly drift	0.0
17 June	Spring	3.75	315	10–15	E; Southerly drift	0.0
2 July	Spring	4.60	235	15–20	E; 1.7	0.12
25 July	Neap	2.75	225	25	E; Southerly drift	0.0
1 Aug	Spring	4.25	235	25 +	E; 1.4	–0.2
9 Aug	Neap	3.00	270	15–20	F; N.D.	0.0
17 Aug	Spring	3.75	270	20–25	E; 1.6	0.02
23 Aug	Neap	2.50	225	10–15	E; N.D.	0.0
29 Aug	Spring	3.80	270	25	F; 1.9	0.04
21 Sept	Neap	1.75	270	10–15	E; N.D.	0.0
22 Sept	Neap	1.70	270	10–15	E; 1.5	0.01
28 Sept	Spring	3.75	315	5–10	N.D.	–0.01
29 Sept	Spring	3.70	270	5–10	N.D.	0.01

1. Negative values indicate net drift offshore.
2. N.D. — no data
3. F — flood tide
4. E — Ebb tide.

During the first one or two hours of flood tide the current vector swinged and stabilized in direction more or less parallel to the coast by around the third hour of the flood tide. The peak velocities of flood occurred in most of the cases about 3 to 4 hours after the low water. An almost similar pattern had been noticed during the high water slack also, when the current vector swinged before the direction was stabilized. By the third hour of the ebb the current direction stabilized. The peak ebb velocities occurred during third and fourth hours of the ebb tides. In almost all cases, higher velocities were observed during the ebb.

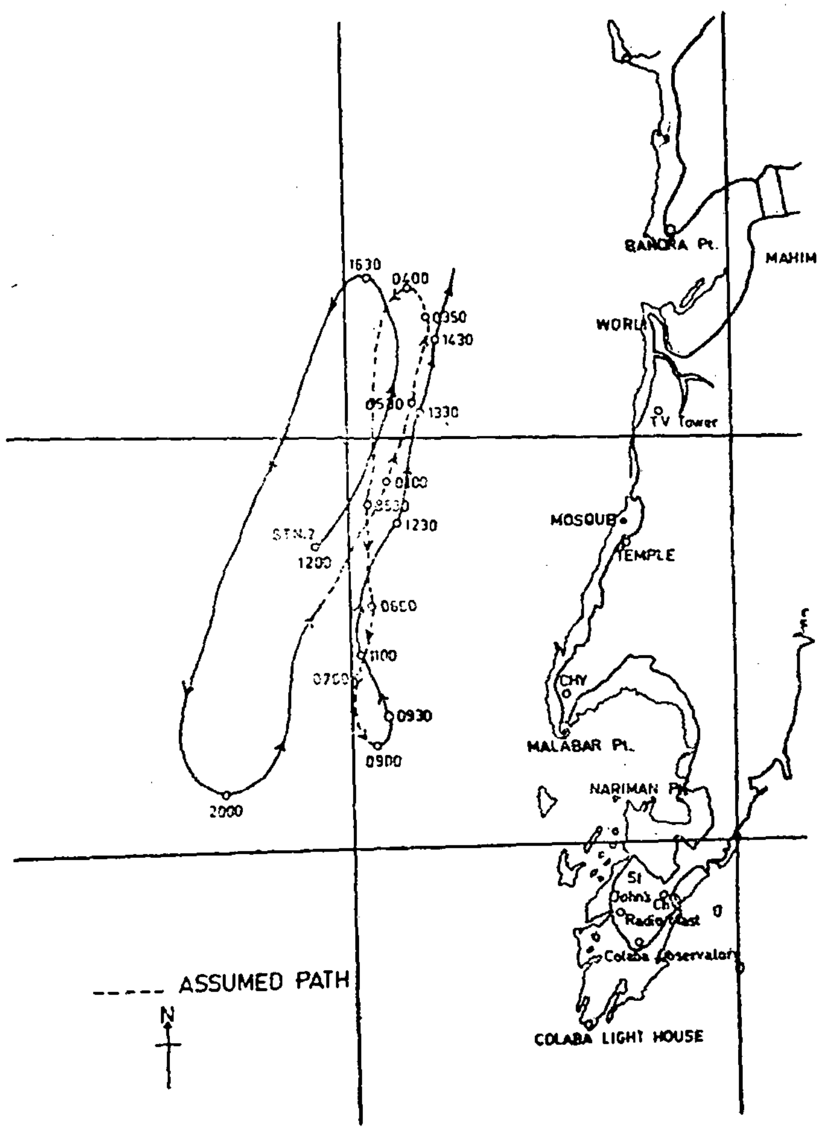

FIG. 2 DYE / DROGUE PATH ON 9/10 DEC. 1976

During the drogue and dye patch studies, the possible behaviour of the waste water at the disposal area and its further transport and dilution was assessed. During the December spring tide study the dye and drogue trajectory indicated that any particle in the proposed disposal area is likely to be carried over a distance of about 42 kms in 24 hours over a counterclockwise rotational path (Fig. 2). This would indicate that the mean surface current speed of 75 cm/sec occur for a significant period of the tidal cycle. Under these conditions the resultant trajectory of the effluent movement would be an ellipse, approximately 10 km long and 2 km wide, with the major axis parallel to the coast. These trajectories also indicated that on a spring tide

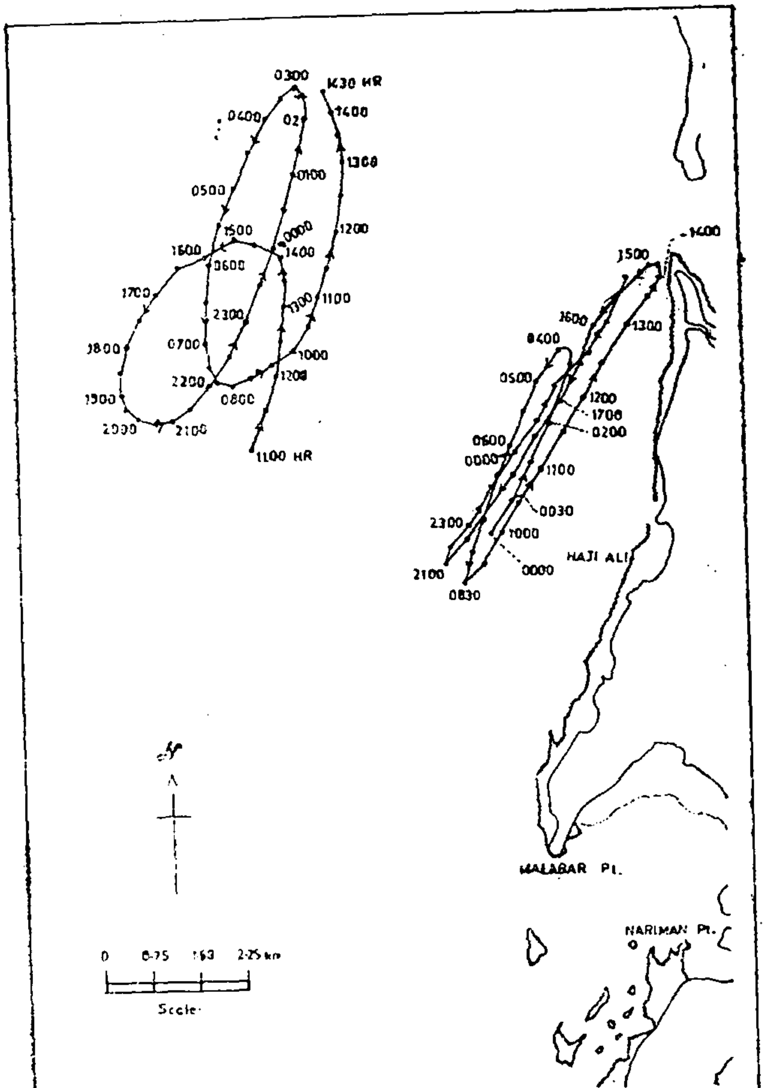

Fig. 3 Arabian Sea offshore current vector plots (9/10-12-76)

the centre of maximum concentration would have a net easterly movement towards the shore. When the wind speeds are normal, the effluents would show a net shoreward drift at the rate of approximately 1.8 kms per 24 hrs. Thus, it may take 4 days for the effluent to reach the shore if it is released at stn 2 and 1½ to 2 days from stn 1. The drogue and dye studies conducted in various other periods also presented a more or less similar picture. During the neap periods, the extent of the elliptical movement was to the order of 50 to 70% of the spring periods. However, the general pattern of elliptical rota-

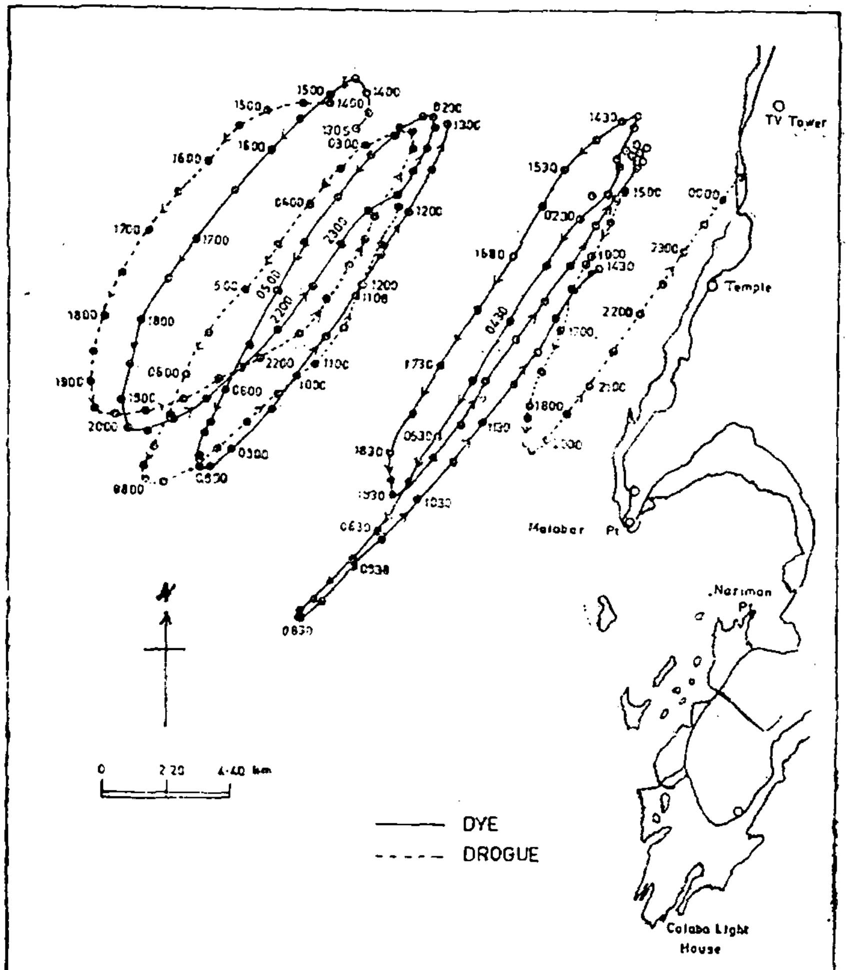

FIG. 4. DYE/DROGUE PATH ON 20/21 JANUARY '77

tional flow with an offshore component was maintained. It was noticed that the longshore component increase with the proximity to the shore, where elliptical pattern becomes longer and narrower (Fig. 4). This results in longer major axis and shorter minor axis as indicated in Table III. This pattern of flow is well established in the current vector plots for December and January

Table III.

Station	Major axis of ellipse, km	Minor axis of ellipse, km	Ratio of major to minor axis	Area of ellipse, sq km	Bearing of major axis, °M	Inshore drift km/24 hr
January						
Current meter data						
1. Surface	10.0	1.3	1.7	10.21	028	0.8
Bottom	–	–	–	–	025	–
2. Surface	7.0	3.0	2.3	16.49	033	1.5
Bottom	7.5	3.0	2.5	17.67	034	1.5
Dye/drogue data						
Offshore	8.0	4.5	1.8	28.27	030	–
Inshore	10.0	3.0	3.3	23.56	025	–
February						
Current meter data						
1. Surface	8.3	0.6	13.8	3.90	028	–0.5
2. Surface	6.4	2.2	2.9	11.06	029	–0.5
Bottom	5.4	0.9	6.0	3.80	021	0.3
March						
Current meter data						
1. Surface	6.8	1.0	6.8	5.34	029	–0.4
Bottom	–	–	–	–	027	–
2. Bottom	6.0	1.3	4.6	6.13	039	–0.4
Mean values	7.5	2.1	3.6	10.36	027	0.3

(Figs. 3 & 4). Some variations in the surface and subsurface flow patterns were also noticed. In many cases surface currents were found to be faster than the mid-depth and bottom currents.

It is quite interesting to note that the dye/drogue path during March changed into a rotational looping pattern (Fig. 5). However, the general trend of mean direction and speed is somewhat maintained. During the monsoon months of late May to September a slightly different pattern of flow was noticed (Fig. 6). During the dry season the spring tides generally resulted in a northerly drift, which reversed to become a southerly drift during the monsoon period. The net southerly drift averaged over a full tidal cycle was approximately 0.20 km/hr and the onshore drift to the order of 0.04 km/hr was also indicated during this period. However, it is estimated that with a sustained wind of 25 knots or more, which could be quite common during this period, it might be possible to generate an inshore drift as high as 0.02 to 0.03 km/hr. Hence, an effluent particle released 3 km offshore could reach the shore in 6 to 10 hours, whereas it might take 2 to 4 days to reach the shore during the fair season. Thus, it was also seen that monsoon period offers a greater risk of getting the effluents ashore in a relatively short time.

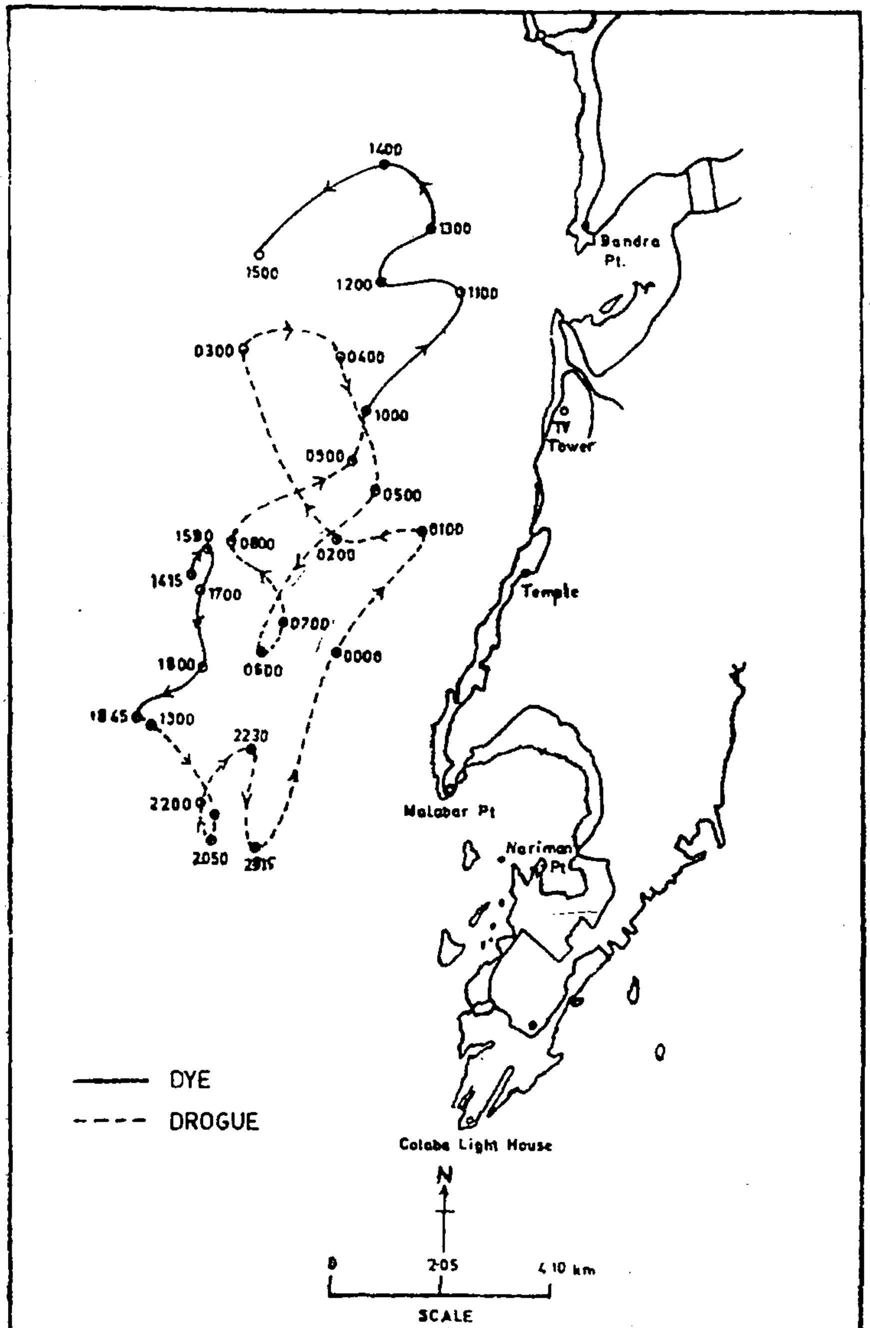

FIG.5 DYE/DROGUE PATH ON 20/21 MARCH '77

The water quality and mixing capacity of the receiving medium were crucial parameters as far as effluent disposal was concerned. The initial dilution of the waste water effluent discharged through a submarine diffuser was achieved by the turbulent jet mixing at the tip of the diffuser. The initial diluiton in the receiving medium could be affected by the stability and density

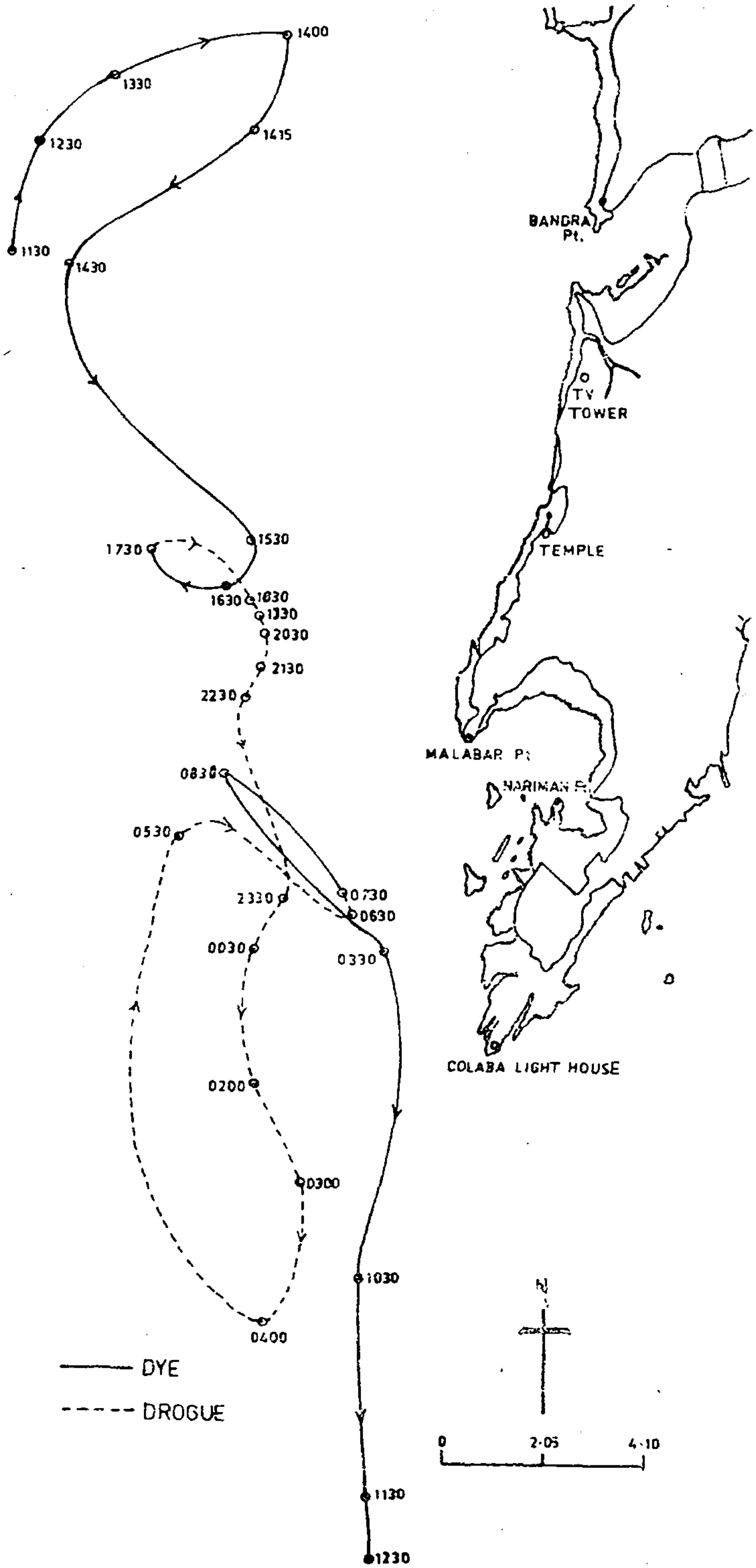

FIG. 6 DYE / DROGUE PATH 27/28 MAY '77

Table IV. Offshore water quality parameters in November 1976.

Station	Depth	Temperature °C	Salinity ‰	Dissolved oxygen mg/l
1	Surface	28.9	33.2	6.0
	Middle	28.2	33.3	6.1
	Bottom	28.0	33.3	6.1
2	Surface	28.6	33.6	7.0
	Middle	28.0	33.6	6.6
	Bottom	27.9	33.7	6.5
3/4	Surface	26.5	33.1	7.5
	Middle	26.3	33.2	6.9
	Bottom	26.1	33.3	6.8
5	Surface	27.8	33.2	7.6
	Middle	27.6	33.2	7.1
	Bottom	27.3	33.3	6.7
6	Surface	29.5	34.1	7.5
	Middle	28.0	34.1	6.5
	Bottom	28.0	34.1	6.3
7	Surface	28.5	34.0	7.3
	Middle	27.8	34.7	6.5
	Bottom	27.8	34.5	6.4

Table V. Average values of σt.

Location	Temperature °C	Salinity ppt	σt	E′
Surface	27.78	33.26	21.175)	
Bottom	27.13	33.28	21.414)	$\leqslant$ 10

stratification of the water body into which the wastes are discharged. Through significant changes in temperature and salinity, complete vertical mixing might not sometimes be possible, which would result in the formation of a submerged layer of waste water. The data on temperature salinity and dissolved oxygen collected from the offshore areas of Bombay extending upto 12 km during the period of study indicated relatively negligible variations. The maximum, vertical difference in temperature on any day was found to be the order of 1.5 °C, the maximum vertical salinity difference was 0.50‰ and the dissolved oxygen 1.5 mg/l (Table IV). These relatively insignificant variation indicates that the waters were essentially homogenous vertically and horizontally. It has also been observed that the water column indicated a neutral stability, the stability value expressed in terms of E′ as

$$E' = \frac{d\,\sigma t}{dz} \times 10^{-3}$$

being to the order of 5 to 20 during most part of the study programme. The mean values for surface and bottom waters are shown in Table V. The mean

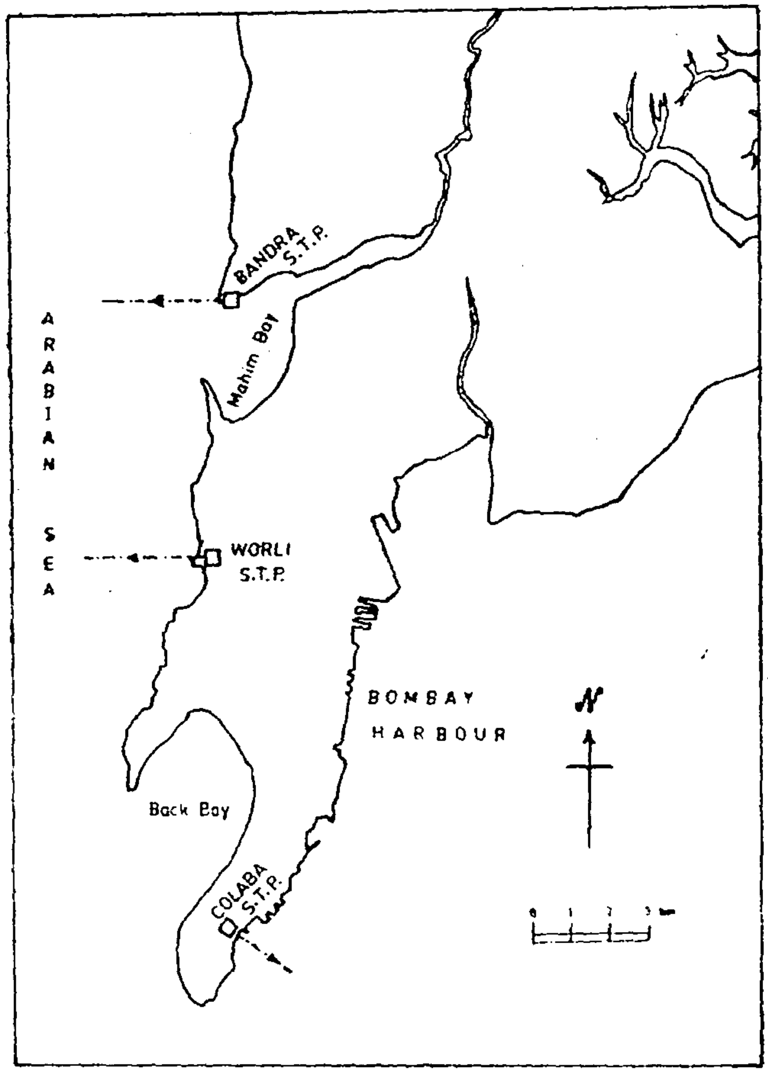

Fig. 7. Locations of proposed submarine outfall.

value of E' $\leqslant$ 10 confirmed neutral stability indicating a thoroughly waters the offshore study area. The data confirmed that the nearshore waters off Bombay were unstratified and thoroughly mixed during monsoon as well as during the dry season. No halocline or thermocline, which would reduce the extent of vertical mixing were observed during any of the studies made off Bombay. The dye dispersion study indicated considerable dilution capacity with the receiving waters. It was also observed that an initial dilution of 50 times is easily attainable even under the calmest weather conditions. This would mean that with an average BOD strength for raw waste water of 250 mg/l, a concentration of no more than 5 mg/l would be realised at the surface directly over the diffuser. This would be then subjected to further dilution to insignificant levels.

Thus, these studies indicated that the offshore region was well suited for the waste water disposal with high capacity for dilution and mixing even in the worst possible conditions of onshore transport. With a reversing tidal current flowing nearby parallel with the coastline, with the existing drainage and other treatment facilities, it was proposed that in case the disposal of waste water in the offshore region was feasible, the pipeline difuser would be likely to be located between stations 1 & 2 and stations 3 & 5. This formed the basis of recommendations for ocean disposal at Colaba, Worli and Bandra (Fig. 7) (Anon. 1978). Thus considering economic viability and technical feasibility of various outfall lengths and corresponding treatment levels, it has been suggested that an outfall and diffuser with a total length of 3 km offshore was the most cost effective and technically feasible solution (Anon. 1979).

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