

Hydrographic Characteristics & Tidal Prism at the Cochin Harbour Mouth*

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Diurnal and seasonal variations (May 1975 to April 1976) in hydrographic characteristics at the inlet of the Cochin Harbour are presented. During the SW monsoon season under the predominant influence of fresh water influx into the estuary no appreciable variations in the temperature and salinity values of the thin surface layer (< 4 m) are observed in relation to tide; whereas the subsurface water (4 m to bottom) shows close relation with the tide. Significant vertical gradients in temperature and salinity are noticeable between surface and bottom layers during this season. Prominent saline wedge is formed with the flood current in this season and during the ebb current homogeneous water of low salinity (< 10‰) pervades the entire depth of the harbour mouth. Mean vertical salinity profiles for the monsoon, post and premonsoon seasons indicate that the highly stratified conditions that exist during the monsoon season gradually change to partially mixed and homogeneous conditions of the post and premonsoon periods apparently due to decreasing river flows and increasing tidal influence. Maximum velocity of the current observed is 174 cm/sec which occurs during the ebb current of the spring tide of the postmonsoon season. Tidal prism in the premonsoon season during which time the fresh water addition to backwaters is least is found to be $31.5 \times 10^6 \text{ m}^3$. During the other seasons, the values of tidal prism vary between $9.5 \times 10^6 \text{ m}^3$ and $132 \times 10^6 \text{ m}^3$. Factors effecting the stability of the inlet are discussed.

The Cochin backwaters estuarine system is formed by an offshore bar built along the shore extending from Cranganore in north to Alleppey in the south covering a length of about 90 km. The estuary is wide (16 km) in the Vembanad Lake area and several narrow canals drain water into the backwaters. Major perennial rivers—the Periyar, the Muvattupuzha and the Pamba—discharge fresh water directly into this estuarine system. The Cochin Harbour mouth is the major inlet connecting the backwaters to the Arabian Sea and the 2nd inlet at Azhikode is relatively shallow. A 3rd opening exists near Thuravur, but it remains closed most part of the year except during floods in the monsoon season. This 3rd opening has no or negligible influence on the backwaters.

Although hydrographic characteristics of the backwaters have been described¹⁻¹¹, no detailed information is available on the intensity of the currents at the surface and subsurface levels and the associated exchange and mixing of the estuarine water with the Arabian Sea coastal waters. It is, therefore, important to study in detail hydrographic characteristics including volume transport across the harbour mouth to know the problem of sedimentation in the harbour, the stability of the inlet, and discharge of pollutants introduced into the backwaters, for model studies and for various harbour development works.

In this paper, hydrographic conditions at the harbour inlet along with volume transports are presented. Factors effecting the stability of the inlet are also briefly discussed.

Materials and Methods

As part of the studies on hydrographic conditions in the inner harbour of Cochin Port for harbour development works undertaken by NIO, extensive data have been collected during May 1975 to April 1976 on temperature, salinity, suspended sediment load and current from 30 stations in the inner harbour region.

The semi diurnal tide at Cochin has a maximum range of 1 m. The diurnal mean sea level is normally low during the monsoon season compared to post and premonsoon periods.

A 30 ft motor boat was moored to anchored buoys for observations. Three stations, A, B and C (Fig. 1) were covered along the cross section at the inlet between Fort Cochin and Vypeen Island. Observations were made at or around Full and New Moon days to represent spring tide conditions and about a week after that to represent neap tide conditions. A total of 6 days observations were made in different months. On each day, continuous hourly observations from surface (0.5 m below) to bottom (1 m above) were made at intervals of 2 m depth. Currents were measured at all the 3 stations and the temperature, salinity and suspended sediment load observations were made at mid station B. Bottom

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soundings were also taken using a lead line. These observations covered a total of 3 spring and 3 neap tide conditions. Some practical difficulties were encountered at the inlet section partly due to drifting of the anchors or snapping of the anchor ropes under the effect of strong currents at mid tide timings.

Surface samples were collected by a plastic sampler, and subsurface samples by a specially designed glass stoppered bottle or an indigenously fabricated plastic sampler. Salinity and temperature of most of the samples were determined using a T-S bridge and the values were read up to first decimal. A few samples were analysed for salinity by normal titration method.

Suspended sediment load was determined by filtration technique using Whatman filter paper No. 42. The currents were measured using a direct reading Plessey current meter which gave integrated values of the current over a period of 28 sec and the direction with reference to magnetic north.

Results and Discussion

Bottom profile of inlet—Cross sectional bottom profile of the inlet between Fort Cochin and Vypeen is shown in Fig. 1. The maximum depth of the inlet is 17 m below the chart datum occurring within a distance of 40 m from the Fort Cochin bank. The inlet bottom slopes steeply with a gradient of 1:2 on the Fort Cochin side and less steeply with a gradient of 1:6 on the Vypeen side. The central part of the inlet bottom gradually slopes to its maximum depth with a gradient of 1:36. This bottom profile represents the condition of dynamic equilibrium as a result of adjustment in topography under the influence of natural factors and no dredging is done to maintain the required depths for safe navigational purpose.

Temperature—Diurnal variation of temperature for the spring tide on 24-25 July 1975 (monsoon season) is shown in Fig. 2A. Variation of temperature is from 24° to 29°C, the surface water usually recording higher value. While the difference in surface water temperature with the tide is only 1.5°C, the subsurface

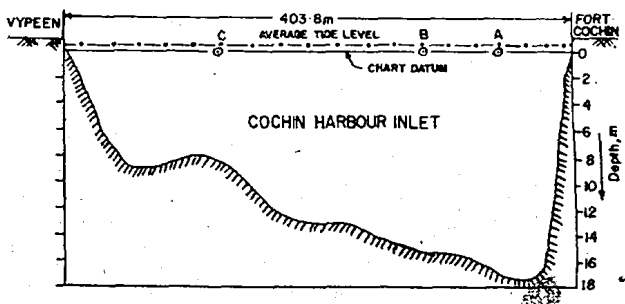


Fig. 1—Cross sectional bottom profile of Cochin Harbour inlet [Lat. 9°58'N, long. 76°14'30"E. Cross sectional area (m²) with reference to average tide level (April 1976): 0-4 m, 1567; 4-8, 1469; 8-12, 1106; 12-16, 675; and >16, 80]

water from 4 m to bottom shows a difference of 4°C with the tide. Vertical temperature gradients vary from 0.36° to 0.1°C/m between flood and ebb tides respectively. The increasing subsurface temperatures are associated with the progress of ebb flow and the decreasing temperatures are associated with the progress of flood flow. Similar variation of temperature with tide is noticed during the neap tide also. Low subsurface temperatures are attributed to the incursion of cool upwelled water from the shelf region into the backwaters⁴. The lowest annual temperature of the Cochin backwaters usually occurs during the monsoon season coinciding with the low temperature period of the coastal waters¹⁰⁻¹². The temperature 24° to 25°C of the bottom water at the inlet during flood tide seems to be due to the inflow of mixed subsurface nearshore water of 20 m depth (temp. 20°-23°C) with that of the estuarine water.

Spring and neap tide observations in December 1975 and April 1976 falling in the post and premonsoon seasons respectively do not show any clear relationship between the surface or subsurface temperature with the tide. Also vertical temperature gradients are small (0.07°C/m) and the temperature varies between 28° and 31°C.

Salinity—Typical diurnal variation of salinity during the same period as for temperature is given in Fig. 2B. The thin surface layer (<4 m) shows salinity variation from almost freshwater to 9‰, but the variation has no relationship with the tide. This indicates the predominant role of the freshwater flow over the tidal flow in the surface layer at the inlet which

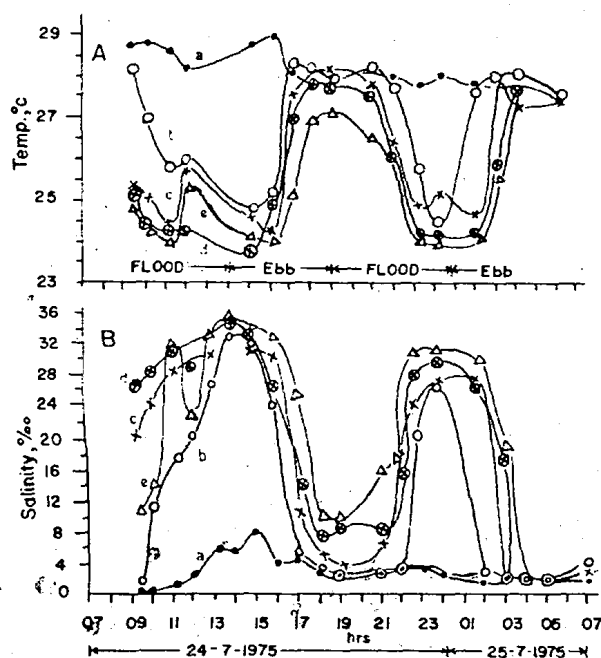


Fig. 2—Diurnal variation of temperature (A) and salinity (B) at station B [Depth (m): a, 0; b, 4; c, 8; d, 12; and e, bottom]

may prevail up to some distance from the coast along the approach channel. The subsurface layer shows wide variation from 2 to 34‰ and the variation shows close relation with the tidal flow, the higher salinity values occurring at HHW or HW and the lower values at LLW or LW timings. Except during the slack periods, marked variations occur in subsurface salinity with the tide leading to steep salinity gradients in the vertical and fast changing salinity conditions, which are typical of this estuary during monsoon season. Similar conditions are observed with the neap tide in July 1975.

Diurnal variations of salinity at the spring tide of December 1975 indicates somewhat similar conditions as those of monsoon, but with reduced salinity variations (12 to 32‰) between surface and bottom layers. Also, during this season, surface and subsurface salinity shows close relation with the tidal flow unlike during monsoon period indicating reduced role of the freshwater discharges over the tidal flow in the surface layer (< 4 m).

Premonsoon spring and neap tide diurnal variations of salinity, observed during 12 to 13 April 1976 and 21 to 22 April 1976 respectively, show salinity variation of 30.5 and 35‰, which has no relationship with the tidal flow.

Mean vertical salinity profiles drawn for all the days of observations are presented in Fig. 3. Steep salinity gradient (of the order of 1.6‰/m), even in the mean values during monsoon season, coupled with low temperatures of bottom layers signify highly stratified conditions. High salinity, low temperature (therefore high density) bottom water moves through the inlet as a saline wedge prominently during flood tides and spreads into the inner channels of the harbour at the bottom.

During postmonsoon season the vertical salinity gradient (0.6‰/m) is smaller indicating partially

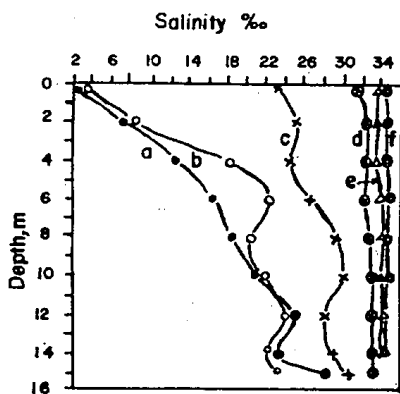


Fig. 3—Mean vertical salinity profile at station B during SW monsoon, pre and post SW monsoon seasons [a, spring—24 to 25 July 1975; b, neap—31 July to 1 August 1975; c, spring—2 to 3 December 1975; d, neap—5 to 6 February 1976; e, spring—12 to 13 April 1976; f, neap—21 to 22 April 1976]

mixed conditions. In premonsoon season, the mean vertical salinity gradient is least indicating well mixed conditions. Thus from the mean vertical salinity distribution, it can be inferred that the hydrographic conditions at the inlet change gradually from highly stratified to partially mixed and well mixed state as the seasons advance from monsoon to post and premonsoon periods respectively. A salinity change of < 50% between surface and bottom water is taken as an indication for well mixed condition and 50 to 75% for partially mixed and > 75% for stratified condition.

Saline wedge—Vertical salinity variation at hourly intervals (Fig. 4) shows that a thin surface layer of low salinity (< 10‰) up to a depth of 2 m overrides the high salinity (25-30‰) bottom water (6 to 16 m) during the flood flow and a marked saline wedge is formed at the inlet. But the saline wedge disappears during the low tide when the entire inlet is occupied by low salinity (< 10‰) water under the combined influence of the ebb current and the outflow of the freshwater through the inlet. One or 2 hr after the flood tide begins, intrusion of the high salinity water can be noticed first near the bottom and later pushing up the low saline water or freshwater to the surface. Similar features of saline wedge are noticed during the neap tide observations in July 1975. The intrusion of saline wedge and its characteristics are important for model studies, improvement in navigation, flood control and disposal of waste material through the inlet.

During the postmonsoon season (December 1975) saline wedge is noticeable for a short duration during the flood flow at certain favourable conditions when fresh water discharges are high, but the salinity difference (10‰) between surface and bottom layer is much smaller compared to that of the monsoon season. During the premonsoon season (April 1975), homogeneous water of salinity around 35‰ is noticed at the inlet from surface to bottom and it is independent of the tidal flow.

Suspended sediment load—Hourly values of suspended sediment load, observed at the inlet, show very high fluctuations at short intervals both in space and time as they did at other stations in the inner harbour. Diurnal variations of suspended sediment load are studied in relation to tide and current but no definite relationship is noticed. Gopinathan and Qasim⁸ have reported that suspended material in the estuary varies markedly with the state of the tide which is not noticed in the present observations. Therefore, an attempt has been made to average the hourly values and study them separately for spring and neap and flood and ebb flow during the 3 seasons to know the general trend (Fig. 5). A general increase in the sediment load from the monsoon season to post and premonsoon seasons can be seen, the highest values

occurring during the postmonsoon season. Also suspended sediment load is higher with increasing depth. Higher sediment load during post and premonsoon seasons than in monsoon season may be partly due to the dredging operations being carried out in the outer channel of the harbour at that time.

Vertical variation of annual mean suspended sediment load for ebb and flood is shown in Fig. 6. The annual mean values vary between 25 and 50 mg/litre. The mean sediment load during flood tide is higher than at ebb tide indicating that during an average tidal period of equal flood and ebb, more suspended sediment moves into the harbour with the flood current.

Current—Diurnal variation of current at spring tide on 24-25 July 1975 at the inlet is shown in Fig. 7. In the monsoon season, ebb currents predominate in intensity and duration at all depths. At times, during the rising tide, the surface flow shows high ebb velocities while the tide rises solely due to the flood current in the subsurface layers. Similar dominant ebb currents are observed during the neap tide of the monsoon season. In the other 2 seasons, mostly rhythmic variations of flood and ebb currents take place throughout the depths with rising and falling tides.

Highest velocity observed in the inlet is 174 cm/sec. It occurs during the ebb current of spring tide in the

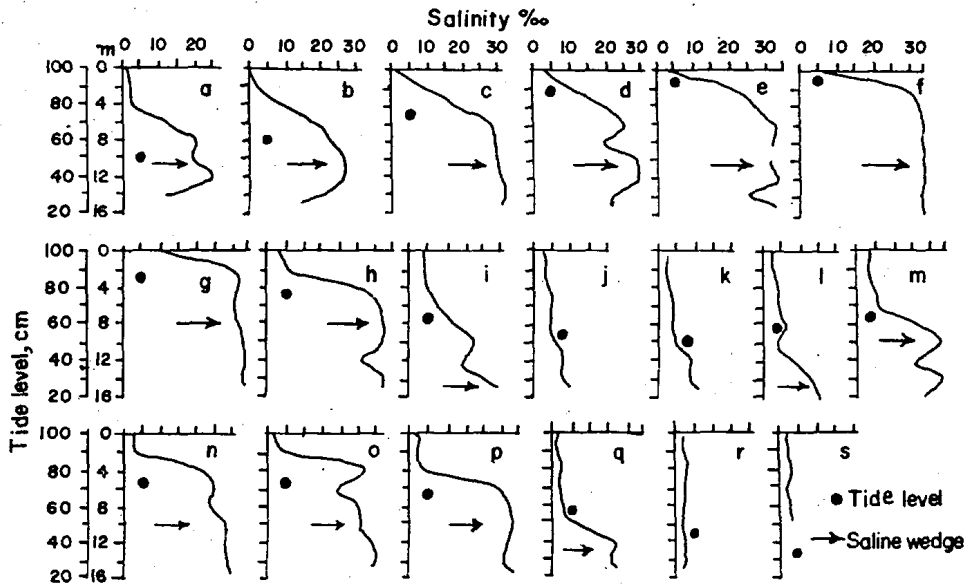


Fig. 4—Diurnal vertical salinity variation during spring tide 24 to 25 July 1975 at station B [Time (hrs): a, 0930; b, 1010; c, 1115; d, 1200; e, 1330; f, 1410; g, 1515; h, 1610; i, 1705; j, 1800; k, 1900; l, 2100; m, 2200; n, 2325; o, 0010; p, 0200; q, 0300; r, 0405; s, 0655]

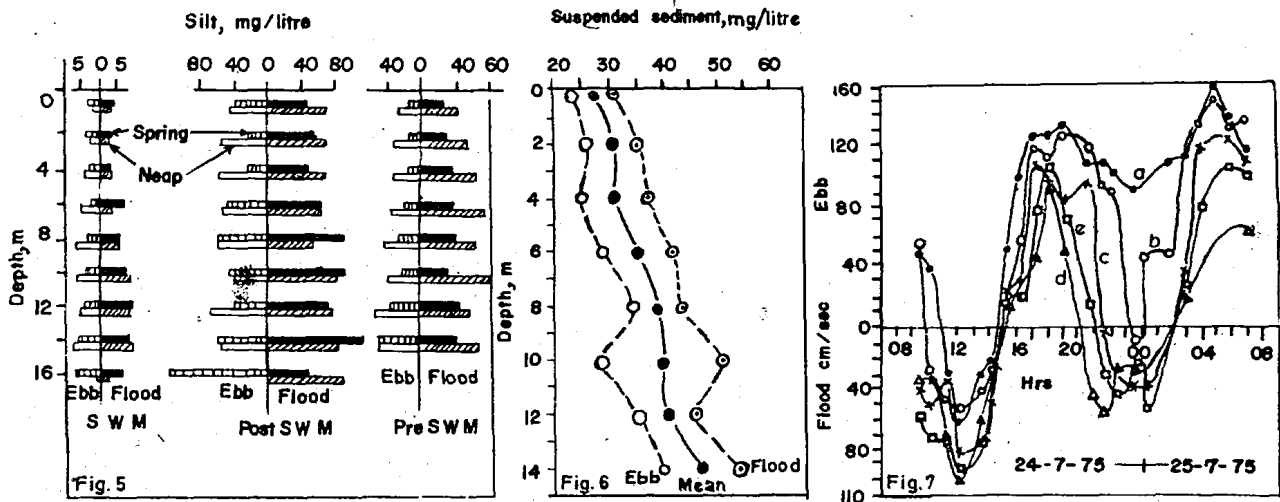


Fig. 5—Average silt content at different depths for ebb and flood of spring and neap tides during SW monsoon, pre and post SW monsoon seasons at station B. Fig. 6—Vertical variation of the annual mean suspended sediment concentration at station B. Fig. 7—Diurnal variation of current at station B [Depth (m): a, 0; b, 4; c, 8; d, 12; e, bottom]

postmonsoon season at the surface but in general the surface current velocities are higher during the monsoon season compared to post and premonsoon periods. Highest velocities observed in the monsoon and premonsoon seasons are 157 and 128 cm/sec respectively.

Diurnal variations of current in the vertical at hourly intervals during the spring tide 24-25 July 1975 (monsoon) and at neap tide on 5-6 February 1976 (premonsoon) are shown in Figs 8 and 9 respectively. Monsoon observations show that the surface and bottom currents are in opposite direction persisting for a few hours during rising or falling tides and the magnitudes of this 2 layer flow at particular times are as much as 120 cm/sec ebb current near surface and 40 cm/sec flood current near bottom. At the end of the flood current, ebb current can be seen throughout the entire depth of the inlet, whereas at the end of the ebb current, flood current begins first near the bottom of the inlet and then gradually extends up to a depth of about 4 m from the surface. Fast changes in the speed of the current with time are also evident.

Sequence of neap tide current changes in the premonsoon season does not show 2 layer flow with rising or falling tides. It also shows that the reversal of current occurs as the tide changes in the entire layer from surface to bottom. The velocity gradients of the current with depth are small compared to those of monsoon season.

Per cent total flow down stream—Percentage distribution of flow down stream with depth in the 3 seasons during spring and neap tides is presented in Fig. 10. Above 50% down stream flow indicates predominance of ebb flow over flood flow and below

50% indicates the predominance of flood flow over ebb flow. Percentage distribution of flow down stream depends on the intensity and duration of flood and ebb currents which in turn are effected by the tides and freshwater discharge into the estuary. The flow during the days of observation (Fig. 10) in the monsoon season is predominantly down stream (ebb current). During the postmonsoon season in December 1975 at spring tide, the ebb flow is predominant whereas in February 1976 at neap tide, the flood flow is predominant. In the premonsoon season, both at spring and neap tides, up stream flow is predominant throughout the depth of the inlet. Predominant down stream flow in the monsoon observations is evidently due to the dominant influence of freshwater discharge over the tidal flow. In the premonsoon season the predominant up stream flow is due to dominant influence of the tidal flow.

Tidal prism—Tidal prism for the inlet, i.e. total volume of water exchanged, has been calculated using the average current velocities of the layers, 0-4, 4-8,

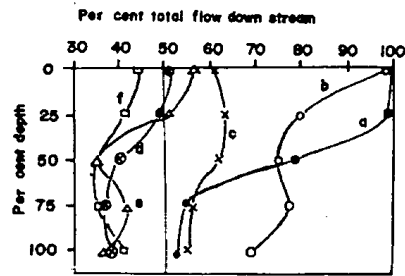


Fig. 10—Vertical distribution of flow in the 3 seasons [a, spring—24 to 25 July 1975; b, neap—31 July to 1 August 1975; c, spring—2 to 3 December 1975; d, neap—5 to 6 February 1976; e, spring—12 to 13 April 1976; and f, neap—21 to 22 April 1976]

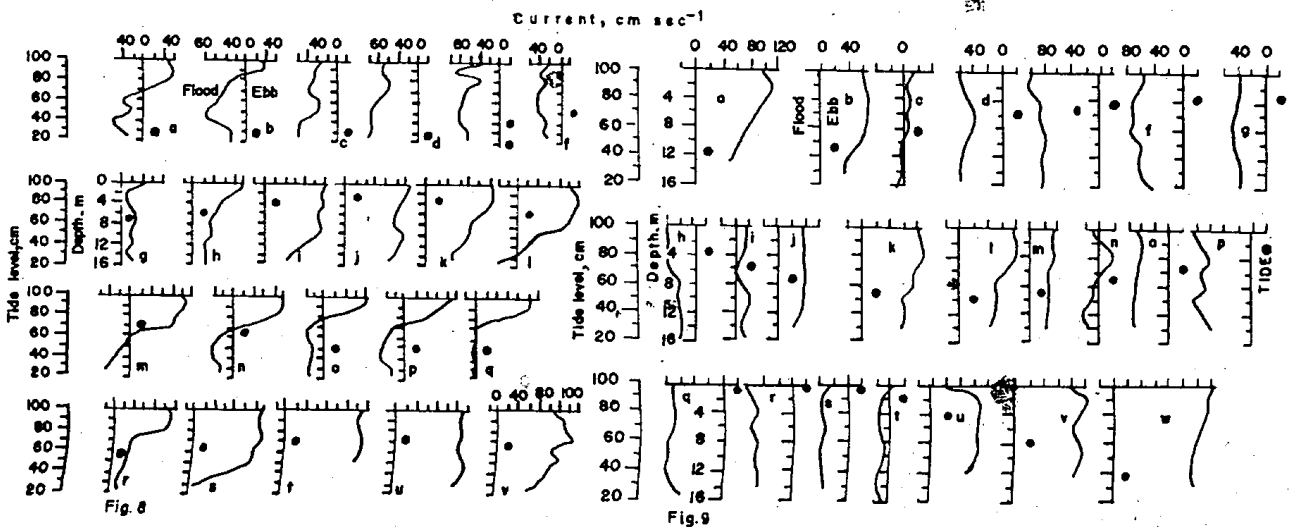


Fig. 8—Diurnal vertical variation of current during spring tide 24 to 25 July 1975 at station B [Time (hrs): a, 0930; b, 1010; c, 1115; d, 1200; e, 1330; f, 1410; g, 1515; h, 1610; i, 1705; j, 1800; k, 1900; l, 2100; m, 2135; n, 2200; o, 2345; p, 0015; q, 0200; r, 0300; s, 0405; t, 0500; u, 0600; v, 0655]. Fig. 9—Diurnal vertical variation of current during neap tide 5 to 6 February 1976 at station B [Time (hrs): a, 1015; b, 1110; c, 1200; d, 1310; e, 1410; f, 1500; g, 1610; h, 1700; i, 1800; j, 1900; k, 2015; l, 2140; m, 2200; n, 2300; o, 0000; p, 0100; q, 0210; r, 0300; s, 0400; t, 0500; u, 0600; v, 0700; w, 0900]

8-12 and 12 m to bottom and the respective cross sectional areas. Spring tide periods are chosen to get the maximum possible values of tidal prism for flood and ebb tides in the 3 seasons. The average tidal prism for the spring tide in the premonsoon season is $31.5 \times 10^6 \text{m}^3$ (35.3×10^6 for flood and 27.7×10^6 for ebb). The freshwater inflow into the backwaters is least in this season and consequently the down stream flow of low salinity water in the inlet is small. The effect of freshwater inflow on the tidal prism during monsoon and postmonsoon seasons is very significant. Tidal prism values range between 9.5×10^6 and $83 \times 10^6 \text{m}^3$ for flood and 27.7×10^6 and $132.6 \times 10^6 \text{m}^3$ for ebb tide. These values represent the order of magnitude and considerable variations occur depending on the tidal range and duration, quantity of freshwater discharge into the estuary, intrusion of saline wedge, etc.

Stability of the inlet—While considering the stability of the inlet, changes in the location of the inlet itself and changes in its cross sectional area are to be considered. If N represents total rate of transport of sediment through the bed load as well as suspended sediment load across the inlet, taking the direction of ebb flow as positive X direction, the condition for stability of the inlet cross section over a period of time t is

$$\int_0^t \frac{\partial N}{\partial x} dt = 0$$

$$\text{if } \int_0^t \frac{\partial N}{\partial x} dt > 0 \text{ erosion of inlet occurs, and}$$

$$\text{if } \int_0^t \frac{\partial N}{\partial x} dt < 0 \text{ deposition at inlet occurs.}$$

As seen from the survey charts of the Cochin Port, the inlet has remained practically in its present location for the last few decades and so appears to have location stability. As the location stability of an inlet is likely to be altered mainly through major changes in the channel orientation, the inlet may have location stability as long as the orientation of the outer and inner approach channels is not tampered with.

The inlet has not been dredged as the need for it in the context of safe navigation has not arisen so far. The high tidal current velocities near the bottom appear to sweep the bottom and no net sediment accumulation is taking place at the central part of the inlet.

According to Bruun and Gerritsen¹³, cross sectional stability of an inlet may be altered by any or a combination of the factors: (i) prolongation of inlet channel; (ii) abnormal deposition of littoral drift material during severe cyclones; (iii) splitting of main inlet channel into 2 or more channels; and (iv) changes

in the bay area from which water flows into the inlet—construction of dams or reclamation of land by constructing bunds, etc.

In respect of the Cochin Harbour inlet, items i to iii are not important as the prolongation of the inlet channel or bifurcation of it can be ruled out for obvious reasons and the abnormal deposition of littoral drift material also may not be expected as the few cyclones that reach this part of the coastline usually lose their severity. Therefore, the most important factor to be considered is the man-made causes like construction of dams and reclamation of land from backwaters. The reduction in bay volume leads to reduced volume exchange through the inlet over a tidal cycle and consequent reduced maximum velocities of the tidal current.

The Thanneermukkam Bund construction has been completed a few years back separating the Vembanad Lake with the rest of the backwaters. The flow through the bund is controlled and the intrusion of saline water into the Vembanad Lake during the premonsoon season is prevented, thereby reducing the bay area for tidal flow. In the monsoon and postmonsoon seasons the flood water of the Vembanad Lake is allowed to pass through the bund. Therefore, the effect of Thanneermukkam Bund on the Cochin Harbour is mainly on the reduction of flow through the inlet in the premonsoon season which results in reduced maximum tidal velocities that can cause increased sedimentation rates in the harbour area. Considerable amount of siltation occurring in the outer channel at a distance of 1800 m from the inlet has been reported earlier¹⁴. It is important for the Cochin Harbour to assess the sedimentation rates in the harbour, study the bed load movement at the inlet and watch for shoaling area so as to connect the cause and effect, if any.

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