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SILTING IN NAVIGATIONAL CHANNELS OF THE COCHIN HARBOUR AREA

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ABSTRACT

Suspended material in the Cochin Backwater varies considerably with the state of tides and seasons. The water column has maximum suspended material during the monsoon period, but its quantity declines progressively during the post-monsoon and pre-monsoon months. Short term changes induced by the tidal currents are quite large and during the pre- and post-monsoon months the total material transported from the sea into the backwater amounts to approximately 900 tonnes/day.

The total amount of material dredged annually from the navigational channels is about 2×10^6 m^3. Of this, nearly 1.2×10^6 m^3/year is dredged from the approach channel to the harbour. At one point, where much of the silting takes place during the monsoon months, the bed of the approach channel rises 1.2-1.8 m every year. In the adjoining backwater, where silting occurs during the pre- and post-monsoon months, most of the silted material gets resuspended during the monsoon months, and with the strong ebb currents, gets transported into the sea. Thus the two processes—transportation of the material from the sea into the backwater during the post- and pre-monsoon months and its retransportation from the backwater into the sea during the monsoon months—seem to alternate with each other. The peculiar pattern of circulation in the estuary influences the transportation of material into one of the inner channels where heavy silting occurs.

INTRODUCTION

THE distribution of suspended material and sedimentation rate in estuaries, especially in those where engineering works have been undertaken, is of much practical value. Burt (1955) discussed the distribution of suspended material in the Chesapeake Bay, while Biggs (1970) developed models of the sedimentation process for the upper and middle sections of the same bay. Krey (1961) observed that 40-90% of the suspended material present in the North Sea was in the form of detritus. The general mechanism associated with the transport of sediments into the estuaries has been explained by Postma (1967). A few reports on the sedimentation process and other related aspects in estuaries and coastal waters of India are available from the Centenary Conference on Port and Harbour Management, which was held at Calcutta (Institute of Port Management, 1970).

In recent years the hydrography of the Cochin Backwater has been studied intensively (Qasim and Gopinathan, 1969 ; Qasim *et al.*, 1968 and 1969 ; Sankaranarayanan and Qasim, 1969). A few investigations on the problems associated with the rate of sedimentation have been made earlier (DuCane, Bristow, Brown and Keen, 1938 ; Das, Hariharan and Varadachari, 1966 and Sundararaman, unpublished).

The Cochin Harbour (Lat. 9°58′N and Long. 76°15′E) is situated along the south-west coast of India. It has a dredged approach channel, 6 km long, which is oriented along an east-west direction for the entry of ships into the harbour. The extension of the approach channel into the backwater gets forked and forms the Ernakulam and Mattanchery Channels, because of the presence of Willingdon Island in between (Fig. 1). Dredging is being undertaken at regular intervals as the Channels get silted up fairly quickly. To get some idea, therefore, of the silting process, several series of observations were made on the rate of sedimentation and on the distribution of the suspended material in the harbour area. These observations form the basis of the present communication.

We are grateful to the authorities of the Cochin Port Trust for making us available the data on sounding in the backwater and the data on dredging around the harbour area. A part of this work was carried out while we were on the staff of the National Institute of Oceanography. We thank Dr. N. K. Panikkar for the facilities we enjoyed.

Procedure and Methods

Water samples from 6 stations in the Cochin Backwater were collected using a Van Dorn sampler. These were from the surface, mid-depth and 1 m above the bottom. Stations 1 and 2 were almost perpendicular to the coastline, while the other 4 stations were nearly parallel to the coastline (see Fig. 1). The depth at station 3 and 6 was about 5 m, whereas at the other stations it was about 10 m. Seasonal changes in the quantity of suspended material in the water column were studied by collecting water samples at fortnightly intervals throughout the year, normally during the slack tide, either at HLW or at LHW. These samples were thoroughly shaken and then a known volume of water was filtered through Whatman 42 filter pads (pore-size 1.1μ) of known weight. After filtration the pads were washed to remove traces of seawater. These were then dried in a desiccator and reweighed. The difference in weight gave the amount of suspended material in a given volume of water. The method used was very similar to that of Krey (1961) for the estimation of seston. The temperature of the water was measured by reversing thermometers and salinity by an induction salinometer or by the conventional titration method.

The distribution of suspended material in relation to tides was studied by conducting four surveys at two stations, each of which lasted 12 to 24 hours. During these surveys the estimation of suspended material was done at 1 to 2 hourly intervals in relation to tidal heights, which were determined by constructing marigrams using the Indian Tide Tables published by the Geodetic and Research Branch, Survey of India. The depth sounding data which formed the basis of further analysis of the silting process in the backwater were supplied by the Cochin Port Trust.

General Hydrographic Features

According to Bristow (1938) the surface currents in the nearshore areas off Cochin is southerly from February to September and northerly from October to January. The predominant wave period at Cochin is generally less than 5 seconds (Srivastava *et al.*, 1967 and 1968). The waves are northerly from November to February, north-westerly from April to July and westerly from August to October. The average significant wave height is about 1.5 m in July. This coincides with the rough weather conditions prevailing in the Arabian Sea at Cochin during this month.

The annual meteorological and hydrographical conditions of the area can arbitrarily be divided into three well marked seasons, each of 4 months : (1) monsoon,

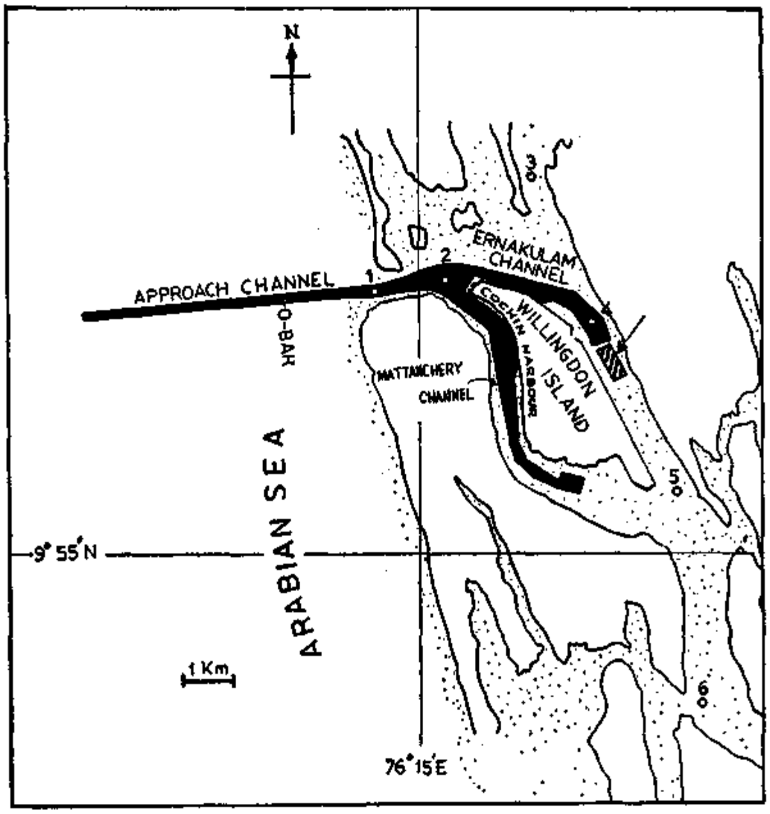

FIG. 1. Map showing the Cochin Backwater with the locations of 6 stations, the dredged approach channel to Cochin Harbour and the dredged Mattanchery and Ernakulam Channels. The area measuring 0.26 km², where seasonal variations in the bed profile were studied, has been marked and indicated by arrow. O-bar in the approach channel gives the position of the outer sand-bar which was cut across when the approach channel was constructed.

from mid-May to mid-September (2) post-monsoon, from mid-September to mid-January and (3) pre-monsoon from mid-January to mid-May. The average meteorological conditions (air temperature, relative humidity and rainfall) together with some hydrographical features (water temperature, salinity and the total transport of water through the harbour entrance) pertaining to the three seasons have been given in Table 1. The pre-monsoon period in the backwater is marked by a uniformly high salinity ($\simeq 32‰$) and high temperature (29-32°C). The freshwater discharge into the backwater during this period is very little and hence there is no stratification in the water column. Following heavy rainfall and runoff during the monsoon season, a pycnocline develops in the water column, with colder seawater at the bottom and warmer freshwater at the top. In the beginning, the seawater zone at the bottom remains shallow, but gradually it gets enlarged and reduces the freshwater column above into a thinner zone (see Sankaranarayanan and Qasim, 1969). During the monsoon season the temperature and salinity variations are of the order of 23-28° C and 0-30‰ respectively. In the post-monsoon period both temperature

TABLE 1 : *Average meteorological and hydrographical conditions of the Cochin Backwater area during the three seasons*

Season	Period	Mean air temperature	Percentage relative humidity	Average rainfall (mm/month)	Average surface temperature	Range in surface salinity	Average near bottom temperature	Average near bottom salinity	Average water transport through the harbour entrance, between MLLW and MHHW: Ebb	Flood
Pre-monsoon	Mid-Jan. to Mid-May	32°C	75	26	31°C	30-32‰	30°C	33‰	83×10^6 m^3	85×10^6 m^3
Monsoon	Mid-May to Mid-Sept.	27°C	85	470	28.5°C	1-18‰	25°C	25‰	182×10^6 m^3	36×10^6 m^3
Post-monsoon	Mid-Sept. to Mid-Jan.	25°C	70	170	30°C	18-28‰	28°C	30‰	82×10^6 m^3	90×10^6 m^3

and salinity show a progressive increase. The average temperature and salinity during this period is approximately 30° C and 30‰ respectively.

Results

Distribution of suspended material with tides

The tides in the backwater play an important role in the transportation of sediments in the area. The tides are of a mixed type, predominantly semidiurnal (Qasim and Gopinathan, 1969). Fig. 2 gives three marigrams representing the three seasons

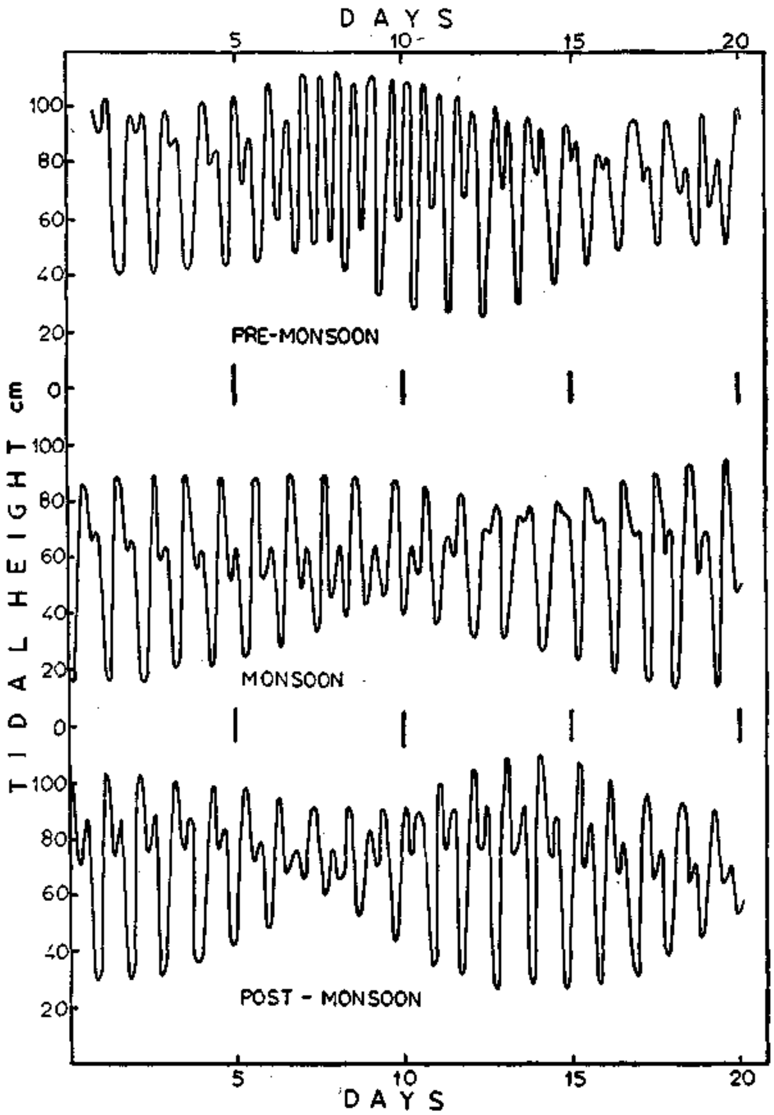

FIG. 2. Marigrams representing an approximation of tidal rhythm in the Cochin Backwater during pre-monsoon (March 1970), monsoon (July 1970) and post-monsoon (November 1970).

(pre-monsoon, monsoon and post-monsoon). A close examination of the tidal cycle will reveal that generally there is a steep rise in the water level from LLW to HHW in about 6 hours. This is followed by a fall in the water level and again a rise forming a smaller peak, the LHW (Fig. 2). The time taken for the water level to fall to the initial LLW is nearly 18 hours. It can also be seen from Fig. 2 that the tidal oscillations in the monsoon months are of a lower range (20-80 cm) than in the other seasons (40-100 cm).

Observations on the tidal currents at station 1 showed that the change in the tidal current from ebb to flood starts near the bottom which gradually moves up to the surface. The change from flood to ebb, on the other hand, takes place in a reverse manner, that is, the ebb current starts at the surface and then progressively reaches the bottom. The force of the flood current is maximum near the bottom, but that of the ebb is maximum near the surface. During the monsoon months, because of large influx of freshwater, the ebb currents from surface to bottom are very strong. The maximum speed of the flood current varies from 1 to 1.5 knots, while the ebb current has always a greater intensity and during the monsoon months it varies from 2.5 to 3.5 knots.

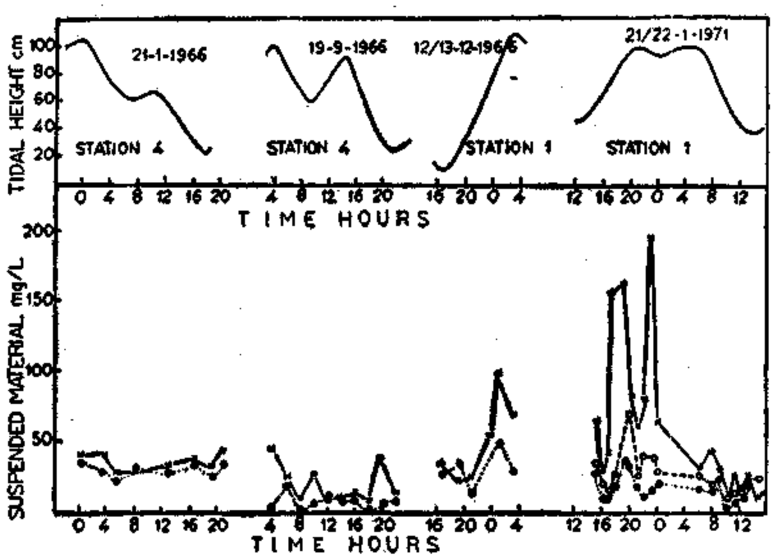

FIG. 3. Changes in the concentration of suspended material in relation to the state of tides. Top drawings represent the tidal heights as a function of time on respective dates. The lower drawings show changes in suspended material at different depths. Closed circles, surface; open circles, mid-depth; crosses, 1 m above bottom.

The quantity of suspended material in the estuary varies markedly with the state of the tides (Fig. 3). At station 4, the variation in the suspended material was small, but there was a clear increase in the values with the flood during the post-monsoon months. A similar increase was noticed with the ebb during the monsoon months. At station 1, the increase was considerable (Fig. 3), particularly during the pre-monsoon month (January).

Distribution of suspended material with seasons

Mon thly values of the suspended material at different depths of all the 6 stations have been shown in Fig. 4. The values for each fortnight were combined to give the monthly averages shown in the figure.

During the pre-monsoon months, the suspended material at all the stations was relatively low. At stations 2 and 3 the values were about 10 mg/l at the surface and with little change these concentrations continued to occur till about mid-May. At the other stations, the values at the surface were still lower (1mg/l). Such low values were recorded in February at station 4, in March at station 5, and from February to May at station 6. The values near the bottom at all the stations were higher than those at the surface. In the backwater, maximum transparency of water has been reported during the pre-monsoon period (Qasim *et al.*, 1968).

During the monsoon months the suspended material increased sharply throughout the water column at all the stations. Values as high as 30 mg/l were found at the surface; 50-60 mg/l at mid-depth, and 60-90 mg/l near the bottom. At station 6, the maximum concentration was recorded in August. As compared to the other stations, the suspended material was maximum at station 1 and the values near the bottom were as high as 100 mg/l in August (Fig. 4). During the post-monsoon months the suspended material at all the stations was far less than during the monsoon months.

Silting in navigational channels

The navigational channels of the Cochin Harbour area consist of an approach channel and two inner channels—the Ernakulam Channel and the Mattanchery Channel (Fig. 1). These are approximately 6 km, 3 km and 4 km long respectively. A gradual rise in the bed of these channels occurs every year and the quantity of material removed from the channels is of the order of 2×10^6 m^3/year. Nearly 70% of this material is taken out from the approach channel, 28% from the Mattanchery Channel and the rest from the Ernakulam Channel. The data on silting in the approach channel for the different months during 1965-66 and the average monthly silting for the last 15 years, from the data made available to us by the Cochin Port Trust, have been shown in Fig. 5. Normally, January and February are the months when the approach channel is dredged and therefore no data on silting for this period are available. Silting starts in March soon after the dredging is over. It increases considerably during the months of July, August and September (Fig. 5). From October it decreases and probably no silting occurs in the approach channel in December. The data on silting in the approach channel for 1965-66 showed considerable variation as compared to the average values of silting for the past 15 years. During 1965-66, silting in the approach channel was of the order of 30×10^4m^3/month for the monsoon period. For the same period, the average of the past 15 years works out to be 18×10^4m^3/month. The rise in the level of bed, based on the average of 15 years, was 1.37 m/year. However, large variations from this value were noticed in certain years.

Transportation of material through the entrance

The changes in the suspended material during the flood in the pre-monsoon and post-monsoon months were very large. For instance, on 12/13 December 1966 (see Fig. 3), the suspended material in the water column was of the order of 25 mg/l at the low tide. It became approximately 75 mg/l within 3 hours during flooding. The increase at each hour from the initial value was found to be 8.8 mg/l, 25 mg/l and 53 mg/l. Taking the cross sectional area at station 1 as 4700 m^2 below LWOST and the average current velocity at each hour as 30, 50 and 70 cm/second, the total

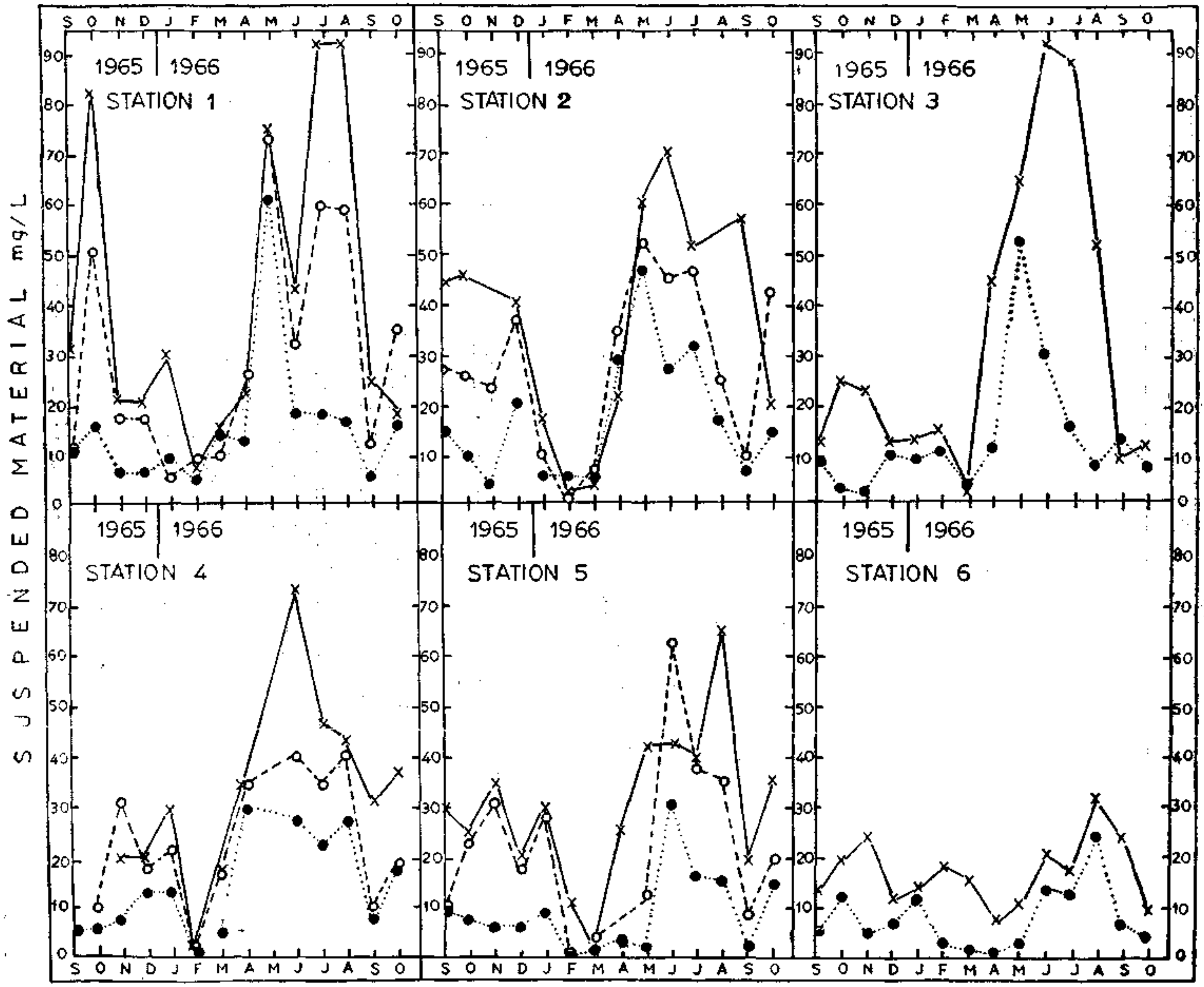

Fig. 4. Seasonal variations in the concentration of suspended material at 6 stations in the Cochin Backwater for the period September 1965 to October 1966. Closed circles, surface ; open circles, mid-depth ; crosses, 1 m above bottom.

silt transported into the backwater would be of the order of 880 tonnes/day. The transport of water into the backwater during flooding between MLLW and MHHW

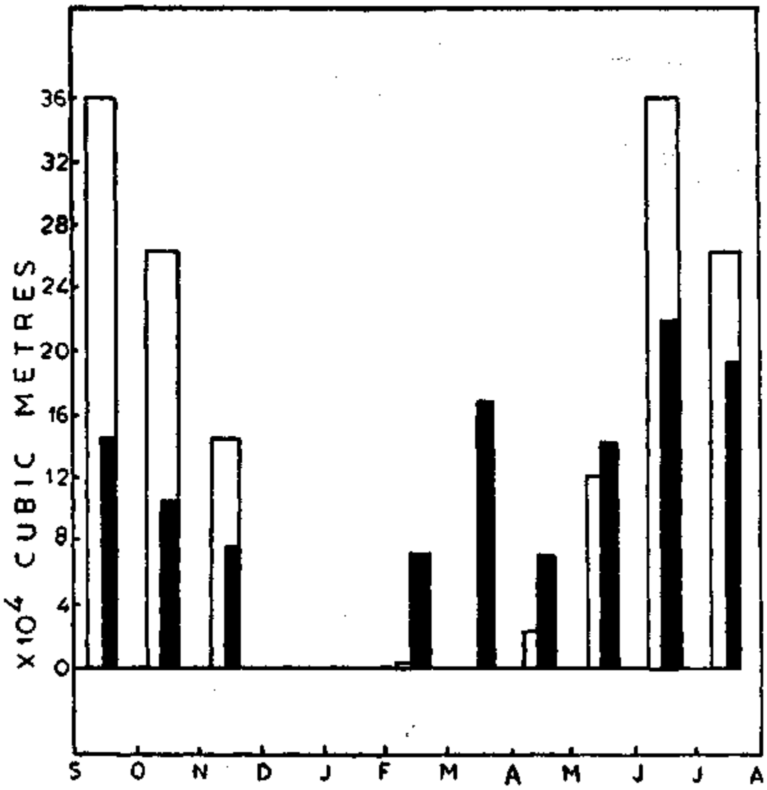

FIG. 5. Monthly variations in the rate of silting in the approach channel. Open histograms repreent the period September 1965 to August 1966; filled histograms give the monthly averages for the last 15 years, 1956-1970.

is nearly 85×10^6 m^3. The above calculation takes into account the water transported into the backwater as 25×10^6 m^3. This is an average value and therefore, the value of the sediment transport given above is a conservative estimate.

If a similar computation is made for the observation on 21/22-1-1971 (see Fig. 3), the sediment transported into the backwater by the flood tide would be of a much greater magnitude. From Fig. 3 it can also be deduced that very little of the transported material will escape into the sea during the ebb tide. Though the ebb current is stronger than the flood, the material is not stirred up and so the ebb water carries very little material with it. This condition seems to prevail during the post-monsoon and the pre-monsoon months. During the monsoon months, on the other hand, the sediments get stirred up and are transported from the backwater to the sea (see below).

Silting in the adjoining backwater

To give a comprehensive picture of the rate of silting in the backwater, the bathemetry of an area measuring 0.26 km^2, which has been indicated in Fig. 1, was

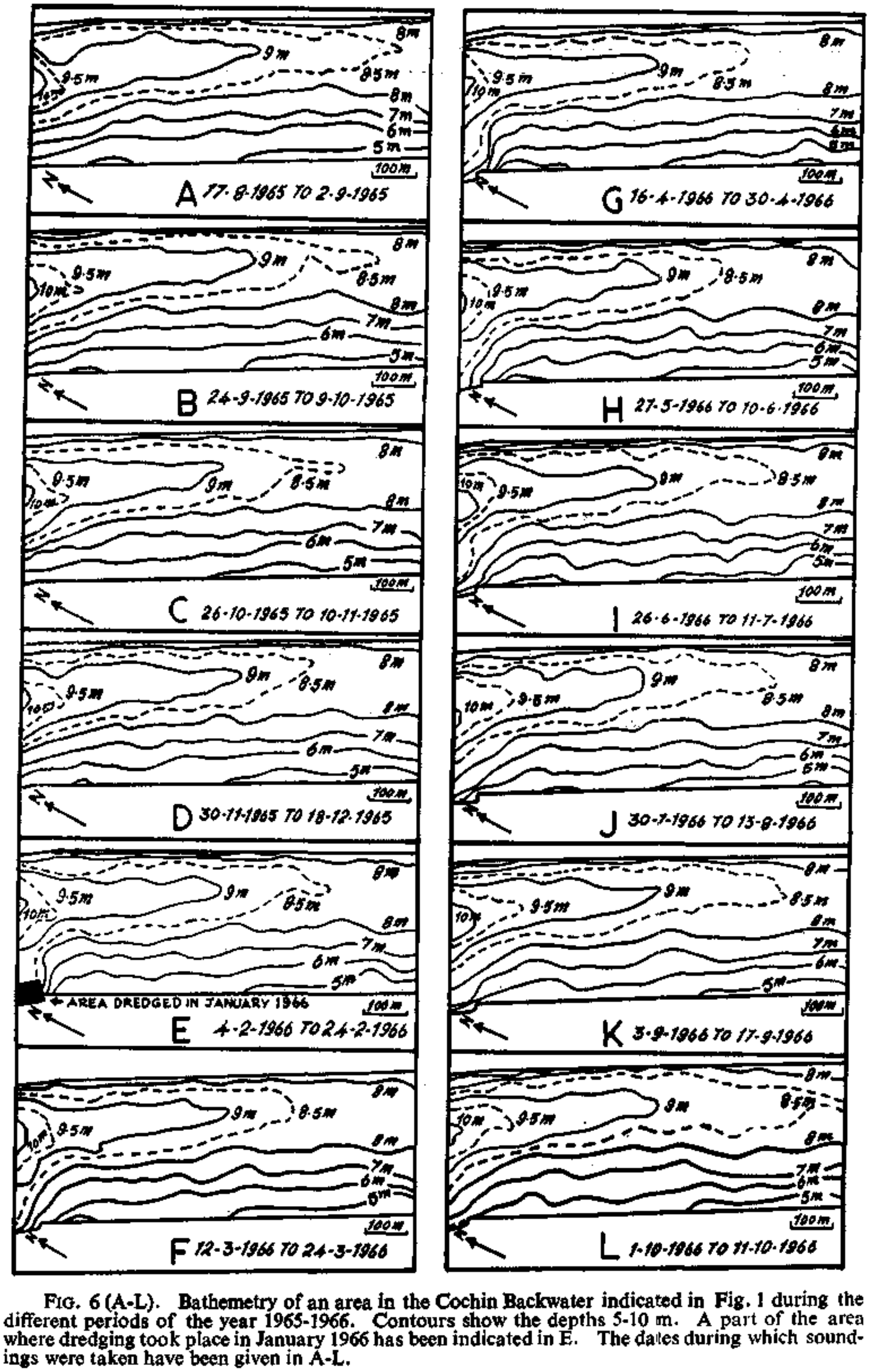

FIG. 6 (A-L). Bathemetry of an area in the Cochin Backwater indicated in Fig. 1 during the different periods of the year 1965-1966. Contours show the depths 5-10 m. A part of the area where dredging took place in January 1966 has been indicated in E. The dates during which soundings were taken have been given in A-L.

examined in detail. The depth contours in this area for the different periods of the year have been given in Fig. 6, A-L. The areas bound by the depth contours 5-10 m were measured by a planimeter and the total amount of material deposited or removed was calculated for the different periods. These have been shown in Fig. 7. As can be seen from Figs. 6 and 7, maximum silting took place from September to December. This was in contrast to the approach channel where maximum silting

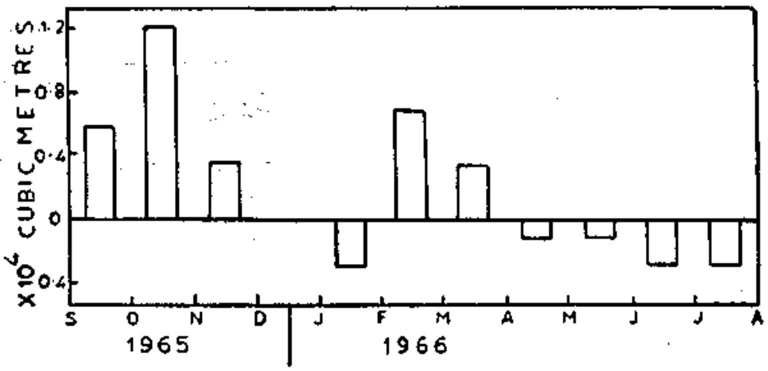

FIG. 7. Average rate of silting in different months calculated from the changes indicated in Fig. 6. The histograms represent the period September 1965 to August 1966.

occurred during the monsoon months (see Fig. 5). The removal of material observed between January and February and indicated in Fig. 7, below zero, was as a result of dredging which took place in January 1966 (see Fig. 6E). Silting again occurred in March and April (Fig. 7). From these data it can be assumed that unless dredging takes place, silting continues to occur, with varying degrees, from September to about April. By May, when the monsoon season starts the material deposited during the earlier months gets stirred up by the strong freshwater outflow and is removed into the sea and perhaps gets deposited in the approach channel. Thus in the backwater the two processes during the year maintain a state of balance and the overall effect of silting and desilting gives rise to almost constant depth in the backwater (see Fig. 6 A-L).

DISCUSSION

The approach channel at Cochin was constructed in 1928. Before that, there was a sand bar at a distance of 1.6 km west of the coast. The depth of water over this dome-shaped bar was about 3 m below LWOST, increasing on either side, along the east and west. The approach channel was constructed by cutting the bar across. The position of the former bar is shown as O-bar in Fig. 1. The material which got silted up after the construction of the channel was dredged out next year, during January and February (1929), when the sea became calm. Since then the two processes, silting and the removal of the silted material by dredging, have been going on alternately. The main region in the approach channel, which is subjected to heavy silting, is a 140 m wide and 4.3 km long area, west of the point O-bar. This area gets silted up to a level of 1.2 to 1.8 m every year. The material removed from the channel in the form of fluid mud is dumped about 600 m away along the sides of the channel. From 1928 to 1937, the dredged material from the approach channel was dumped along the northern side of the channel and from 1937 to 1962 along the southern side. Since 1962, the dumping started on the northern side again.

Presumably the idea of changing the dumping site arbitrarily was to have an effective dispersion of the dredged material into the sea. DuCane *et al.* (1938) indicated that the heavy silting observed in certain years was definitely influenced by the appearance and movements of the mud banks in close vicinity of the channel.

In recent years, some studies on the silt movement in the area were conducted by the Cochin Port Trust in collaboration with the Bhabha Atomic Research Centre, Trombay, and the Central Water and Power Research Station, Poona (Gole and Tarapore, 1966 ; Sunderaraman, unpublished). The silt movement in the area was studied by the radioactive-tracer technique. Three experiments were conducted during the post-monsoon and pre-monsoon months of 1962-63 and a fourth experiment was carried out during the monsoon months of 1970. The results of these experiments showed that the material dumped about 850 m away, either on the southern or northern sides of the approach channel, found its way into the channel. It subsequently came through the bifurcated channels into the backwater. The material dumped about 2 km south of the approach channel also found its way into the channel. The experiment which was carried out in the monsoon months of 1970 showed that the material dumped at a point, 2 km north of the channel, and 5 km west of the coast, did not find its way into the channel.

One of the factors affecting the silting in the channels is the sedimentation of the suspended material in the estuary during the post- and pre-monsoon months. An area just outside the dredged channels will experience maximum sedimentation of the suspended material during the post-monsoon season, whereas in the upper reaches of the estuary, sedimentation would be maximum during the pre-monsoon season. As a result of typical estuarine circulation as indicated by Postma (1967), the material from the sea may find its way into the lower parts of the rivers where seawater hardly ever penetrates. Thus it seems likely that the portion of the backwater which is nearer to the harbour will receive larger quantities of marine mud during the post- and pre-monsoon months than the other parts of the backwater. The high values of the suspended material in the backwater during the monsoon months suggest that the sedimented material is probably resuspended by the freshwater runoff. The tidal action and the strong ebb currents during the monsoon months further accelerate the resuspension of the bottom sediment. This suspended material seems to move slowly towards the entrance of the estuary in an oscillatory fashion. High values of the suspended material recorded at station 1 during the monsoon months seem to signify such a movement which leads to what has been termed as the ' turbidity maximum ' at the estuarine entrance (Postma, 1967). Seawater is always present in the approach channel, even during the monsoon months, when the freshwater discharge from the backwater is maximum. In the approach channel, the freshwater, which is heavily loaded with suspended material, mixes with the denser seawater at the bottom. Because of some electrostatic property of the material in suspension, while such a mixing is taking place, the fine particles aggregate into larger particles and quickly sink to the bottom (DuCane *et al.*, 1938 ; Ippen, 1966). Although such a mechanism would seem to operate all along the approach channel during the monsoon season, because of strong currents near the entrance, its settlement there seems to be prevented. Probably because of the slackening of the currents in some parts of the approach channel, the material settles more readily along the west of O-bar, which is a well-known area of maximum silting.

Of the two channels encircling the Willingdon Island, the Mattanchery Channel is subjected to a much greater silting than that of the Ernakulam Channel. Nearly 1/3 of the reported silting in the three dredged channels during the year occurs in the

Mattanchery Channel. Certainly this channel seems to be greatly influenced by the peculiar pattern of circulation prevalent in the Cochin Backwater. It has been observed that the flood currents, during the monsoon months, flow mainly through the Mattanchery Channel into the backwater, south of the Willingdon Island. Observations on the synoptic distribution of salinity within the area during the same period have clearly shown that the near bottom circulation around the Willingdon Island is anti-clockwise. Thus, the sediment-loaded bottom water entering the Mattanchery Channel during the flood tide seems to leave behind a part of its sediment load as it passes the Mattanchery Channel.

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