

CHAPTER 79

SALINITY DISTRIBUTION AND EFFECT OF FRESH WATER FLOWS IN THE HOOGLHY RIVER

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ABSTRACT

An examination of the hydraulic characteristics of the Hooghly river with particular reference to the pattern of salinity intrusion and the effects of fresh water flows has been made in this contribution. It is seen that the conditions prevailing are such that during the brief period of fresh water flows the problem of salinity intrusion is absent. The beneficial effect of fresh water flows in improving the navigable depths along the river is also shown. The cessation of fresh water flows causes the deterioration of navigable depths due to the landward movement of sediment; it also results in the upstream encroachment of salinity affecting the supply of drinking water to the City of Calcutta. It has also been shown that even during the period in the freshet when the salinity profiles exist the estuary remains well-mixed. The need for augmentation of fresh water flows for improving the conditions has also been brought out. A few remarks on the comparative features of Hooghly and other tidal rivers have also been added to spotlight on the vastly different characteristics of the Hooghly.

1. INTRODUCTION

The Port of Calcutta located about 100 N.miles inland from the sea on the river Hooghly (Lat. $22^{\circ} 32' 53''$ N. Long. $88^{\circ} 18' 05''$ East) has steadily developed since it was founded by Job Charnock in 1690 and is one of India's most important Ports to-day. (Fig.1). With an annual tonnage handled being over 11 m.tons, the port's primary exports are - Coal, Tea, Jute, Manganese ore, Pig Iron etc. while the chief imports are - Petroleum, Foodgrains, Machinery etc. In view of the importance of the port, the navigability along the river has been a subject of detailed consideration since some time.

2. HOOGLHY RIVER

The Hooghly river is formed by the confluence of three rivers, generally referred to as Nadia rivers, viz, the Bhagirathi, Jalangi and Mathabhanga-Churni, of which the

Bhagirathi which takes off from the river Ganges at Biswanathpur, is the most important since it is the main channel bringing fresh water discharge into the Hooghly. The Hooghly river is subject to varying tidal action due to the tides emanating from the Bay of Bengal, (maximum range at the mouth 17 ft.). The tidal limit extends to Swarupgunj about 76 N. miles upstream of Calcutta in the dry season but is pushed down during the period of fresh water flows. The tidal currents exhibit seasonal variation in their strength and attain their maximum during the period when there is no fresh water flows.

A notable feature in the Hooghly is the formation of 'bore-tides' characterised by a sudden and almost vertical rise of water level immediately after low water. 'Bores' now occur practically on every spring tide. The maximum 'bore' height is of the order of 8 ft. and speed of travel about 18 to 20 miles per hour.

The channel geometry is very irregular as evident from the variation of areas and widths along the river. This is primarily due to the existence of numerous curves and bends and sudden divergence of sections. The existence of these **curves** and bends gives rise to the divergence of 'flood and ebb' axes with the result the crossing from one bank to the other remains shallow, necessitating dredging for the required navigable depths to be maintained. Along the river several such bars/crossings exist from Calcutta right upto the sea and the important ones are - Panchpara, Sankrail-Munikhali, Pirserang, Poojali, Moyapur, Royapur, Ninan-Nurpur, Eastern Gut, Balari (Fig.2). As the strength of the chain lies in its weakest link, the minimum depth over these bars governs the permissible draft and hence the movement of ships.

Upland Fresh Water Flows - The Hooghly receives its major share of fresh water flows from the Ganges through the Bhagirathi. Owing to the high level of the off-take the spill from the Ganges to the Bhagirathi occurs only during the period when the levels in Ganges are fairly high. Figure 3 shows the hydrographs at Kalna for the period 1962-65 (23 N.miles downstream of Swarupgunj). It is apparent that significant fresh water flows occur only during the period July to October. Barring abnormal flows the normal maximum flow is of the order of 1,20,000 cfs. It is of interest to note that the hydrographs exhibit rapid rise and fall, which are important in regard to the distribution of salinity and also the navigable depths along the river. Considerable sediment load is brought down by the fresh water flows, estimated to be of the order of 50 m.cu.yds. It is the pattern

of movement of this sediment that governs the navigable depth along the river.

3. SALINITY DISTRIBUTION

The importance of salinity in estuarine environments has been recognized since quite sometime in view of the possibility of the problems of sedimentation in navigable waterways being interlinked with the pattern of salinity variation and the resulting distribution of current velocities. Depending upon the degree of mixing between the fresh and saline waters, an estuary may vary from a well-mixed type to a stratified type, the former indicating the predominance of tidal forces over the fresh water flows and the latter the other extreme case of minimum mixing and maximum variation in the salinity distribution over the vertical arising due to weak tidal action and large fresh water flows. Where mixing is not of a high order, the density currents set up along the bottom of the channel would tend to transport the material along the bed upstream causing formation of a shoal near about the limit of 'intrusion'. It is, therefore, generally appreciated that studies relating to the improvement of waterways should consider the effects on salinity distribution to avoid any such illeffects.

As in the case of other tidal rivers, the Hooghly also exhibits its own characteristic salinity distribution along its length. Apparently the inflow of fresh water from upstream is intimately connected with the pattern of salinity distribution along the river.

With the onset of fresh water flows, the salinity decreases from the upper reaches, this effect progressively travelling downwards with the increase in the fresh water flows. By the time the discharge is about 40,000 cfs. the salinity limit is pushed down below Calcutta and the effect of the further rapid rise in discharge is such that even at Balari where the dry season salinity is of the order of 30 PPT the water is rendered practically sweet. The rate of rise of the inflow hydrograph governs the time by which Balari waters become sweet. And since the discharge continues at this high level, despite the fluctuations in the hydrograph, no encroachment of salinity occurs. Even at Auckland bar, 13 km below Saugor the salinities are substantially reduced during freshets, as can be seen from the values given below -

Date	Salinity in PPT at		
	Auckland Bar	Haldia	Balari
12-7-64	15		
1-9-64	1.38	0.06	
7-7-65			28.65
11-7-65		12.22	
14-8-65	12.5	0.66 approx.	
10-9-65		0.48	0.39
20-9-65	4.9	0.41	

By the end of September the hydrograph shows a falling trend and by November the flows are very small. However, the impounded fresh waters have the beneficial effect of arresting a sudden encroachment of salinity as soon as the discharge falls down. Thus in December the salinity at Haldia is of the order of 4 PPT whereas at the upper stations, Moyapur and Garden Reach, the salinities are well below potable limit. The salinity gradually increases first at Moyapur by the end of December and at Garden Reach the effect is felt only by the beginning of February, this lag again depending upon the fresh water flows during the earlier period. Over the period July to October when the freshet flow exists the Hooghly river over its main problem zone remains sweet and free from any salinity effect. Figure 4 shows the salinities at different stations for the period October to August.

The salinity encroaches into the upstream reaches gradually after the fresh water flow ceases and the tidal forces gain in strength. In the absence of fresh water flows the intrusion takes place in a homogeneous fashion. The formation of 'bores' in the dry season also helps in creating additional turbulence which helps to effect a thorough mixing of the water contents in the river. The maximum salinities at Calcutta are of the order of 8 PPT.

The encroachment of salinity into the upper reaches in the dry season poses a problem of direct concern since this affects the supply of water to the Calcutta City. Water supply for drinking purposes to the City are drawn from the Hooghly through the water works at Palta, about 18 miles north of Calcutta. Originally when the water works were established in 1867 it was possible to supply sweet water from the river round the year but of late due to the deterioration of the channel capacities and the upstream encroachment of salinity, supply of sweet water during the dry weather period, say March to June, is becoming a serious problem. It has become essential to arrest this intrusion by

suitable measures and restore the water supply position.

It can thus be seen that the salinity distribution along the Hooghly in the dry season is vastly different from that in the freshet season unlike many other tidal rivers.

Though the river waters have some salinity only for a brief period of about a month, after the freshets begin, after which the increase in discharge pushes the salinity limit down to below Haldia, it will be interesting to make an assessment of the mixing characteristics in the zone of salinity intrusion in this transition period.

(1)

Of the approaches postulated by Schultz & Simmons, Abbot⁽²⁾ and Ippen & Harleman^(3,4) the application of the method indicated by M/s Ippen & Harleman is made herein. The method essentially consists of assessing the ratio, of the rate of dissipation of turbulent energy per unit mass of fluid to the rate of gain of potential energy per unit mass of the fresh water flow in its travel through the saline zone, termed the stratification parameter (G/J). G, the rate of dissipation of energy per unit mass is obtained from analysis of prototype tidal data. J, the rate of gain of potential energy per unit mass is obtained by considering that the net flow over any section is only due to fresh water discharge and ascertaining the average increase in density in the intrusion zone from known salinity distribution, and is given by the formula -

$$J = \frac{\gamma_x - \gamma_f}{\gamma_f} gh V_f / L$$

where V_f is the fresh water velocity,

γ_x = density at any section x,

γ_f = fresh water density,

h = mean depth

L = length of intrusion.

Large value of this ratio is indicative of well-mixed conditions. It has been suggested that values of the order of 2000 are indicative of a very high degree of mixing.

The basic data used and the results of computation are given in Table I.

These show that the values are large (2000 or near about) representing highly mixed conditions. This is also borne out from the available data of salinity and velocity distribution over the vertical at different stations which show no trend for reversal. (Fig.5) In order to obtain the

critical value of this stratification parameter below which stratified conditions would exist, for practical purposes, it would be necessary to extend the computations over the various combinations of tidal ranges and upland discharges.

In the dry season due to the significant lack of upland discharge the values of G/J would be automatically very high implying highly mixed conditions in the estuary, which is obvious.

4. SHOALING ALONG THE RIVER

As briefly mentioned in para 2, the peculiar geometry of the river is mainly responsible for the pattern of shoaling taking place. The existence of bends/curves results in the divergence of the flood and ebb axes. This divergence also varies due to seasonal changes in the ebb and flood currents so that the extent of the bar along the crossing & the navigable depths over this naturally exhibit large seasonal variation. The navigable depths over two typical bars/crossings are shown in figure 6 which depict the conditions adequately. With the onset of the freshet the channels tend to improve due to the increased ebb preponderance after an initial period of readjustment, so that beyond August depths improve considerably till the situation is offset in the dry weather period with the gain of tidal strength when the distribution of material takes place in the landward direction. During the freshets the flood cul-de-sac shifts down and the head of the sands build up; the situation reverses in the dry season. Figure 7 illustrates this condition very well.

A typical example of the shoaling occurring in the Hooghly is obtained by the study of the conditions at Sankrail reach about 8 N.miles below Calcutta. The situation of Sankrail reach spotlights the effects of the divergence of the flood and ebb axes. Below and above Akra the river sections are narrow (width 2700 ft.approx.) but inbetween the river width is excessively large (width 4750 ft.) due to the progressive erosion of the Akra bank by the flood flow (Fig.8). The widening of the river was accompanied by the formation of Sankrail Sand extending from Hangman's Point to Munikhali Crossing. This formation gave rise to the divergence of channels for the flood and ebb currents; the ebb following the deep channel at Sankrail while the flood runs along the opposite Akra bank over the sand. During the freshets, due to the ebb preponderance the channel at Sankrail bight and Munikhali Crossing improves but the flood preponderance during the dry season results in the flood cul-de-sac extending through the Sankrail Sand to the detriment of the navigation channel. Both Sankrail and Munikhali Crossing carry

reduced depths and improvement of this reach had to be done by construction of a flood repelling spur at Akra for deflecting the flood on to the Sankrail bight.

The deterioration in depths at other bars are generally due to this cause, though varying in degree. Since the deterioration in depths occurs due to the large tidal preponderance it would be necessary to offset this by establishing the ebb preponderance by extending the period of fresh water flows.

The material over the bars is predominantly composed of medium/fine sand varying in mean diameter from 0.15 mm. to about 0.1 mm. and specific gravity of about 2.6. The percentage of clay and silt generally does not exceed 10 %. So that the possibility of flocculation in the problem reach does not exist.

5. SOME ADDITIONAL REMARKS

From the various available examples of tidal rivers it can be appreciated that it is hard to generalise on the hydraulic conditions since no two systems exhibit identical characteristics and as such the problem and solution would depend on the particular situation in hand. In comparison with other estuaries like Delaware, Savannah, Charleston or Thames, the Hooghly river shows markedly different characteristics. In addition to the great tortuous length of about 186 miles, the turbulence level is also high as seen from the current velocities which reach about 10 ft./sec. The occurrence of 'bore-tides' is a feature of significance both from the point of view of distribution of sediment and hazards to navigation. The salinity intrusion is particularly interesting in that during the period of freshet the river waters are rendered practically sweet. During the dry season the longitudinal salinity profile extends over a great length so that the gradient is much flatter compared with Delaware or Thames which implies that salinity effects are not significant. (Delaware 20 PPT/52 miles, Thames 20 PPT/30 miles, Hooghly 20 PPT/75 miles). It is also interesting to note that the encroachment of salinity occurring only in this season is not of the "arrested type" as in other estuaries which carry a minimum amount of fresh water flow round the year. Due to the geometry of river, in a section, generally the deep channels exhibit 'ebb preponderance' whereas the shallower regions exhibit flood preponderance, (Table II), which is very much different from the situation prevailing in estuaries influenced by density effects, where over the vertical the circulation pattern would indicate ebb preponderance along the surface and flood preponderance along the bottom. The

navigable route from the entrance to the Port is beset with numerous obstacles and shoaling problem is not confined to a particular reach. The fresh water flows are again characteristic in that the flows exist only for a short period unlike as in Delaware or Savannah but their importance lies in the fact that they bring in considerable benefits to the river. The large semi-diurnal variation in tidal amplitudes, further, does not give rise to any sustained pattern of hydraulic equilibrium. The suspended sediment concentration in the Hooghly river is also of a high order as compared to the other estuaries. The absence of clay is conspicuous as far as shoaling due to flocculation is concerned. It will be interesting to note that in Savannah, Charleston & Thames flocculation is the major cause of shoaling in the river. Figures 9 to 12 show some of the hydraulic parameters of Savannah, Delaware and Hooghly compared.

6. CONCLUSIONS

From a study of the salinity intrusion pattern in the Hooghly river it is seen that the intrusion assumes importance only during the period when no fresh water flows are available. The upland hydrographs show that presently the river receives fresh water flows only for a short period of 4 months in a year. The fresh water flows have the beneficial effects of pushing down the salinity limit to almost the river mouth and improving the depths along the tortuous navigable route. The deterioration in channel depths and the encroachment of salinity affecting drinking water supplies are both the result of lack of adequate fresh water flow which have to be offset by extending the period of fresh water flows.

7. ACKNOWLEDGEMENT

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TABLE I
The Basic Data Used & The Results Of Computation

Date	Tidal Range at Saugor	Fresh Water Discharge (at Kalna) in cfs.	Saugor	Haldia	Diamond Harbour	Mean salinities (in ppt) at Fulta Moyapur Garden Reach	G/J		
7-7-64	10'10"	12,500		33.3	17.61	12.36	7.11	0.42	2500
12-7-64	14'5"	23,000	22.30		14.40	12.5	3.20	0.50	2980
13-7-64	13'0"	30,000	20.40		13.20	3.90	2.40	0.49	2122
14-7-64	11'7"	43,000			11.25	2.70	1.70	0.47	1462

TABLE II
PERCENTAGE EBB PREDOMINANCE (ACROSS A SECTION)
AT DIFFERENT STATIONS ALONG RIVER HOOGHLY.

DATE	STATION	PERCENTAGE EBB PREDOMINANCE	
		SURFACE	BOTTOM
6 9 1964	DIAMOND A	75 30	72 04
	B	77 83	74 47
	C	52 53	44 41
1 2 1963	DIAMOND A	80 74	61 37
	C	46 21	24 22
29 8 1963	OUTRAM B	100 00	99 29
14 3 1963	OUTRAM A	66 17	63 84
	B	52 86	46 11
	C	47 5	44 00
25 5 1964	MOYAPUR A	46 67	45 90
	B	56 82	57 21
	C	75 64	78 83
9 8 1965	MOYAPUR A	34 94	26 17
	B	80 54	75 24
	C	91 38	89 19

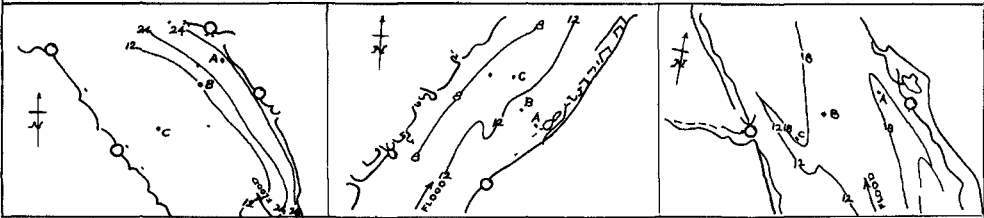
KEY PLANS

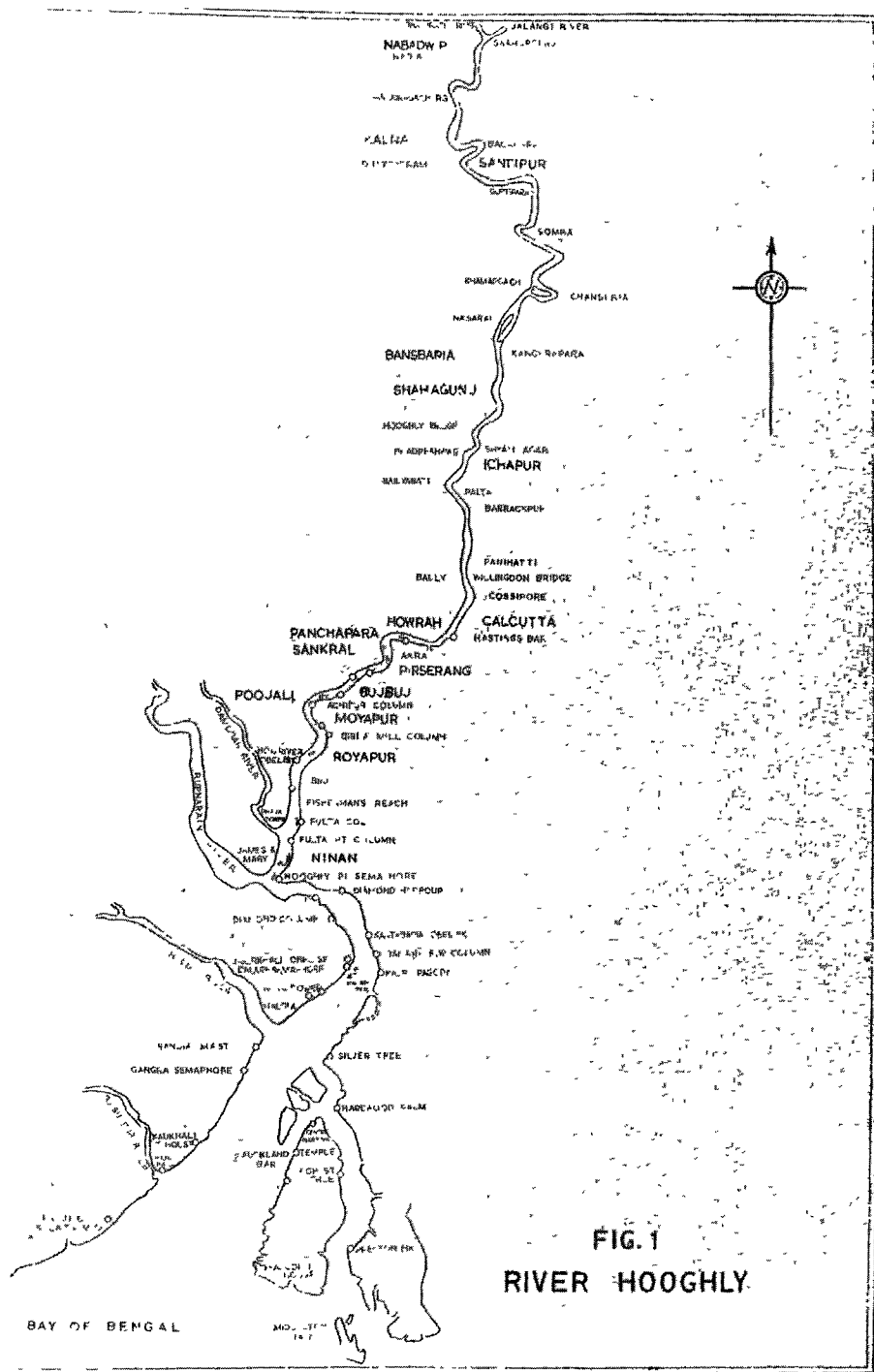
SHOWING POINTS OF OBSERVATION

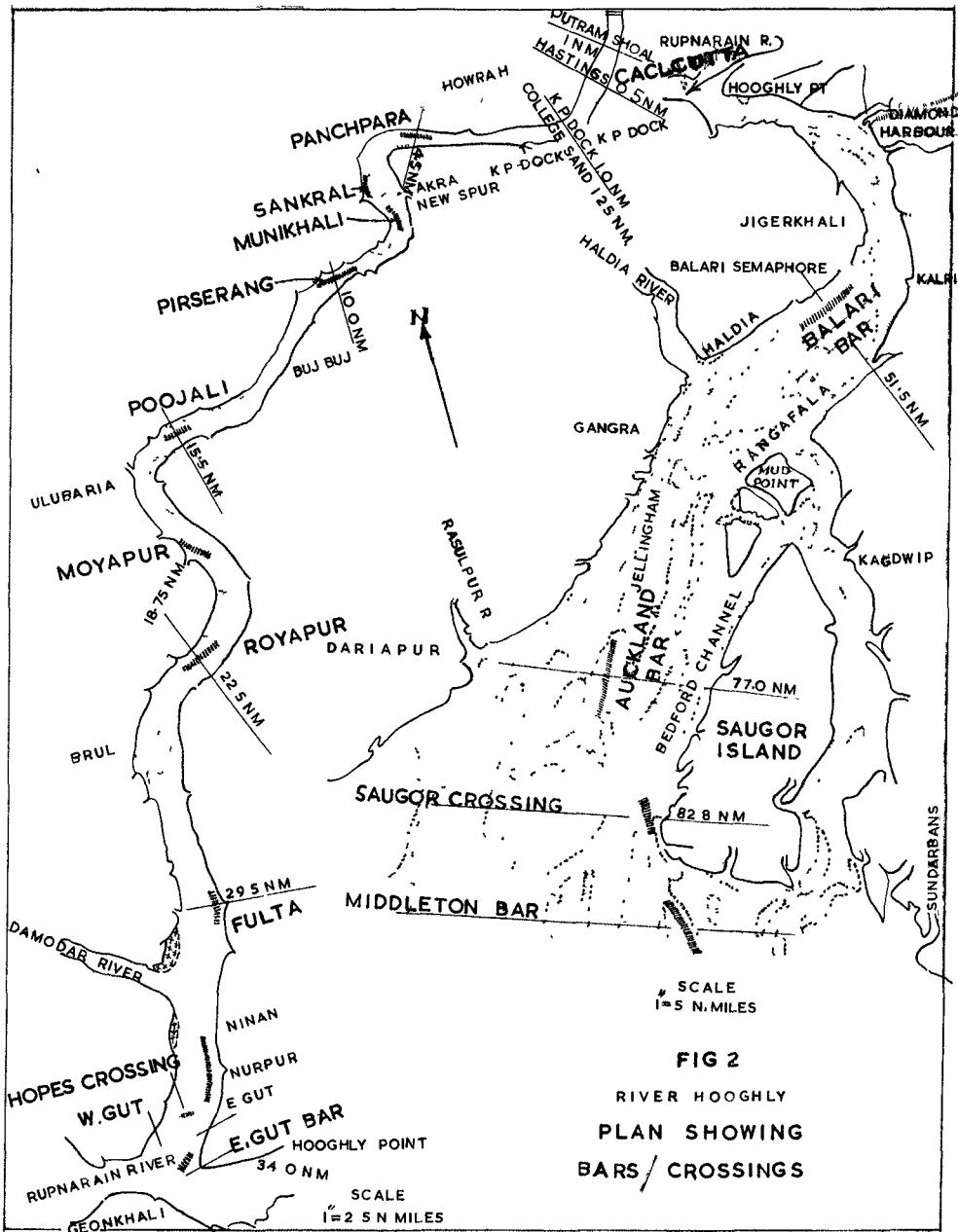
DIAMOND REACH

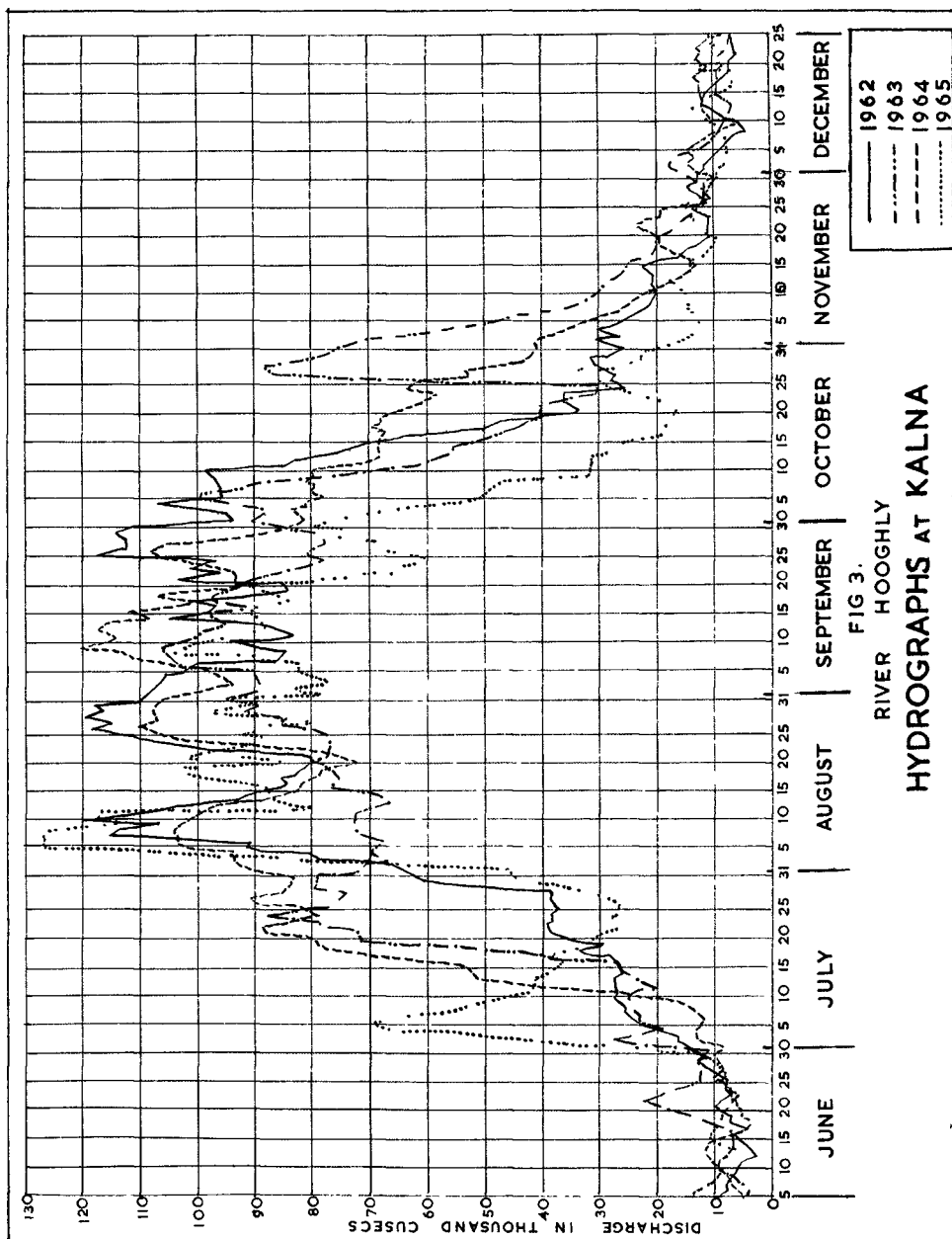
OUTRAM GHAT

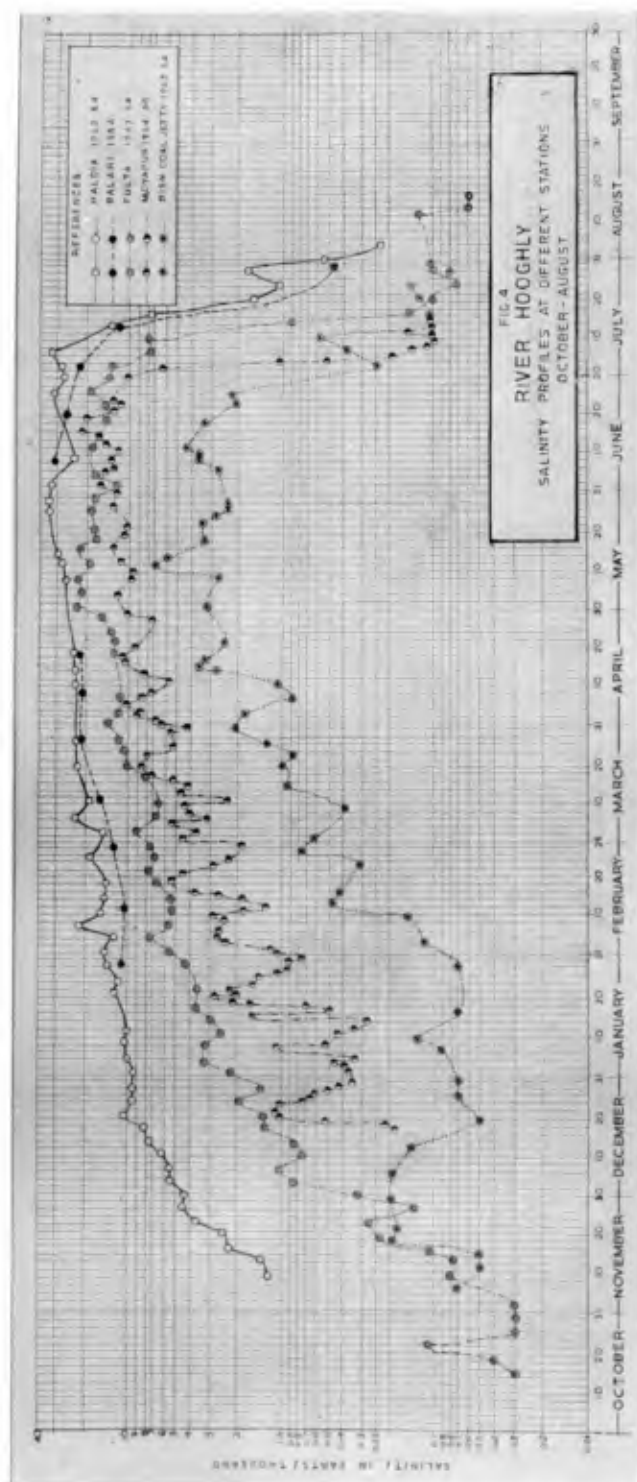
MOYAPUR

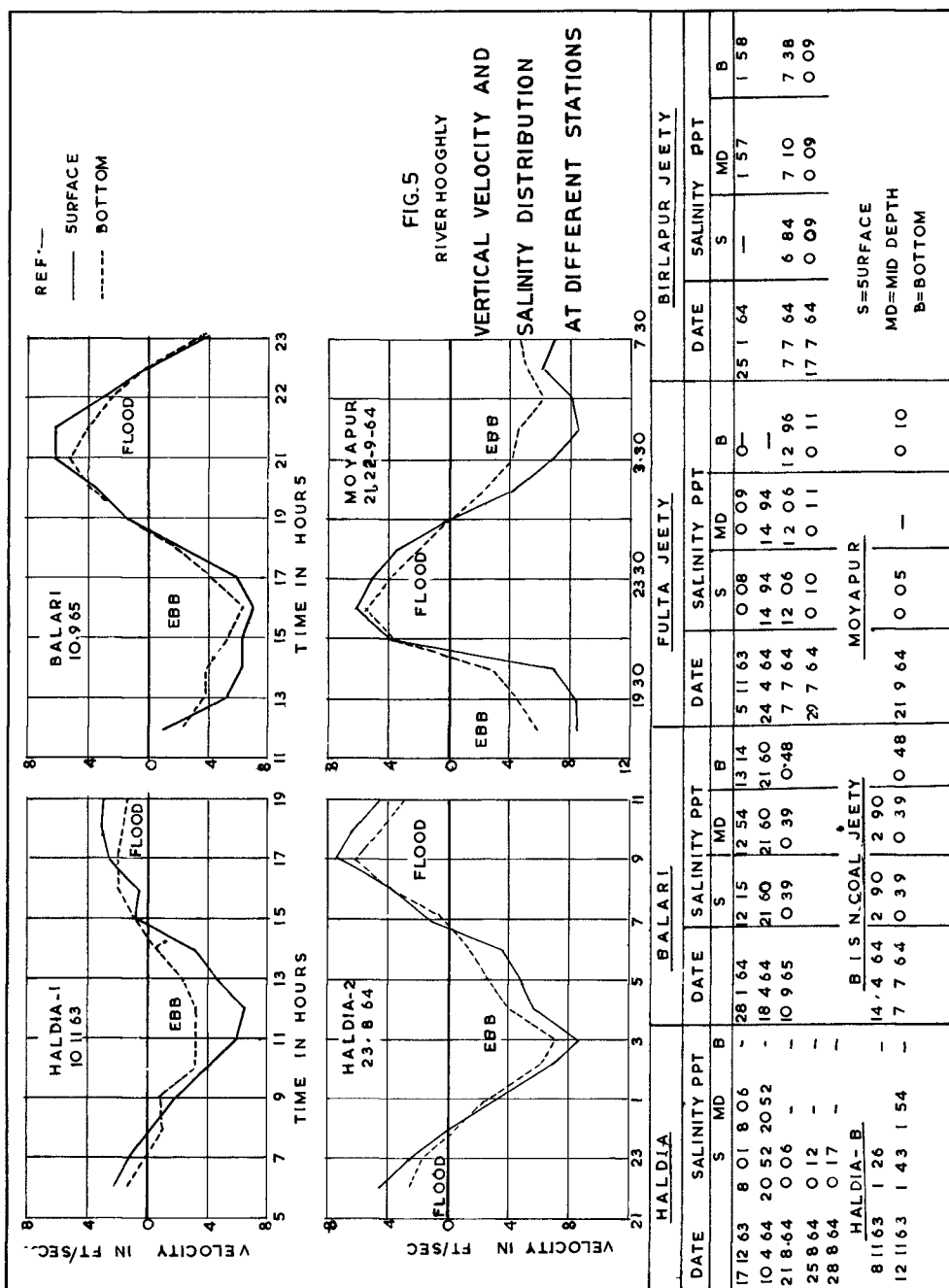


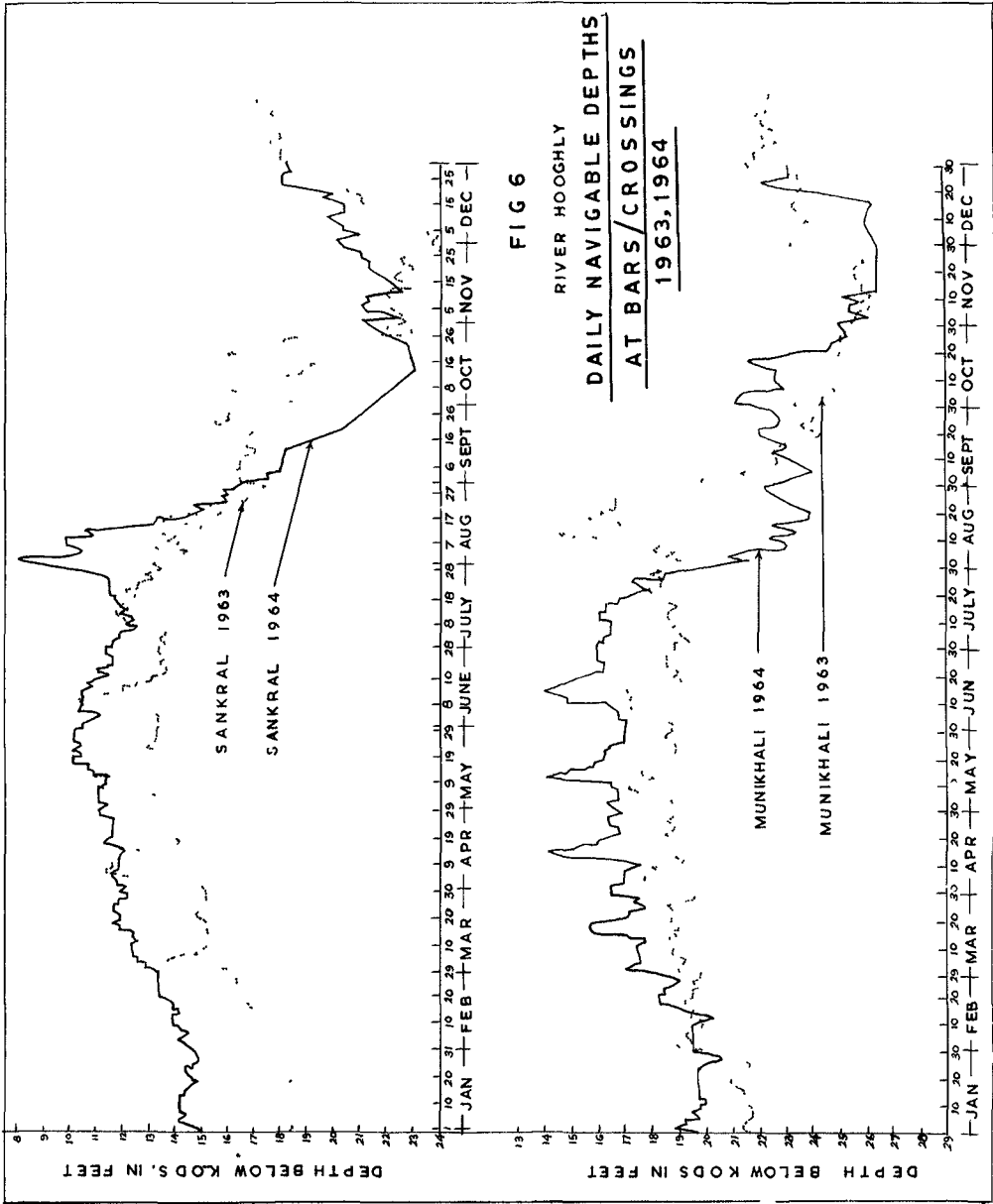


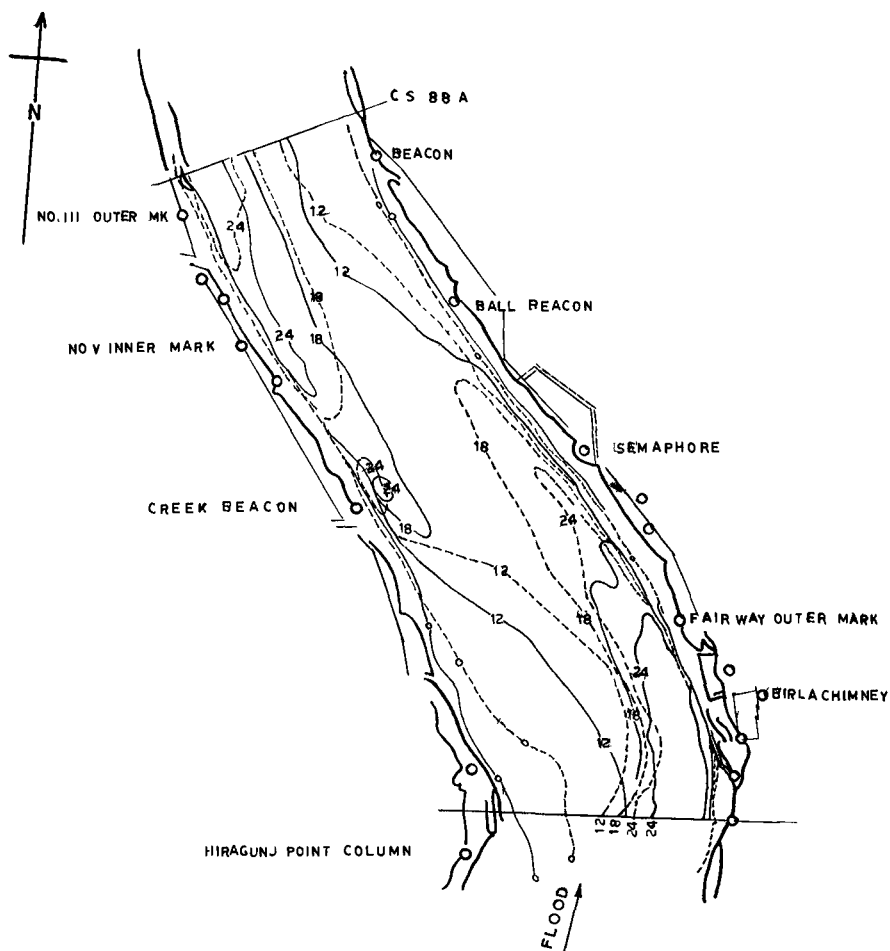










REFERENCE -

----- MAY-JUNE 1957

————— NOV-DEC 1957

FIG. 7

RIVER HOOGHLY

POST & PREFRESHETCHANNEL CONDITIONSAT MOYAPUR BAR

