

A Study for the Improvement of the Chilka Lake Tidal Inlet, East Coast of India

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ABSTRACT

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Chilka Lake, the largest tidal inlet connected to the Bay of Bengal is hydraulically found poor with little exchange of water between the sea and the lake. The shorefront of the lake is exposed to a high rate of littoral drift, one million cubic metre per year. A One year study showed the migration of the inlet mouth to approximately 500 m northward. The flow of salt water from the sea into the lake as well as into the Chilka Lake eco-system is severely limited by conditions as follows: reduced inlet cross section associated with lengthening of the inlet channel; extremely low tidal prism as compared to the volume of water in the lake; and the significant fresh water discharge into the lake during the monsoon season. The stability criteria based on the ratio of tidal prism and the annual littoral drift shows that the tidal inlet is hydraulically very poor. An artificial opening of a channel about 480 m in width dredged to a depth of 10 m is suggested in the paper to increase the tidal prism to about 1.5×10^6 m³. This will considerably improve the water exchange between the sea and the lake to maintain the lake eco-system.

ADDITIONAL INDEX WORDS: Bay of Bengal, littoral drift, limnology.

INTRODUCTION

A tidal inlet is a narrow waterway, connecting either a bay or lagoon with the ocean, which is maintained by the tide with its ebb and flood flows. The ecological ramifications of enhanced human activity and various engineering projects taking place along the lands bordering tidal inlets have long been drawing the attention of hydraulic engineers. (BROWN, 1928; BRUNN and GERRITSEN, 1960; CHAPMAN, 1923; EADS, 1971; ESCOFFIER, 1940; KEULEGAN, 1967; O'BRIEN, 1931; WATT, 1905; MEHTA and JOSHI, 1988; MACHEMEHL, HERBICH and Jo, 1991). Most of the tidal inlets of engineering importance are of littoral drift origin, where the littoral sediment transport determines the stability and dynamic equilibrium of the inlet. Stability of the inlet depends on the resultant state of the forcing parameters between the tidal prism, i.e., the amount of water flow into the inlet between two consecutive slack tides and the littoral drift across the mouth. The history of any inlet demonstrates a continuous change in its geometry by the variation in the length of the inlet channel and its configuration and the cross sec-

tional area of the gorge. Most of the inlets migrate in the direction of the predominant littoral drift. If the littoral drift is less and the tidal prism is relatively large, more breakthroughs may occur and inlets may remain open for a longer period. Consequently, if the littoral drift is large and the tidal prism is relatively small, inlets will be choked and short lived.

India has a long coastline of about 6,500 km. It mostly consists of sandy beaches with large littoral shore drifts. There are lagoons and lakes occurring behind barriers and spits. Largest among the lagoons is the Chilka Lake on the east coast of India with a lake surface area of 756 km² connecting to the Bay of Bengal. A large volume of littoral transport across the inlet mouth causes instability and migration of the inlet mouth in the down drift direction. It progressively reduces the inlet cross section causing reduction in the tidal prism. This natural inlet is becoming deteriorated and is causing great concern for the preservation of the eco-system of the entire body of brackish water in the lake. The present study discusses the geomorphological and hydrological characteristics of the inlet and investigates the feasibility of creating an artificial opening to improve the Chilka Lake and its ecosystem.

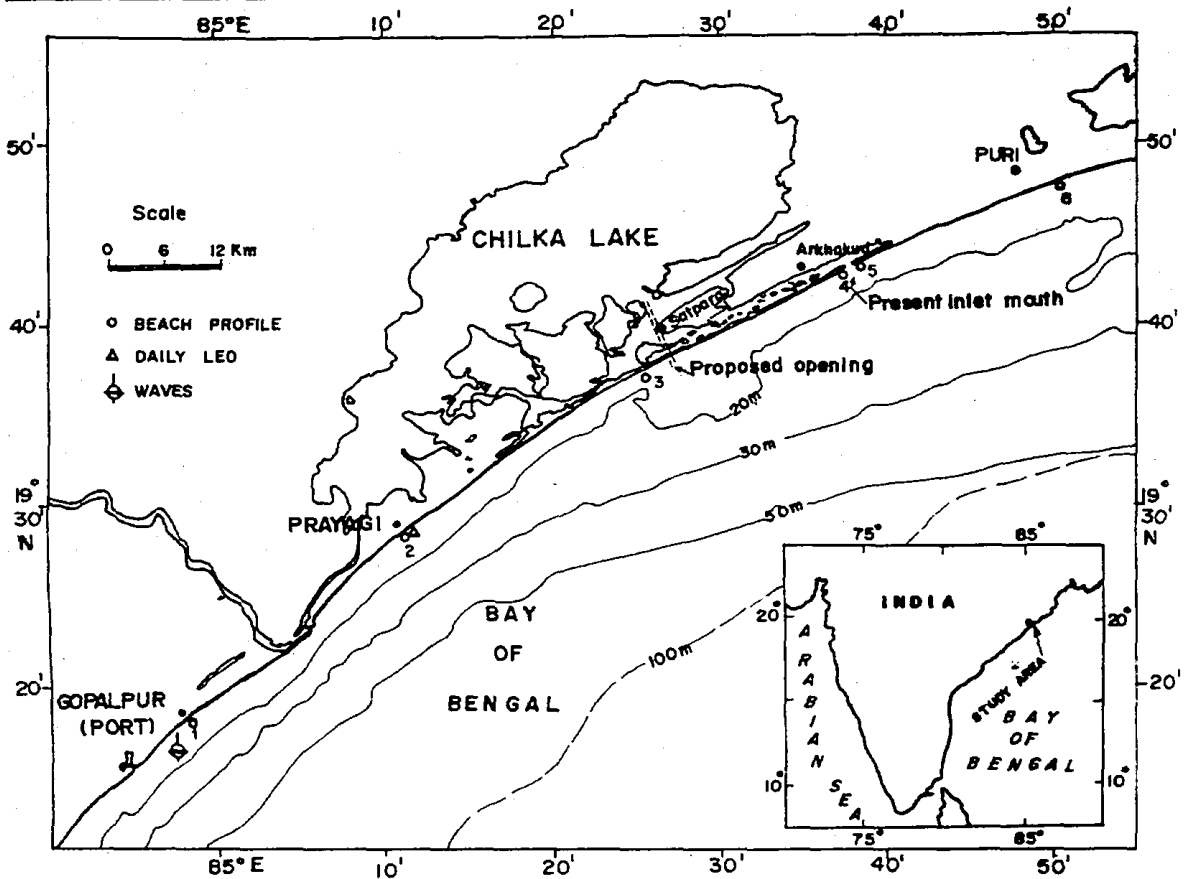


Figure 1. Location map.

STUDY AREA

The Chilka Lake is situated on the east coast of India at latitude $19^{\circ} 45'N$ and longitude $85^{\circ} 20'E$ (Figure 1). It is about 64 km long in NE-SW direction, with an average width of 13.5 km. The average depth of the lake is 1.3 m. The land on the northeast and east of the lake is low and plain. The bank on the north is marked by a rocky coast and islands that are surrounded by marshy land. Chilka Lake constitutes an embayment in the local shoreline. The formation of a large sand spit near the mouth could have led to the origin of this brackish water lake (AHMAD, 1972). Geomorphology of the region suggests that the earlier coast line was irregular, and the formation of spits at the lake mouth has resulted in the straightening of the coast. The existence of rocky islands and hills on the northwest bank of the lake suggests a case of local submergence in this region as compared to the local emergence in the northeast

region of the lake, where there is a regular, shallow and marshy shore receiving distributaries of the nearby Mahanadi River. During fair weather, the lake is relatively brackish owing to the inflow of salt water from the ocean during flood tide. The lake becomes relatively fresh during the southwest monsoon, due to high inflow of fresh water into the lake caused by high precipitation in the catchment area of the lake, resulting in the dilution of brackish lake water and flushing out into the ocean.

METHODS

The locations of various measurement stations established to evaluate the littoral environment are shown in Figure 1. A waverider buoy was deployed at 10 m water depth off Gopalpur Port, and the time series data on wave amplitude was recorded for 20 minute durations, every 3 hours from June 1990 to May 1991. Monthly beach pro-

files were measured at 6 stations along a transect from the backshore dune to 1 m water depth below low water. Daily, from June 1990 to May 1991, measurement on longshore current velocity and direction was made at Prayagi (stn. 2) by releasing the fluorescent dye tracer in the surfzone and noting the distance it travelled in 2 minutes. Sieve analysis was carried out for determining grain size distribution of the beach sediment collected close to the waterline. Numerical wave refraction analysis was carried out based on the procedure presented by SKOVGAARD, JONSSON and BERTELSEN (1975). Nearshore bathymetry for the refraction study was obtained from the Indian Naval Hydrographic Chart No. 353, published by the Naval Hydrographic Office, India.

The longshore sediment transport rates along the coastline near Chilka Lake were estimated using the Walton's equation (WALTON, 1980; WALTON and BRUNO, 1989),

$$Q = \frac{1,290\rho g H_b W v C_f}{\kappa(5\pi/2)(v/v_0)_{LH}} \quad (1)$$

where, Q = annual longshore sediment transport rate in $m^3/year$, ρ = mass density of sea water = $1,025 \text{ kg/m}^3$, g = acceleration due to gravity, H_b = significant breaking wave height in m, W = surf zone width in m, v = longshore current velocity in m/sec, C_f = coefficient of friction for bottom roughness = 0.01, κ = ratio of breaker height to breaking depth, and $(v/v_0)_{LH}$ = theoretical dimensionless longshore current velocity (LONGUET-HIGGINS, 1970; WALTON and BRUNO, 1989). The surfzone width and the longshore current speed and direction measured every day at Prayagi (stn. 2) were used in Equation 1 for estimating the sediment transport rates. The breaking wave heights were estimated from the significant wave heights computed from the wave rider data. Correction for wave shoaling and depth refraction effects (SHORE PROTECTION MANUAL, 1984) were applied.

The inlet configuration was mapped by triangulation survey, using one second Auto Theodolite. The cross section of the inlet mouth was measured using lead soundings. The current at the mouth was measured over a tidal cycle using the self recording S4 current meter in September 1990 and using drifters in February, March and April 1991.

For equilibrium inlets, KRISHNAMURTHY (1977) has given the following expression for estimating the tidal prism (P),

$$P = (2.5)(Wh_c)V_{fc} \times \int_0^{T/2} \left[\ln\left(\frac{10.93h_c}{k}\right) + \ln\left(1 + \frac{a_0}{h_c} \sin \sigma t\right) \right] dt + 2.5(Wh_c)V_{fc} \frac{a_0}{h_c} \times \int_0^{T/2} \left[(\sin \sigma t) \left(\ln \frac{10.93h_c}{k} + (\sin \sigma t) \ln\left(1 + \frac{a_0}{h_c} \sin \sigma t\right) \right) \right] dt \quad (2)$$

where, W = width of the cross section, h_c = depth of flow at mean sea level, V_{fc} = the friction velocity corresponding to critical shear stress = $\sqrt{\tau_0/\rho}$, τ_0 = critical shear stress of the bed material, ρ = mass density of seawater, κ = the bed roughness coefficient, a_0 = amplitude of the ocean tide, $\sigma = 2\pi/T$ = frequency of ocean tide, T = period of ocean tide, and t = time.

The measured cross section of the inlet mouth and the amplitude of the spring tide were used in Equation 2, and the tidal prism was estimated.

BRUNO and GERRITSEN (1960) proposed a criterion for determining the overall stability (S) of the entrance of the tidal inlet, based on the ratio of tidal prism (P) and annual gross longshore transport rate (Q),

$$S = P/Q \quad (3)$$

RESULTS AND DISCUSSION

The data on the morphodynamics of the coast and the hydraulics of the inlet highlight various factors leading to the poor performance of the Chilka tidal inlet and deterioration of the ecosystem.

Waves and Tides

The wave climate in the Bay of Bengal can be discussed under three characteristic seasons of the year, viz. southwest monsoon (June–September), northeast monsoon (October–January) and fair weather period (February–May). Based on the analysis of the wave data, the season wise distribution of the significant wave heights and the zero crossing wave periods are presented in Figure 2. The significant wave height varied between 0.5–2.2 m during June to September, 0.2–2.4 m during October to January, and 0.2–2.2 during February to May. The highest maximum wave

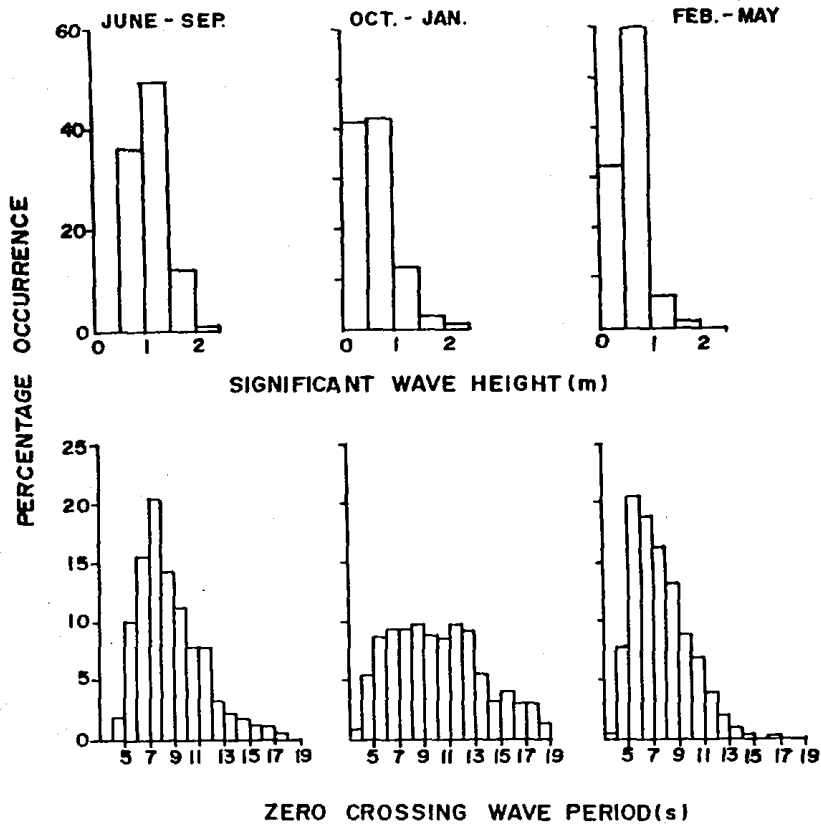


Figure 2. Seasonal variation of significant wave heights and zero crossing wave periods off Chilka Lake.

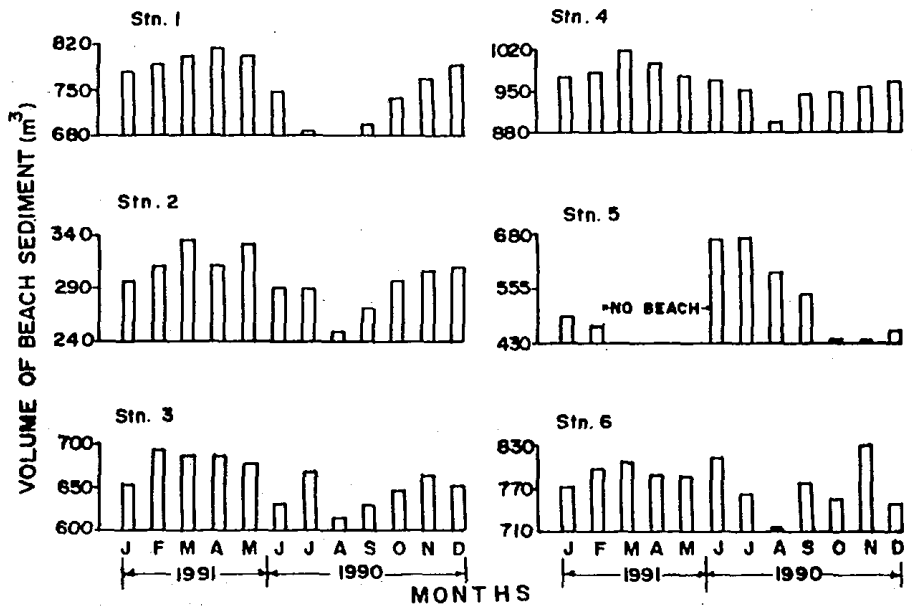


Figure 3. Monthly variation of beach sediment volume per metre length of the beach.

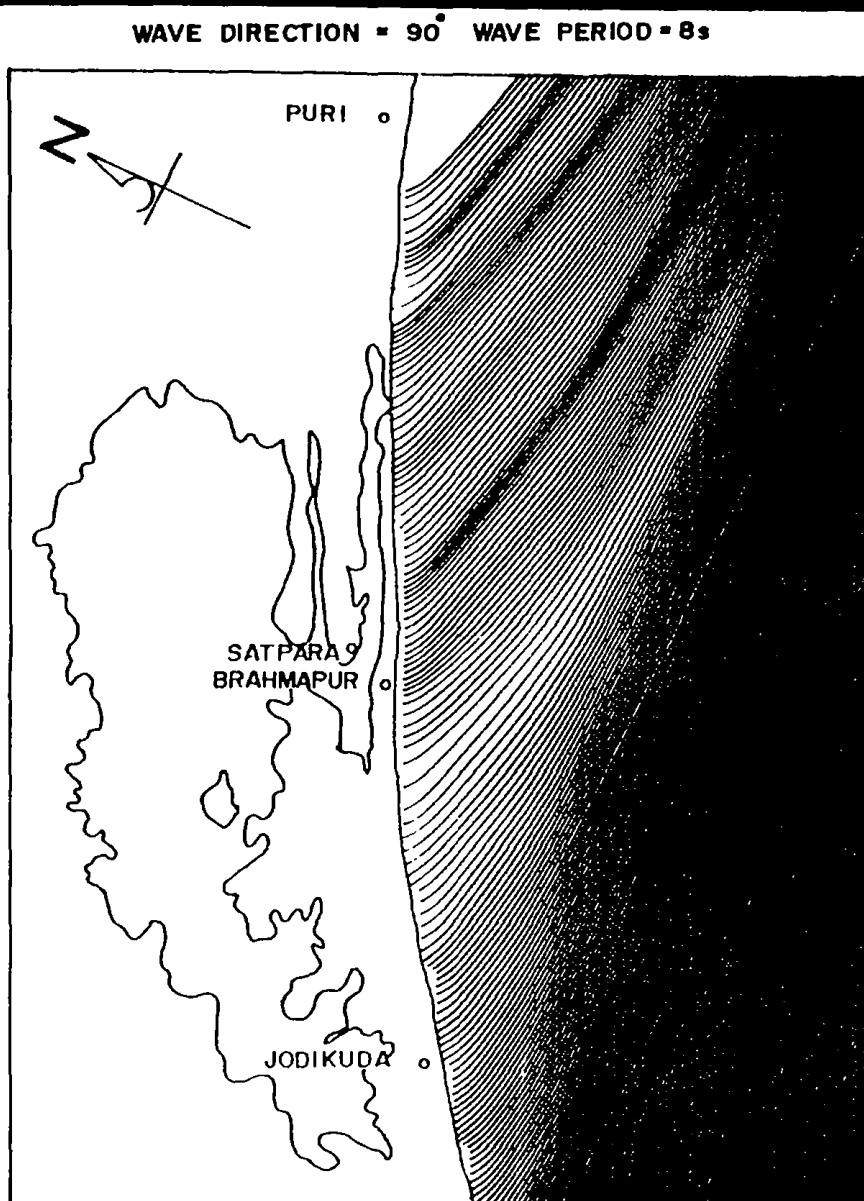


Figure 4. Wave refraction.

height of 3.8 m was measured in December. The zero-crossing period varied between 6–18 sec during June to September, 5–18 sec during October to January, and 4–15 sec during February to April. Based on the ship reported visual wave data compiled for the years 1968 to 1986, for the grid 15°–20° N latitude and 85°–90° E longitude, the predominant wave direction with respect to north varied between 210° and 230° from March to July, 170° and 200° from August to October, and 40°

and 90° from November to February (CHANDRAMOHAN, NAYAK and RAJU, 1989). The tides in this region are semidiurnal. Based on the predicted tide levels for the year 1990, the average spring and neap tidal ranges were 2.39 m and 0.85 m respectively.

Beach Processes

The relative changes in the volume of sediment per metre length of the beach as measured up to

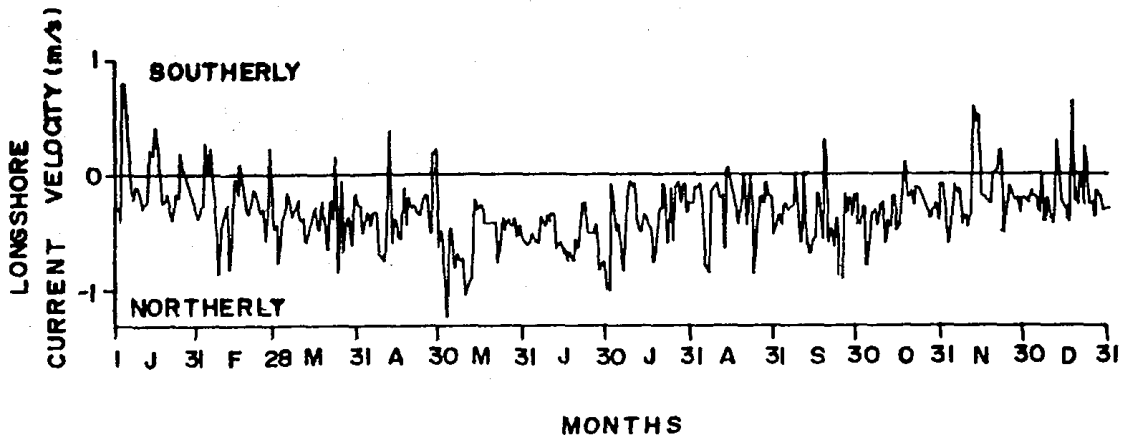


Figure 5. Daily variation of longshore current at Prayagi (stn. 2).

the lowest low water line are presented in Figure 3. Stns. 1, 2, 3, 4 and 6 had the lowest profile during the southwest monsoon. Stn. 5, which was about 500 m north of the inlet mouth in June 1990, was washed off in March 1991, due to the migration of the inlet mouth northward. Except near stn. 5, the entire stretch of the beach along the shore front of Chilka Lake was stable and recovered its original profile in annual process.

The refraction of wave diagram for waves approaching from the east is shown in Figure 4. It shows divergence of orthogonals near the inlet mouth and slight convergence along a small stretch on the northern and southern side of the entrance channel. The refraction of wave orthogonals for

the waves arriving from south and southeast indicates that the wave energy is uniformly distributed along the entire stretch of the shorefront.

The variation of longshore current velocity and direction measured at Prayagi (stn. 2) is shown in Figure 5. The longshore current was predominantly northward throughout the year. The longshore current velocity exceeded 0.8 m/sec in May and June, around 0.4 m sec⁻¹ in March, April, July and September and around 0.3 m sec⁻¹ during the other months of the year.

The median size (d_{50}) of the beach sediment near Prayagi (stn. 2) remained between 0.09–0.13 mm in January, February, November and December, 0.2–0.23 mm in March, May to July, Septem-

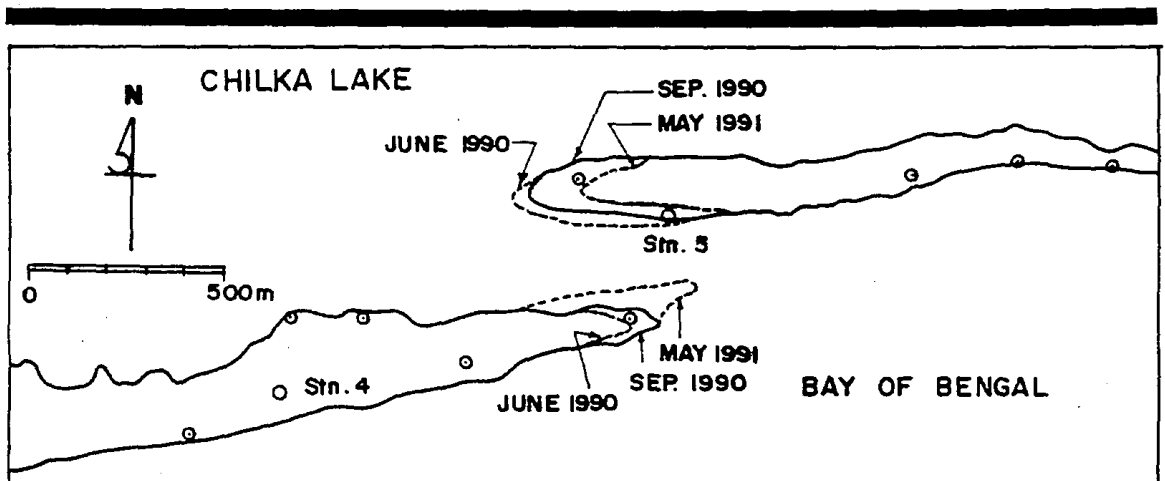


Figure 6. Configuration of the inlet mouth.

Table 1. Longshore sediment transport rate (m^3).

Month	Northerly	Southerly	Monthly Net (northerly)
Jan	7,269	5,929	1,339
Feb	10,501	1,181	9,320
Mar	24,860	353	24,507
Apr	66,840	9,843	56,997
May	197,596	1,237	196,359
Jun	206,965	3,314	203,651
Jul	140,055	3,392	136,663
Aug	96,621	2,920	93,701
Sep	81,045	4,102	76,943
Oct	62,664	1,710	60,954
Nov	29,031	8,322	20,709
Dec	19,115	12,731	6,384

Annual northerly transport = $942,562 m^3 yr^{-1}$

Annual southerly transport = $55,033 m^3 yr^{-1}$

Annual net transport = $887,529 m^3 yr^{-1}$ (northerly)

Annual gross transport = $997,595 m^3 yr^{-1}$

ber and October. It was more than 0.3 mm in April and August. In general, the sediment was relatively finer during fair weather and northeast monsoon periods and coarser during southwest monsoon periods.

The monthly longshore sediment transport rates estimated using Equation 1 are presented in Table 1. The sediment transport rate was relatively high exceeding $19 \times 10^4 m^3$ per month in May and June, and low showing less than $0.9 \times 10^4 m^3$ per month in December, January and February. The annual northerly transport was $0.94 \times 10^6 m^3 yr^{-1}$ and southerly transport was $0.06 \times 10^6 m^3 yr^{-1}$, with an annual gross longshore sediment transport rate of $1 \times 10^6 m^3 yr^{-1}$ and net northerly transport rate of $0.88 \times 10^6 m^3 yr^{-1}$. The longshore sediment transport was predominantly northward throughout the year along the shorefront of the Chilka Lake.

Inlet Hydraulics

No historical data on the rate of migration of the mouth is available. Based on visual observations, it was reported that the mouth is not stable and is progressively migrating towards the north. The positions of the inlet mouth mapped during June 1990, September 1990 and May 1991 are shown in Figure 6. During the period of study, the inlet mouth has migrated about 500 m northward. It was, however, felt that the rate of migration was not the same every year. Based on the opinion of the local residents, the migration rate recorded during the study period appears to be on the higher side. The major shifting of the

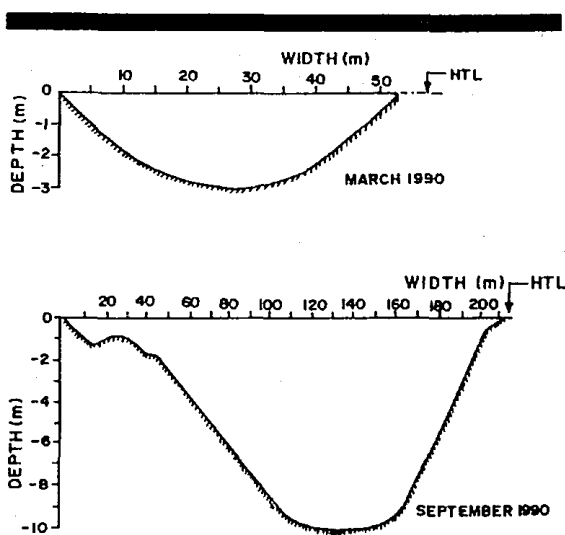


Figure 7. The cross section of the inlet mouth.

inlet mouth takes place during June to October, when the fresh water flow from the lake to the ocean and the northward littoral drift rate is high. The inlet mouth remains relatively stationary during the rest of the year.

The cross sections of the entrance channel measured in March 1990 and September 1990 are shown in Figure 7. In March 1990, the cross section was small and nearly parabolic with a surface width about 55 m and a maximum depth of 3 m at the centre during the high tide level. A relatively large cross section was observed in September 1990, when there was a heavy discharge of fresh water flow from the lake to the ocean. The channel cross section was nearly trapezoidal with the surface width of about 220 m and a maximum depth of 10 m. The large discharge of the fresh water from the lake flushes out part of the choked up sediment at the mouth and increases the cross sectional area for draining out the rain water.

The currents measured in September 1990, using a self recording current meter, at mid depth near the inlet mouth over a tidal cycle is presented in Figure 8. The current was unidirectional flowing from the lake to the ocean with the average velocity of $0.96 m sec^{-1}$ at the mouth. No significant variation in current velocity was observed with the tide arising from high fresh water discharge into the lake due to precipitation in the catchment area. The current measurements carried out using drifters at the gorge section of the entrance channel in February, March and April

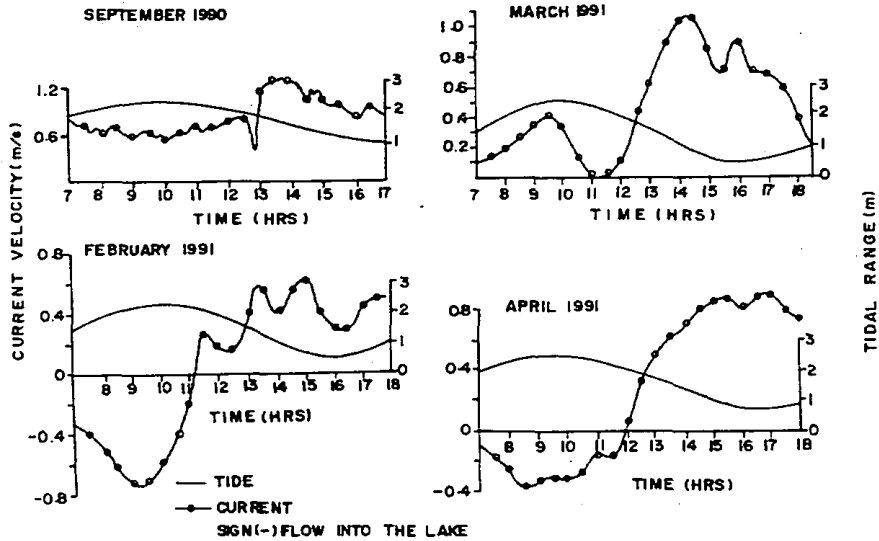


Figure 8. Variation of current over a tidal cycle at the inlet mouth.

1991 are presented in Figure 8. In February, the flow velocities reversed their direction with tides, showing a maximum flood current of 0.75 m sec^{-1} towards the lake and ebb current of 0.62 m sec^{-1} towards the ocean. In March, the reversal of current direction was not observed with tide, but the magnitude of flow velocities changed with tide. Maximum ebb current velocity of 1.08 m sec^{-1} was observed. In April, the reversal of current direction was observed with tide, showing the maximum flood current velocity of 0.3 m sec^{-1} and ebb current velocity of 0.88 m sec^{-1} . The reduced inlet cross section associated with low flood tidal current limits greatly the inflow of sea-water into the lake.

Inlet Stability

The current was unidirectional during the monsoon from June to October, flowing from the lake to the ocean. Using the cross section and the current pattern measured at the inlet mouth in September 1990, and assuming the velocity distribution for the uniform trapezoidal channel (VEN TE CHOW, 1973), the average fresh water discharge over a tidal cycle is estimated $978 \times 10^6 \text{ m}^3 \text{ sec}^{-1}$. Hence, approximate discharge due to the monsoon from July to October is estimated to be $1.28 \times 10^{16} \text{ m}^3$. As there is no tidal inflow into the bay, the tidal prism during July to October is absent.

Using the cross section of the inlet entrance measured in March 1990 in Equation 2, the tidal prism is estimated as $0.78 \times 10^6 \text{ m}^3$ during the non-monsoon period from December to May. November and June are the months of transition period during which the tidal prism changes from monsoon to non-monsoon conditions. The order of magnitude of tidal prism compared with the volume of water in the lake ($\approx 1 \times 10^9 \text{ m}^3$), shows negligible flow of sea water over a tidal cycle. The low tidal prism indicates that the flood flow from the sea is confined within the 21 km long channel connecting the lake with the ocean.

Using the estimated annual gross longshore sediment transport rate and the tidal prism in Equation 3, the stability ratio of the tidal inlet is given by,

$$S = 0.78 \times 10^6 / 1 \times 10^9 = 0.78.$$

The classification of the tidal inlets (BRUNN and GERRITSEN, 1960) based on this stability ratio (Figure 9) infers that the stability condition of the Chilka Lake inlet is very poor.

Improvement of the Inlet

The possibility of an artificial opening of the mouth protected by groins on either side of the channel is proposed close to Satpara (Figure 1). Though this may considerably reduce the existing channel length and increase the tidal flow into the

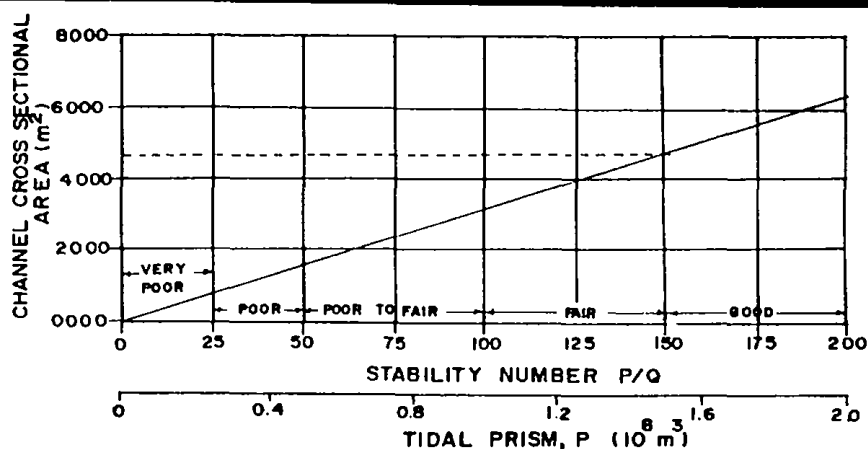


Figure 9. The required cross sectional area for various tidal prisms for the annual gross littoral drift of $1 \times 10^6 \text{ m}^3$.

lake, the impact of such exercise on the eco-system is yet to be assessed. Groins have to be oriented in such a way as to bypass the littoral drift across the channel with minimum of deposition at the inlet mouth.

The stability of the inlet can be enhanced either by increasing the tidal prism or by controlling the longshore sediment transport across the inlet (BRUNN, 1978). For the prevailing annual gross longshore sediment transport rate of $1 \times 10^6 \text{ m}^3$, to achieve various stability criteria, the required cross sectional area of the inlet channel is presented in Figure 9. In order to obtain good stable condition with a stability number of 150, the estimated tidal prism would be $1.5 \times 10^6 \text{ m}^3$. Referring to Figure 9 and proposing the channel would be dredged to 10 m depth, a channel width of 480 m would be required to generate the required tidal prism. The proposed channel section of $480 \text{ m} \times 10 \text{ m}$ has to be dredged for 10 km length, to connect the main bay of the lake and the ocean (Figure 1). In this case, the improved tidal prism would form one sixth of the volume of Chilka Lake which could accelerate the exchange of water between the lake and the sea and improve the flow circulation in the lake.

CONCLUSION

The east coast of India is subjected to variable wave climate, showing the longshore sediment transport towards north during March to October and south during November to January. Further, the annual longshore transport rate is observed

to increase northward along the east coast of India (SAXENA, VAIDYARAMAN and SRINIVASAN, 1976). The Chilka Lake is situated almost on the northern end of the Bay of Bengal and the waves approaching from north are limited. The data on daily littoral current observation showed that the longshore sediment transport is northward throughout the year along the shorefront of the Chilka Lake. The major rivers *viz.*, Krishna, Godavari, and Mahanadi, supply a large quantity of sediment in this region. The fresh water discharge during the southwest monsoon flushes out the part of the sediment deposited in the inlet mouth. The migration rate of the inlet mouth is higher during the southwest monsoon period. In the fair weather season, the inlet mouth gets silted up since the tidal prism becomes very low. The length of the connecting channel between the sea and the lake is too long, about 21 km, and the hydraulic head loss due to the frictional effects causes further reduction in the flood flow into the lake. An artificial cut near Satpara as suggested here would increase the tidal prism considerably to improve the eco-system of the Chilka Lake, provided the cut could be maintained. It would be equally important to investigate the behaviour of the proposed cut, its effect on the environment, the problem of maintaining the opening by constructing suitable jetties, bypassing requirements, prevention of siltation in the inlet channel, etc.

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