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INLAND DELTA BUILDING ACTIVITY OF KOSI RIVER

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INTRODUCTION

The Kosi River is known as the river of sorrow of north Bihar. After the Indus and Brahmaputra Rivers, the third largest rivers emptying from the Himalayas, the Kosi has shifted from east to west over 70 miles in the last 200 years, spreading devastation and laying an area of approximately 3,000 sq miles bare with sand deposits.

GENERAL FEATURES[3]

The Kosi (known as Kaushiki in Sanskrit literature) rises in Tibet at a height of approximately 18,000 ft, and after traversing through Nepal and India for about 450 miles, it joins the Ganga River near Kursela. The three major streams of the Kosi River are the Sun Kosi, Arun, and Tamur, which unite together at Tribeni. The river above Tribeni, and for about seven miles downstream, flows in a deep gorge in the Himalayas until it empties into the Gangetic plain at Chatra. The river below Chatra builds up its plain by dividing into several channels spread over a width varying from 4 to 10 miles. Entering the plain, the Kosi is joined by a number of major tributaries, viz., the Trijuga, Balan, Kamala, and Bagmati (Fig. 1).

The Kosi River is notorious for its capricious nature. It carries with it an enormous load of sand which it is unable to transport and unload into the main drainage channel, the Ganga River. The Kosi, therefore, deposits huge quantities of sand. In the process of building up an inland delta, it has shifted over 70 miles from east to west during the period from 1736 to 1964 (Fig. 2). In

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3 Mookerjea, D., and Aich, B. N., "Sedimentation in the Kosi—A Unique Problem," Journal of the Institution of Engineers, India, January, 1963, pp. 187–198.

this movement, about 3,000 sq miles of land in Bihar and approximately 500 sq miles in Nepal have been laid waste as a result of sand deposition. In the course of shifting, many towns and villages are wiped out and heavy losses of property, cattle, and even human life are inflicted. The annual average damage and loss is estimated to be between 50 to 100 million rupees.

HYDROLOGY

The Kosi drains a catchment basin of approximately 22,888 sq miles. The three major tributaries, the Sun Kosi, the Arun, and the Tamur (shown in Fig. 1) divide the watershed in the proportion of 32%, 58%, and 10%, with an average rain fall of 62 in., 50 in., and 65 in., respectively.

The annual total run-off measured at Barakshetra, in the Himalayan Gorge, averages to 43 million acre-ft of which 81% is contributed from June to Octo-

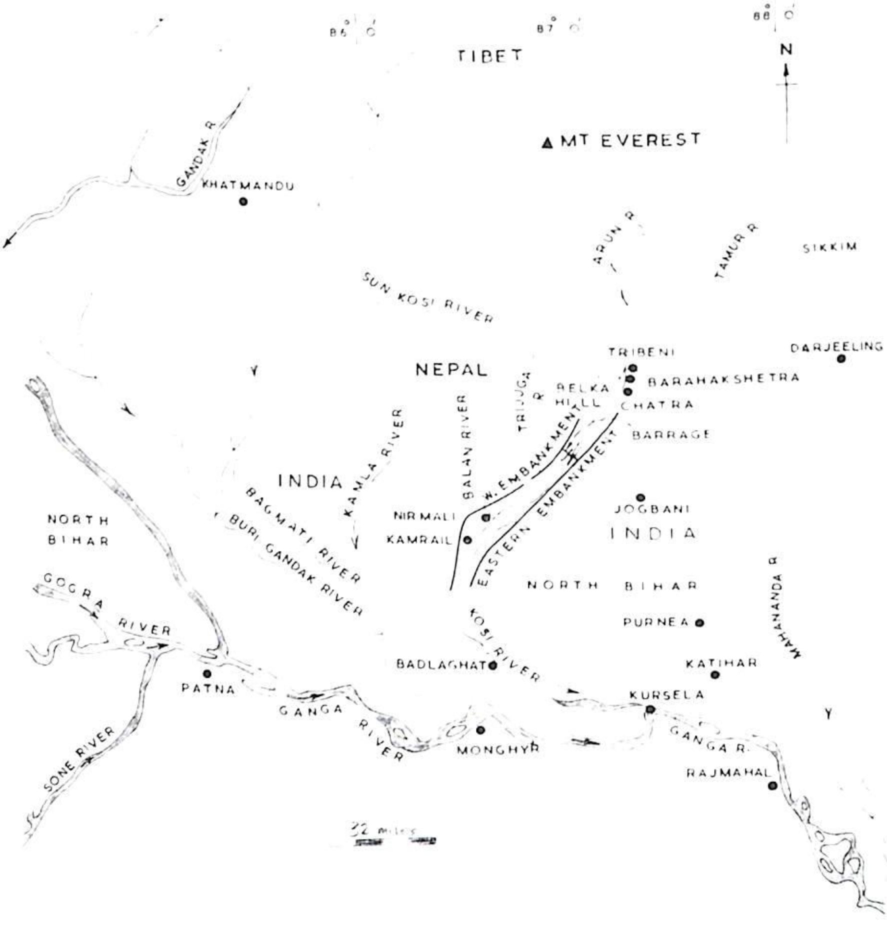

FIG. 1.—KOSI RIVER BASIN

ber. The annual maximum discharge occurs from the middle of July to the end of September and varies from 0.2 million cfs to 0.86 million cfs. The Kosi River is subject to sudden spate, sometimes rising over 30 ft in 24 hr in the Himalayan Gorge.

SEDIMENT LOAD AND SHIFTING OF THE RIVER

Average annual sediment load of the Kosi at Tribeni is 19,000, 28,000, and 49,000 acre-ft of coarse (0.6 mm to 0.2 mm), medium (0.2 mm to 0.075 mm) and fine (below 0.075 mm) sediment respectively. This gives respective concentration of 0.04%, 0.07%, and 0.14% of the average run off and 0.24% for

TABLE 1.—SEDIMENT CHARACTERISTICS OF THE KOSI COMPARED WITH OTHER RIVERS

S. No (1)	Item (2)	Kosi at Barahshetra (3)	Mahanadi at Hira-Kud (4)	Sutlej at Bhakra Dam (5)	Colorado at Hoover Dam (6)	Nile at Aswan Dam (7)
1.	Catchment area, in square miles	22,800	32,200	21,960	167,000	620,000
2.	Average annual rainfall, in inches	60	65.6	45	10	-
3.	Average annual run-off, in million acre-feet	42.73	34.47	16	10.5	66
4.	Average annual silt load, in acre-feet	96,000	25,587	19,600	137,000	52,872
5.	Average annual silt yield in acre-feet per 100 sq miles of catchment	336	89	90	82	8.5
6.	Average annual silt concentration as percentage of runoff	0.21	0.083	0.112	0.91	0.08

three grades together—the maximum observed being 0.47% for the unprecedented high flood of 0.86 million cfs, in 1954. Of the total sediment load, approximately 50% is contributed by the Sun Kosi and 25% each by the Arun and Tamur. The sediment data of Kosi in comparison with a few other rivers is given in Table 1.

There are several reasons for the heavy contribution of silt in the Kosi River. Geologically, the river is very old, while the mountain through which it is passing is very young. The uplift and the gradual building of the Himalayas continued for a very long period. During the process of uplift, folding, and faulting the rivers—although maintaining their original course—flowed with increased gradient, causing side and bed erosion all along their courses. In the outer valley—also as a result of this deep cutting—sides have become

TABLE 2.—KOSI RIVER DATA

S. No.	Station	Reach	Distance, in miles	Average % to corresponding values at Barakhetra of suspended sediment				HFL, in feet	HFL slope, in feet per mile	Bed level, in feet	Bed slopes, in, feet per mile
				Coarse	Medium	Fine	Total				
1	Chatra	A	0	109	95	11.5	109	361.50		335.19	
2	Galpharia	B	11	98.5	93.5	127.5	111		5.00		4.70
3	Kausaha		21	91	100	155	123.5				
4	Raniganj	C	26					232.10		213.51	
5	Hanumannagar		32	83	100	170	141.5		2.62		2.20
6	Bhaptiahi	D	46					186.93	1.13	169.92	1.0
7	Saupaul		71					158.72		145.23	
8	Karhara		77	22	79.5	107.5	96.5		0.66		1.20
9	Dhamra Ghat	E	131					118.94		64.24	
10	Basua		148	4	17.5	55	27.5		0.17		0.12
11	Nangachia	F	184					109.42	0.39	56.40	0.30
12	Kursela		198	2	9	42	24	104.02		36.50	

steep causing frequent land slides. In addition, frequent seismic disturbances have caused further loosening and disintegration of the already shattered rock in this region. Because of the absence of a flat valley in the upper catchment of the Kosi River, the entire sediment load is carried lower down. After emptying from the Himalayas into the Gangetic Plain, the sediment is gradually deposited. The sediment concentration at various sites in the Plain, in relation to that at Barakhshetra in the Gorge, is indicated in Table 2.

It would be seen that the bulk of the coarse and medium sediments deposit in reaches D and E, respectively. Medium and fine sediment increases between Chatra and Hanumannagar as a result of bank erosion along the Belka hill face. The sudden flattening of the slope in reaches below Hanumannagar leads to the deposition of sediment.

With gradual flattening of the slope, sorting of bed material takes place. At Chatra, the river is in a boulder stage. The bed load consisting of boulders, pebbles, and shingles generally gets deposited in reaches A, B, and C; the coarser pebbles and shingles rarely go below Belka, 9-1/2 miles from Chatra. The lighter shingle is deposited down at Hanumannagar. Beyond Kamrail, the coarse material practically disappears. The bed material is composed of medium and fine grades of sediment and clay.

The Kosi River starts widening immediately downstream of Chatra, which is a characteristic feature of the boulder stage. Braiding is, however, conspicuous from Belka downstream wherein interlacing channels are spread over a width of approximately 4 miles. At Belka, the bed fall changes from 5 to 3.2 ft per mile. For about 10 to 20 miles below Hanumannagar, the river exhibits a stable pattern. As a result of flattening of slope from 2 ft per mile to 1 ft per mile below this reach, the river divides into several channels occupying a width of as many as 10 miles or so. Further downstream, channels unite and beyond Badlaghat the river flows in one or two defined channels.

The features noted in Table 2 are characteristic of inland delta building activity. In the process, the river has been shifting from east to west, over a wide area between Mahananda river on the east and Balan river on the west. It is believed that the Kosi River originally joined the Mahananda River.[4] The survey of 1731 reveals that the river was flowing West of Purnea, while at present it is flowing along Nirmali—a distance of approximately 70 miles having been travelled in about 230 years (see Fig. 2). After shifting, it leaves destruction and devastation in its wake, ruining towns and villages, covering agricultural land with sand, turning wide depressions into marshy land as a result of high water tables, thus making the countryside uninhabitable and unhygenic.

THE KOSI PROJECT

In order to provide relief to the areas affected by the river in North Bihar and Nepal the Kosi project was undertaken (Fig. 1). The project consists of (1) the construction of levees on both the banks to confine spills that formerly spread far beyond and (2) the construction of a barrage (gated structure) near Hanumannagar which could raise the highest flood level (in stages) by about 8 ft and provide annual irrigation of 2.6 million acres and power generation of about 20,000 kw. The work of constructing 150 miles of levees, which were

[4] Krishnan, M. S., "Geology of India and Burma," 4th Edition, 1960, p. 30.

begun in 1955, was completed by 1959 and the river was diverted through the barrage in 1963. The barrage at present has a pond of 10 ft which may be gradually raised to 20 ft in the future to avoid drastic changes caused by the deposition of sand in the upper reaches. With comparatively sediment-free water downstream of the barrage, the river channel downstream would scour. The existing measures may be shortlived and for effective control of the river, it would be necessary to adopt soil conservation measures and to construct

FIG. 2.—SHIFTING COURSES OF THE KOSI RIVER

storage reservoirs. Obviously, the future of the Kosi project would depend on timely action to assure the safety of the various components of the over-all scheme; such action would stem from the intimate knowledge of the river behavior and the ability to foresee possible river changes. Recently, in 1963, the western flood embankment (about 8 miles downstream of the barrage) breached over a length of about 4,000 ft, emphasizing the necessity of the early prediction of likely changes in the river regime both upstream and downstream of the barrage. This would be possible only with proper understanding of the causes of shifting courses and of the processes associated with the delta building activity.

CAUSES OF SHIFTING COURSES OF KOSI RIVER

In the past, the Kosi problem engaged the attention of many investigators. Their findings are mostly contained in departmental records and not published. Among them, Shillingfield (1893), in referring to the Kosi oscillations, opined that in contradiction to the slow western movement, the eastward movement would take place in one great sweep. Sir Claude Inglis attributed the shift to the natural east-west slope of the country and the excessive sand load carried

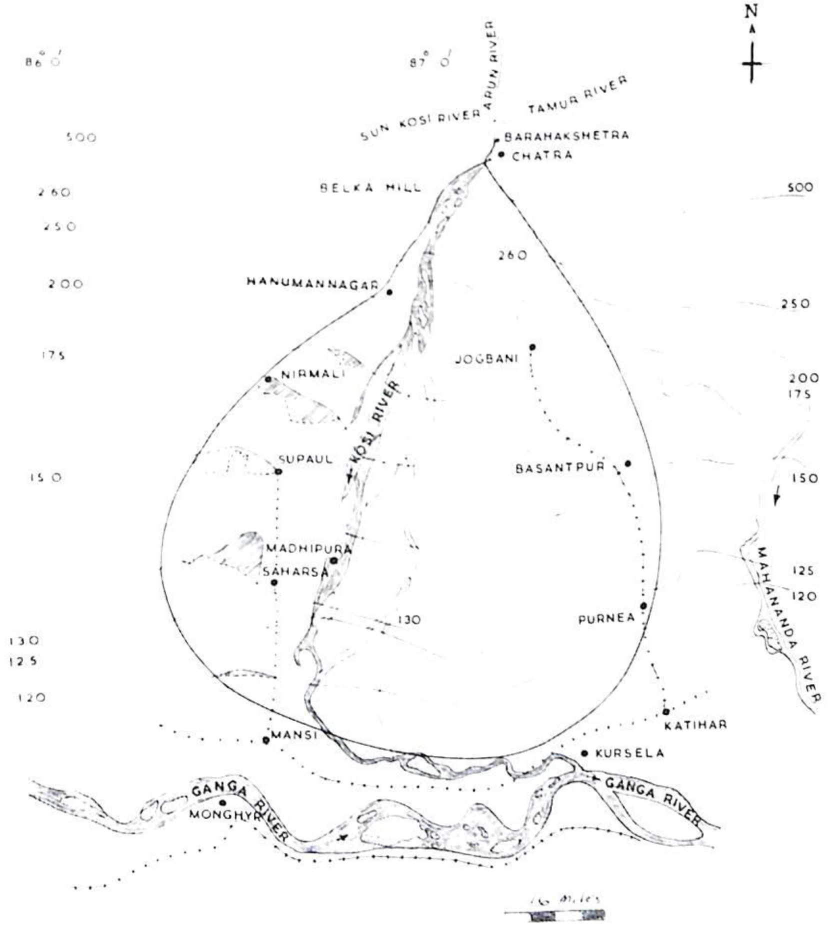

FIG. 3.—CONTOUR PLAN OF KOSI BASIN PREPARED FROM 1926-1938 SURVEY

by the river. M. P. Mathrani considered the undeveloped topography and the friable nature of rocky formations in the Kosi Gorge as the principal causes of Kosi trouble. Mathrani suggested a study to seek reasons why the Kosi basin has not completely filled, despite the short distance from Chatra to its outfall in the Ganga. Leopold and Maddock (1954) considering Kosi behavior, stated that a braided stream will tend to shift laterally at a rate dependent on the rate of accumulation of material being deposited. As one course becomes

TABLE 3.—QUANTITY OF SEDIMENT DEPOSITS ON KOSI BASIN BETWEEN 1938 AND 1957

Location	Thickness of Deposits, in feet		Width of Deposits, in miles		Length in between the contour lines	Deposits, in acre feet
	On the contour line	In between the contour lines	On the contour line	In between the contour lines		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		.5		2	7	4,480
On 120 contour	1		4			
		2		7	14	125,000
On 130 contour	3		10			
		4		12	14	430,000
On 150 contour	5		14			
		5.5		15	14	740,000
On 175 contour	6		16			
		4		11	10	282,000
On 200 contour	2		6			
		1		3	5	9,600
Total in 19 years						1,591,080
Per year						83,500

higher than possible adjacent paths, the river would shift. No other explanation for the observed shift of the Kosi was considered necessary, although the continued movement in one direction during the period of oscillation was felt by them to be somewhat surprising.

In order to understand the process of the shifting courses of the river and the delta building activity, a topographic plan of 1926-1938 was prepared by the writers for the Kosi basin, bounded by Mahananda River on the east and Balan River on the west (Fig. 3). The base plane on which the Kosi delta is being built has a slope from north to south, and west to east. On this plane, the Kosi is building a conical delta with contours running almost circumferentially with the center situated in the vicinity of Belka Hill. The toe line of the Kosi Delta could easily be demarcated in Fig. 3, by comparing the contours of the base plane with those of the Kosi Delta, which rest on it. On the east, the delta appears to extend a little east of Katihar-Jogbani railway line, beyond which the area is occupied by the Mahananda valley. On the west, westernmost Kosi channel of the present river course is running almost along the other edge of the cone.

In the process of building up the land, the Kosi River moved westward to Madhipura by 1938, and the cone between the easternmost limit and the Mansi-Saharsa railway line was fully developed by then. Further west the contours show a sudden depression indicating the part of the cone to be built next after 1938. This remaining part of the cone was occupied by the Kosi by 1957, and the land was partly raised by sediment deposition resulting in partial smoothening of the 1938 contour lines. The thickness of sand deposition after the Kosi has passed over a part of the cone could be gaged from the pattern of the contours. The maximum thickness appears to be on the order of 6 ft in the middle reach in between the contours of 150 and 175 (Fig. 3). Knowing the thickness of sediment deposition and the part of the cone over which deposition has occurred during the period 1938 to 1957, the total quantity of sediment deposit works out to 1.6 million acre-ft in 19 yr, i.e., .083 million acre-ft per yr (Table 3).

Annual sediment deposition could also be estimated approximately from the sediment observations made along the river. Average sediment concentration at Hanumannagar and Kursela was observed to be 1.42 and 0.24 times that at Barakhetra, respectively (Table 2). Average annual sediment load at Barakhetra worked out from observations extending over a period 1948 to 1959 is 87,000 acre-ft.[5] Annual sediment deposition, therefore, works out to 87,000 (1.42-0.24) = 103,000 acre-ft. It may be noted that the increase in load of 42% in the reach from Barakhetra down to Hanumannagar is confined to fine material resulting mostly from erosion of Belka Hill face. Because rapid erosion of Belka Hill is known to have occurred only in recent years, the addition of fine material due to this cause at the time of 1938 survey is expected to have been much smaller if at all. The absence of fine sediment load in the earlier years could be allowed for by assuming that the concentration of fines does not appreciably increase beyond Chatra which is about 8 miles upstream of Belka Hill. The annual sediment deposition would then be 87,000 (1.21 - 0.24) = 84,500 acre-ft, which is close to the figure of 83,500 acre-ft per yr obtained previously (Table 3) from contour development.

The course the river has occupied in various years, as related to the delta cone, reveals that the river has a tendency to flow almost straight radially from the apex down to the toe of the delta, spreading out channels confined within approximately 10° of the apex angle. After reaching the base of the cone, the river flows along the toe line of the delta cone which provides the steepest bed gradient until it meets the main drainage channel, viz., the Ganga. Obviously, the bed slope of the Kosi on the delta cone would be steep. After reaching the base plane the river slope would be guided by the slope of this plane along the toe line and would be much flatter. Although gage data at a site located at the junction point of cone with base plane are not available, the slope over the cone near its base is roughly 1.2 ft per mile, while over the base plane it is 0.12 ft per mile.

On the east of the north-south line, passing through Chatra and Kursela, various old river channels—after reaching the base plane—occupied the

[5] Mookerjea, D., "The Kosi—A Challenge in River Control," Journal of the Institution of Engineers, Calcutta, India, November, 1961, p. 125.

courses permitting the shortest distance the outfall in the Ganga. On the west of the north-south line, the river—on reaching the base plane—was, however, required to flow along the toe line of the delta as it provided the most favorable slope. This is the reason why the behavior of the river, after meeting the base plane, has been different on either side of the north-south line.

The progressive movement of the river from one end of the delta towards the other could also be visualized with the help of the contour plan in Fig. 3. As stated above, any one course of the river occupied a part of the cone with an apex angle of approximately 10°. After deposits were formed where the river slope was deficient for carrying material further down, the adjoining part of the cone remained low, inviting the river to shift towards the low ground. This shifting was neither very systematic nor regular. However, the general pattern was the same. Out of the several flowing channels, only a few channels at a time carry major discharge. When these channels get silted up and their beds are raised adjoining channels carry more discharge

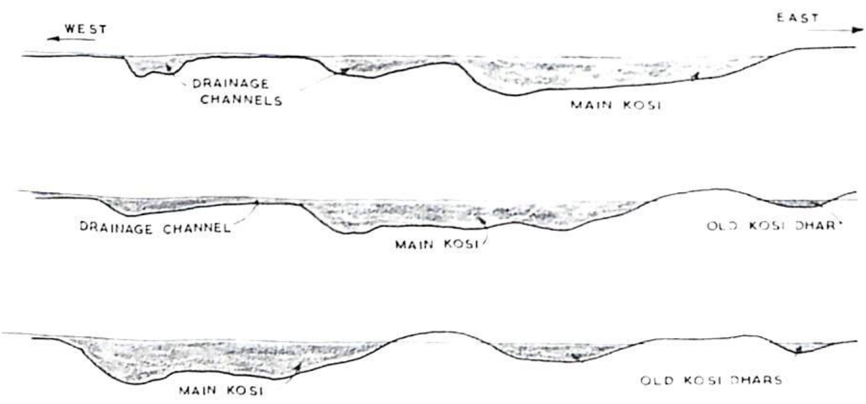

FIG. 4.—SCHEMATICAL REPRESENTATION OF PROCESS OF SHIFTING OF KOSI RIVER FROM EAST TO WEST

and, in turn, become the major channels. Thus in the progressive shift of the river from east to west, the major channels existing at any one time slowly went on dying, while channels further west progressively opened out. This movement and progressive shift in the river course is schematically shown along a circumferential line of the delta in Fig. 4.

The radial distance of the river from the apex to the base plane is maximum on the longitude of 87° (Fig. 3). Because of the slope of the base plane from north to south, the length of the river on the face of the cone from apex down to toe line progressively goes on reducing both on the east and west of the 87° longitude. The area available for the river to deposit excess load of sediment before it swings on the adjoining low level area of the delta is, therefore, maximum along the course running along longitude 87°. The river should accordingly be expected to take longer period to build up part of the cone along longitude 87° while towards the eastern and western edges of the cone shifting may be expected to be at a comparatively faster rate. This explains why the river was known to be more stable when it occupied the course mostly north-south in the period 1807 to 1879. The rate of shift of the river as it moved further away from the north-south line through the apex of the cone was, on the contrary, faster, as borne out by past data (see Table 4).

The rate of movement of the river could be estimated also by an independent approach. Cone formation of Kosi Delta is seen to be more or less perfect, as indicated by regular circumferential contours. The rate of shift of the river being the same as that of cone building, it could therefore be worked out be ascertaining the cubic contents of sediment deposition in different parts of the cone. Thickness of deposits on different contours were adopted from Table 3 while the surface area in successive parts of the cone for every 10° apex angle were worked out from contour plan of the basin in Fig. 3. The toe line of the delta was delineated previously in Fig. 3. The cubic contents worked out from the above data are given in Column 2 of Table 5. The rate of shift could

TABLE 4.—APPROXIMATE RATE OF MOVEMENT OF THE KOSI SINCE 1736 MEASURED ON A LINE PASSING THROUGH BHELHI AND PURNEA

Year	Period of movement, in years	Distance moved, in miles	Distance moved, in miles per year	Remarks
1736-1770	34	6.7	0.2	(see Fig. 2)
1770-1823	53	5.8	0.1	
1823-1856	33	3.8	0.1	
1856-1883	27	8.0	0.3	Direct course from Chatra to Kursela
1883-1907	24	11.5	0.5	
1907-1922	15	6.8	0.45	
1922-1933	11	18.0	1.60	
1933-1950	17	11.0	0.65	

then be estimated, knowing the annual quantity of sediment deposition which was adopted (see Column 3, Table 5).

It would be seen that the predicted rate of shift of the river in the area of the delta occupied in more recent times compares fairly well with the actual rate. For instance, the estimated rate for the period after 1926 varies between 0.82 and 1.7 miles per yr while, observed rate varied between 1.6 and 0.65 miles per yr. The predicted rate of shift in distant past is, however, considerably higher than observed. Computed rates of approximately 1900, 1800, and 1750 are 0.82, 0.82, and 0.92 miles per yr, although observed rates were 0.5, 0.1, and 0.2 miles per yr. It is contended that this disparity is attributable to the smaller rate of sediment production on the watershed in olden times. Because of deforestation and intensive land use in the Kosi catchment, sediment yield has increased in more recent years. The rate of annual deposition based on present day observations of sediment concentration is therefore not applicable in computations of cone building activity in the remote past. Observed rates of movement indicate that sediment yield has recently increased by 4 to 5 times. This feature is alarming and emphasizes the need for implementation of a rigorous soil conservation program.

From Fig. 1, the river Ganga is seen to take a sudden turn southward near Rajmahal. Upstream of this, the river is flowing from west to east. On the north, the Kosi Delta would prevent the Ganga from moving towards north, while on the south the Monghyr, Santhal Paragana, and Rajmahal hills prevent the southward movement of Ganga. South of Kosi delta the present position of the Ganga river is thus fixed. If Kosi is left to itself, the delta building process would continue and the river would shift from east to west and back to east, and so on, over the cone. One such sweep of the river from east to west has been found to take a period of about 200 yr. With an increased rate of sediment

TABLE 5.—RATE OF MOVEMENT OF THE KOSI

Cone part starting from eastern edge (1)	Cubic contents, in acre-feet (2)	Sediment deposition, in acre-feet per year assumed[a] (3)	Years required to complete deposition (4)	Estimated rate of movement along contour line of 130 (i.e., circumferential distance of 11 miles per 10° apex angle) in miles per year (5)	Year in which the Kosi occupied this position of the delta cone (6)
0° -10°	6,86,000	66000	10.4	1.06	-
10° -20°	7,86,000	66000	12.0	0.92	1731
20° -30°	8,55,000	66000	13.0	0.85	1770
30° -40°	8,92,000	66000	13.5	0.82	1807-39
40° -50°	8,92,000	66000	13.5	0.82	1839-73
50° -60°	8,92,000	66000	13.5	0.82	1892-1921
60° -70°	8,55,000	66000	13.5	0.82	1926-36,26-48
70° -80°	6,86,000	84500	8.11	1.4	1950
80° -90°	5,66,000	84500	6.7	1.7	1964

[a] Sediment deposition in the distant past is assumed to be equal to the total load brought down at Barkhetra less that carried into the Ganga. Because the river was away from Belka hill, the contribution of fine sediment due to erosion of the hill face, as it occurs now, was then absent.

yield, as at present, this period should become smaller in the future. The limit of the delta cone with every swing should extend beyond the previous limits, both on the east and west boundaries as well as on the south. This gradual extention of the delta would depend on the thickness of the sand deposits in any one such sweep. At present, Kosi River has approached the Ganga closely along the southern edge of the cone. The Kosi, if left to itself, would progressively occupy the remaining land and would ultimately push the Kosi Delta into the Ganga when major changes in the Ganga itself could be expected to occur.

The contour plan of the Kosi Delta from 1947 to 1953 is shown in Fig. 5. Although not covering the whole area of the delta it is helpful in indicating the river reaches that are prone to silting and scouring. From the contours that again run circumferentially south of Hanumannagar, the tendency of cone formation is evident. It may therefore be inferred that the river is aggrading in this reach. North of Hanumannagar, the contours run mostly straight, while near Belka hill the contours are curved in the fashion opposite that indicated downstream of Hanumannagar. This suggests that the Kosi River has a tendency to scour its bed in the reach between Chatra and Belka, whereas the transition reach extends downstream to Hanumannagar. Over the

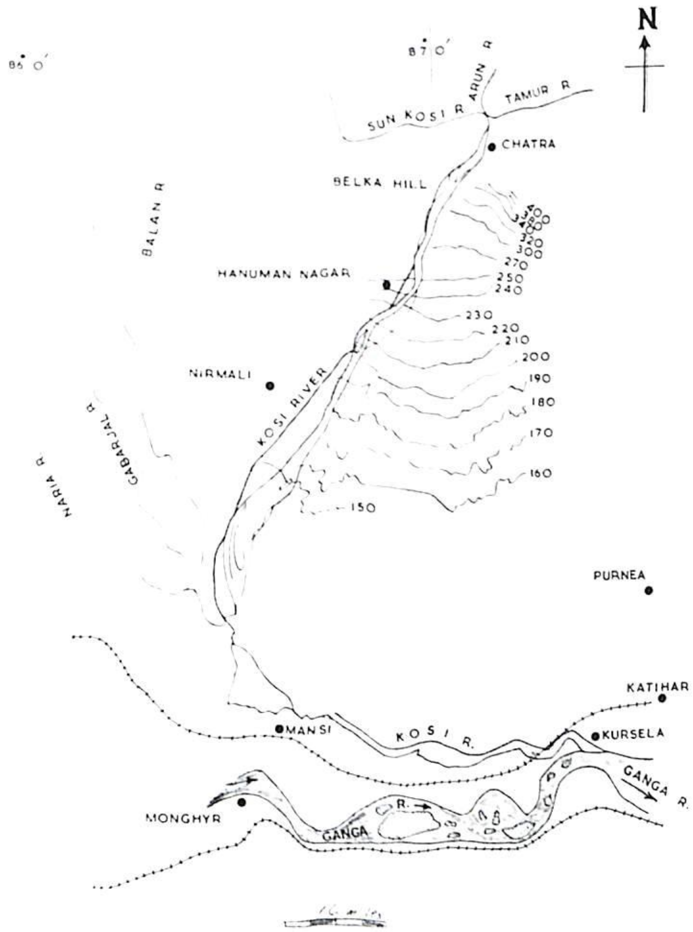

FIG. 5.—CONTOUR PLAN OF KOSI BASIN PREPARED FROM 1947-1953 SURVEY

transition reach it is mostly able to carry the sediment until it starts depositing the excess load below Hanumannagar.

From the above findings, the shifting courses of the Kosi River appears to be caused by the deficient river slope which is not able to carry the excessive sediment load brought down by the river. The hypotheses that the river vagaries are attributable to the excessive charge alone or to undeveloped topography, are therefore not substantiated, but both appear to be the real cause of Kosi troubles. The river in the natural course would have continued building the delta and ultimately achieved such a stable slope, probably along

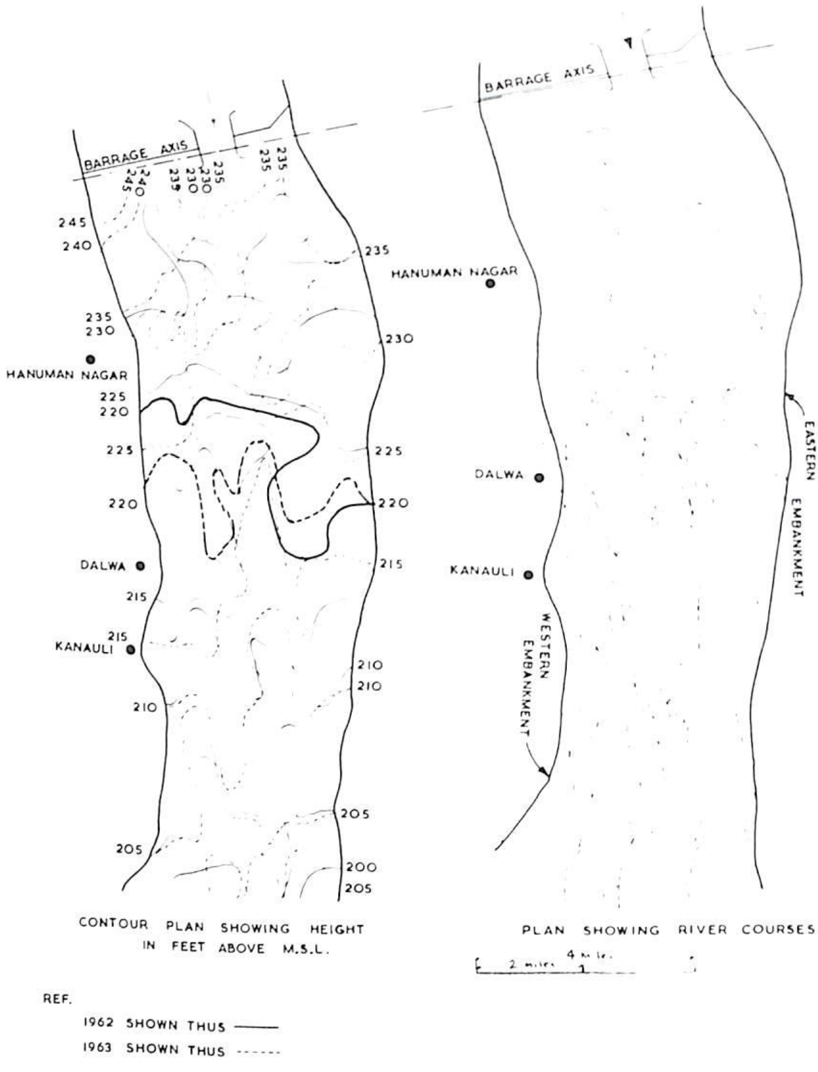

FIG. 6.—PLAN OF KOSI RIVER NEAR DALWA VILLAGE SHOWING CONTOURS AND CONFIGURATION FOR THE YEARS 1962 AND 1963

the line running straight south from Chatra, so that all the sediment could be carried down the river with progressive changes in the bed material load caused by attrition and sorting. This would, however, take a long time and all the area in Kosi Basin would be left to the mercy of the shifting river, awaiting flood devastation at one time or another during the delta building process. It is therefore wise that the Kosi project has been implemented. With the knowledge of the delta building process of the Kosi, repercussions of project works on the river could not be gaged.

The flood embankments cannot prevent the shifting tendency of the river course. The possibility of the river attacking either flood embankment cannot therefore be ignored. Vigilance will therefore be necessary to avert this danger by providing bank protection and retired embankments whenever the live channels of Kosi River approach the embankments. Raising the embankments may also be necessitated as a result of the rise in water level caused by aggradation.

In order to study the river tendency to aggrade in a particular part of the river and to cause a shift in the river course, contour plans could provide a great aid. For instance, the contours within the embankments downstream of the barrage for post flood 1962 (i.e., the year before the river was diverted over the barrage) showed that in the left half, the river has aggraded opposite Dalwa, while on the right side adjoining Dalwa, the river bed was lower (Fig. 6). Thus a contour of 220 is seen to have advanced downstream only in the left half opposite Dalwa. This resulted in the river pressing against the right flood embankment at Dalwa causing a breach of about 4,000 ft. With the shifting of the river towards the right flood embankment at Dalwa, the river bed has now accreted in this part, as depicted by the contour of 220 in the 1963 post-flood survey.

It is felt that a similar contour plan of the whole length of the river from the gorge down to its confluence with Ganga, if made after every flood season, would assist invaluably in understanding the behavior of the river and would forewarn the field engineers of impending changes, so that suitable timely measures could be taken to fight the river. At present, close vigilance appears to be necessary along the right flank for some distance downstream of the barrage. In absence of contours for any reason, even the trend of the shifting course of the Kosi as in Fig. 6 would provide a hint to the future behavior of the river. The barrage would cause accretion of sediment on its upstream. This would lead to the change in river approach to the barrage because of the shift in the river channels. The effect of such change in approach on sediment entry into the pockets of the barrage will have to be watched and appropriate measures taken in time.

Because of deposition of the part of the load in the pond upstream of the barrage, the sediment load downstream would be diminished in the post barrage period. At present, the river reach downstream of Hanumannagar is known to aggrade. With the construction of the barrage, this aggradation immediately downstream of the barrage would be either reduced or completely eliminated. Depending on the pond level maintained at the barrage, the possibility of rapid retrogression in the immediate downstream reach cannot also be ignored. However, a change in the river course as a result of aggradation immediately downstream of the barrage is not to be expected; hence wherever the river course is flowing along the flood embankments at present, as in the reach near Dalwa, the possibility of its moving away appears to be remote. On the contrary, as a result of depletion of the sediment load the existing main channel may scour and stabilize in the same position and thus continue to exert pressure on the embankments whenever it is flowing close to them. The necessity of continued maintenance and protection of these reaches of the embankment would thus be evident.

The effect of retrogression below the barrage would progressively diminish in the downstream direction after which the material picked up in the retrogressed reach may increase the sediment concentration and maintain it to a level commensurate with the existing slope of the river and consequently the carrying capacity.

In the Himalayan Gorge, a dam is being proposed for trapping the heavy sediment load. Similar dams on a few tributaries are also contemplated. The effect of these structures would be to cause heavy retrogression immediately downstream with subsequent deposition of the scoured material further downstream. Such retrogression is known to occur over the extensive lengths. For instance, the Colorado River below Hoover Dam deepened its bed by a maximum of 18 ft and the effect of retrogression was felt over a length of 97 miles downstream. Below Parker Dam on the same river, maximum retrogression experienced was 7 ft and the length affected was 40 miles. In comparison, the sediment load of Kosi is heavier and slopes steeper. These two factors will have conflicting influence on the reach subject to retrogression below the dam.

CONCLUSIONS

A study of the delta cone of Kosi River was not attempted by any of the investigators in the past. Such investigations could, however, provide deeper insight into the problem and useful design data for framing project proposals. In light of the above information, it could now be seen that the contention of Shillingfield that the eastward movement of Kosi will be accomplished in one great sweep, appears to be illfounded. Matrani has questioned the reason why Kosi Basin has not yet filled to stability, in contrast to Gandak and other Himalayan rivers joining the Ganga. The explanation suggested is that whereas other rivers have built up longitudinal valleys, the Kosi is building up a conical delta. Despite the quantity involved in the latter process, being considerably more than in the former, the delta building of the Kosi is still incomplete.

Lastly, Leopold and Maddock expressed that continual movement in one direction during the period of oscillation is somewhat surprising. The explanation is that in conical delta building, sediment deposition, rise of bed levels, and shifting of river course occur progressively from one edge of the cone to the other. After reaching the other edge, the process of deposition and the rise of river bed continue but in the opposite direction. This behavior was examined previously and indicated in Fig. 4.