Sediment Problems in the Indus Basin Part II Sedimentation in River Channels and Floodways.

By

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1. INTRODUCTION.

This is the second paper in the series on "The Sediment Problems in the Indus Basin". The first paper (Ref. 1) related to sediment problems in the mountain valleys of the Indus rivers with particulars reference to the problems of sedimentation in reservoirs. The present paper deals with the sediment problems in the river channels and floodways of the Indus rivers during their passage through the vast alluvial plains from the foot of the Himalayas to the Arabian Sea. The third and last paper in the series will deal with the problems of sedimentation in irrigation canals and will be presented as a separate paper.

The rivers of the Indus system, as they emerge out of the Himalayan ranges, flow for the most part through what, to the normal eye, appears like a perfectly level and unbroken plain devoid of anything that can properly be called a valley. The total length of the rivers in the plains is approximately 2600 miles. In the first paper (Ref. 1) it was estimated that the Indus rivers, when they enter the plains at the rim stations, bring approximately 560 million tons of sediment annually. Revised estimates based on recent observations carried out by WAPDA indicate that the Indus at Tarbela alone carries an average annual suspended sediment load of 360 million tons (Ref. 2). The probable load at Kalabagh, including the contributions from Kabul, Haro and Soan rivers, may be of the order of 420 million tons against the figure of 340 million tons estimated in the first paper. The revised estimate of total average annual sediment load carried by the Indus rivers at the rim stations, including the Eastern Rivers, Ravi, Beas and Sutlej, is of the order of 650 million tons.

There are numerous rivers and hill torrents which join the rivers below the rim stations. The Gomal river and the Kohat Toi on the west bank of the Indus carried 28.3 and 0.9 million tons of suspended sediment respectively during 1960. The Kahan and Bunha rivers, tributaries of the Jhelum ; the Bhimber and Bhandar rivers, tributaries of the Chenab ; and the Deg and Basanter rivers, tributaries of the Ravi, are all known to carry heavy sediment loads during floods. If the contributions of these rivers as well as those of the other numerous hill torrents are included, the average annual sediment inflow into the Indus rivers will probably exceed 700 million tons.

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The eroded material thus added to the flow current is not directly deposited on the bed but is carried for some distance downstream and eventually dropped. This action, called the "caving action at the bends" goes on for several miles through out the bend, each pocket excavated affording an additional point of attack to the current from above. Finally a stage will be reached when the angle of the bend becomes less abrupt, the velocity is reduced and the load is thrown forming a shoal across the chennel.

Again as the river stage rises further, it takes shallow short-cuts across great bends at comparatively low velocity owing to the shallowness and then this low current enters the main deep channel at a local high velocity at the downstream end of each short-cut. If the bend is so big that the short-cut channel has not enough time to erode its bed and banks to any great extent, the result of this action is exhibited in the form of an abortive channel at the fall of the river, which, had the flood lasted longer, might have established itself right accross the bend. But should the flood last long enough for the short-cut channel to erode itself adequately, then owing to the steeper slope in the short-cut channel as compared to that in the long bend, the course of the main current shifts to the short cut channel and within days and probably hours this becomes the main river while the long bend is abandoned and gets silted up in due course. Such short-cutting action is constantly going on at one point or another of the river during-its long journey through the alluvial plains. Sometimes it fails and sometimes it succeeds. But whenever it succeeds, its effect on the river for many miles upstream and downstream of the short-cut would be very disturbing. Banks start caving in rapidly at some places, channels silt up at other places and this process goes on until some sort of a temporary regime is attained, only to be disturbed again by another successful cut-off elsewhere. Cases of this kind are particularly brought to public notice on a river forming an international boundary, for instance the Ravi River below Modhopur, when due to successful action of cut-offs, the Indian villages after one flood season find themselves on the wrong side of the boundary river and *vice versa*.

Another important change during floods is that the higher flooded areas tend to grow higher by silt deposition. Owing to the comparatively brief time during which the flood tops the higher levels which are generally under cultivation, it seldom has time to do any surface erosion. On the other hand owing to the great reduction in velocity due to lesser depth and the restraining influence of the vegetation, the tendency is for the higher places, below high flood levels, to grow still higher to the great benefit of the cultivators whose lands enjoy increased fertility.

Yet another change that takes place during flood is the silting and scouring processes during the rising and falling stages of the river. In a risining stage, the river spreads itself, often for miles of width, and much of the silt brought from the hills and picked up from the bed and banks is deposited on the shallow berms where the velocity is checked on account of shallowness and the water has no longer the power to transport the same silt charge while in the deep channel of the river the process of caving of banks and formation of shoals goes on as described before. On the falling stage on the other hand, all the water on the shallow berms and the adjoining plains which is relatively clear of course sediment and which is still flowing in the form of a sheet at a sluggish pace, returns to the main river. In this process as its velocity is accelerated, its power to pick up and transport silt increases many fold and the tendency for the main channel would be to get deeper. This is nature's way of keeping a deep channel ready made for the next rising season.

Thus the behaviour of the rivers in alluvial plains is a complex and constantly changing phenomenon taking place at every mile and probably every foot of their long journey to the sea. The various stages of the rise and fall ; the caving action at the bends ; the attempts, some successful and some abortive, to form cut-offs ; the deposition in the shallow spreads ; the tendency to fill up hollows in the rising stage and to scour them out in the falling stage, are all processes constantly going on at every place along the many miles of river channels in the plains. Each such change and activity introduces many other changes and their effects vary from site to site depending on the intensity and duration of the floods.

4. SEDIMENT INFLOW AND OUT-FLOW.

Records of sediment observations on the Indus river at Kotri, the lowest station on the river at which observations are made, are available for a long period since the year 1902. Analysis of this data indicates that the average annual sediment load at Kotri is about 330 million tons. This may be assumed as the sediment outflow into the Arabian Sea although the actual outflow into the Sea may be lower due to deposition in the river below Kotri. As discussed earlier, the estimated average annual sediment inflow into the Indus rivers, including the contributions from the tributary rivers and hill torrents below the rim stations is about 700 million tons. The difference of 370 million tons between the inflow and outflow represents the extent of annual sediment deposition in the river channels and floodways between the rim stations and Kotri. In terms of volume, the sediment deposited annually is approximately 975 crore cubic feet. Assuming uniform sediment deposition over a width of one mile throughout the 2500 mile length of the river channels between the rim stations and Kotri, the average depth of deposits will be 1.65 inches annually.

In actual practice, however, the deposition will not be uniform throughout the length of the rivers. Heavier grades of sediment is dropped in the upper reaches while the finer sediment is transported lower down. The lower reaches aggrade at a relatively faster rate on account of their flatter slopes and reduced sediment carrying capacities. Although it may appear that a given particle of sediment flowing in the river at the rim station at a velocity of, say, 5 feet per second or 80 miles per day, should take about 12 days to reach the Sea, it may take 12 months, or for that matter even 12 years before it completes its voyage to the Sea. For the river will be continually dropping some of its load in the shallow places and picking up new load from deeper places and from caving banks and dropping them again at some other places lower down with the result that the given particle when once dropped may be laid there for months or perhaps years before it is picked up again or it may be laid there for ever. During all this time it is subjected to weathering action and in this process loses some of its original size and shape and becomes finer and finer and thus better qualified to be picked up by relatively less powerful currents than those which originally brought it. Thus it travels in stages in short or long hops as in a relay race, sometimes with long periods of rest after each journey until it completes its long voyage to the sea. By that time it would have lost all its identity and would have become very fine silt or almost impalpable matter as found in the deltaic deposits.

Whatever may be the mode or period of transportation of the sediment particles it is obvious from the inflow-outflow data that every year some 370 million tons or 975 crore cubic feet of sediment is lost in the way between the rim stations and Kotri. About half the volume of sediment brought by the rivers does not reach the Sea and is laid in the river channels for ever. The river channels are thus building up their bed or "aggrading" and are not in "regime". This is a known fact. Previous studies by Foy (Ref. 3), Latif (Ref. 4) and others have confirmed this fact and they have even estimated the extent of rise in the river beds in some of the reaches on the basis of specific discharge graphs.

One important hypothesis that follows from these studies is that if the rivers are aggrading progressively and their slopes are continually becoming flatter while the inflow of sediment in the rivers is the same over a period of time or perhaps is even increasing due to the deteriorating conditions of their watersheds, the river must be losing progressively their capacity to transport sediment. In other words, the rate of sediment deposition in the rivers increasing year after year and the outflow at Kotri is progressively decreasing with time. The logic of this hypothesis is obvious but as far as the Writer knows the facts of this hypothesis have not been demonstrated in quantitative terms.

5. ANALYSIS OF SEDIMENT DATA AT SUKKUR & KOTRI :

The Writer initiated a study of sediment data at Sukkur and Kotri with a view to find out the effect of time on the sediment carrying capacity of the rivers. Records of sediment observations at Sukkur and Kotri are available for a long period 1902-1960. For some years the discharge data was not available or was found of doubtful accuracy. Such years (1906, 1941-43, 1948) were excluded from the analysis. In some years the discharge data was available but the sediment data was missing, particularly for Kotri. In order to estimate the sediment loads in the missing years the following relationships were developed between discharge and sediment using the more consistent data for the periods 1920-45 and 1920-40 for Sukkur and Kotri respectively.

Sukkur

$$Q_s = 5.124\, Q_W - 142.66$$

Kotri

$$Q_s = 3.88\ Q_w - 95.54$$

Where Q_w is the annual flow in million acre feet.

Q_s is the observed sediment load in million tons.

Using the above relationship the sediment loads in the missing years were estimated and the data thus completed was used to develop the following relationships for the entire period 1902-60.

Sukkur

$$Q_s = 4.76\ Q_w - 168.83$$

Kotri

$$Q_s = 5.13\ Q_w - 147.75$$

The standard error of estimate in the above relationships was found to be 65.7 and 28.8 million tons respectively. The use of estimates based on the relationship developed for part of the period in order to estimate the sediment load in the missing years and then to use the data thus obtained to develop a relationship for the whole period was found justified as the variances were homogeneous.

The average annual sediment load in the Indus river at Sukkur during the period 1902-1960 was 360.2 million tons and the corresponding figure for Kotri was 330.5 million tons. The range of variation at Sukkur was 194.9 to 630.7 million tons and that for Kotri was 127.4 to 529.2 million tons. The total sediment load passed at Sukkur and Kotri during the period was 21252 and 19500 million tons respectively. This shows that every year about 30 million tons of sediment on the average is being deposited between Sukkur and Kotri and the cumulative deposits during the period 1902-1960 amounted to 1752 million tons or approximately 4600 crore cubic feet.

In order to evaluate the effect of time on the sediment carrying capacity of river, another independent variable T, the lapse of time in number of years with the 1902 as origin, was considered and multiple regression equation describing the functional relationship were developed between sediment load Q_s as dependent variable and the discharge Q_w and the time T (lapse of time since 1902) as independent variables.

Sukkur

$$Q_s = 4.33\ Q_w - 2.48\ T - 56.69$$

Kotri

$$Q_s = 4.998\ Q_w - 0.44\ T - 112.84$$

The values of partial regression coefficients between sediment and discharge and sediment and time gived in the above relationships were found statistically significant. The introduction of the time factor has reduced the standard error of estimate which proves the significance of this factor. The relationship establishes the following hypothesis :—

(*a*) The sediment load increase with the increases in discharge.

(*b*) The sediment load decreases with lapse of time or in other words the carrying capacity of the river decreases with the lapse of time.

The above relationships be used to forecast the decrease in the carrying capacity of the river for any given year in the future provided the discharge and sediment characteristics of the river have the same range of the variation as during the period 1902-1960. However the great water development projects on the Indus rivers that are being executed in India and Pakistan would drastically change both the discharge and sediment characteristics of the river at Sukkur and Kotri and the above relationships will have a limited application.

6. SEDIMENT DATA OF INDUS RIVERS :

Sediment data of Indus rivers based on observations carried out by various organisations including estimates of average annual sediment loads at some of the stations is given in Appendix 2. The data is shown schematically in Figure 1. The sediment loads shown in double circles are based on estimates for long periods. Those shown in single circles are averages for short periods. The data of the Irrigation Research Institute (IRI) is based on the information given in Paper No. 325 W.P.E.C. (Ref. 5).

The data was analysed to examine the seasonal distribution of sediment in the rising period (April-June), the flood period (July-September) and the lowflow period (October-March). The analysis indicates that

(a) Over 88% of their annual loads is carried by the Indus and Chenab rivers during the flood period July to September. The Jhelum river during this period carries only about 50% of its annual load. In the rising period April to June, the Indus and Chenab rivers carry relatively smaller loads per unit volume of water as compared to the Jhelum which carries almost as much load in this period as in the flood months.

(*b*) The sediment outflow at Sukkur and Kotri during the period July to September is about 72% of the total annual load carried at these stations. The percentages are higher during April to June as compared to those of Indus and Chenab but lower than those of Jhelum.

(*c*) During the lowflow period October to March all the three rivers bring almost clear water and the Indus which is the main contributor has particularly a low sediment intensity. At Sukkur and Kotri, on the other hand, the total sediment outflow during this period is more than the inflows at the upper stations.

Considering Darband, Mangla and Alexander Bridge as inflow stations and Sukkur and Kotri as outflow stations the total sediment inflow-outflow balance in million tons, is as follows :—

1960		April-June	July-Sep.	Oct.-Mar.
INFLOWS :				
Indus, Jhelum, Chenab	...	88.6	504.9	4.0
OUTFLOWS :				
Sukkur	...	64.6	196.1	11.5
Kotri	...	61.7	188.6	6.1
SEDIMENTATION :				
Upto Sukkur	...	+24.0	+308.8	—7.5
Upto Kotri	...	+26.9	+316.3	—2.1
1961				
INFLOWS :				
Indus, Jhelum, Chenab	...	80.7	465.3	4.5
OUTFLOWS :				
Sukkur	...	64.6	196.1	11.5
Kotri	...	61.7	188.6	6.1
SEDIMENTATION :				
Upto Sukkur	...	+16.1	+269.2	—7.0
Upto Kotri	...	+19.0	+276.7	—1.6

The above balance sheet is not exact particularly for the period July to September as the inflows from other tributory rivers are not included and the figures for Sukkur and Kotri are based on average for the post-Sukkur barrage period. The trend of sedimentation, however, is obivious. The study of the ratios $Q_w : Q_s$ given in Appendix 3 also leads to the same conclusions. It is also interesting to note the sediment data at Sukkur and Kotri before and after the construction of the Sukkur barrage which indicates that the sedimentation between Sukkur and Kotri after the construction of the barrage has increased.

The data shows that during April to September, sediment is deposited in the river channels and they are aggrading. In the period October to March more sediment is removed from the river channels than that brought in at the inflow stations and the river channels are degrading. The extent of degradation during October to March is small compared to the deposition during April to September and the net result is progressive aggradation. It follows from the above analysis that if the relatively clear water discharge in the period October to March is increased or the silty water discharge in the period April to September is reduced the aggradation problems in the river channels will be improved.

7. FACTORS AFFECTING REGIME OF RIVERS :

For engineering purposes, Prof. Lane (Ref. 6) has defined a regime river as one which is in equilibrium if, over a long period of years, the net amount of change in the river profile is not sufficiently large to be detected by quantative measurements, although it may continually fluctuate between aggradation and degradation. For purposes of analysing qualitatively many problems of changes in river regime, he has given the following general expression :—

$$Q_s \; D \propto Q_w \; S$$

in which Q_s is the quantity of the coarser part of the sediment load or more exactly the bed material load which is defined as the sediment in transport of sizes readily available in considerable quantity in the stream bed,

D is the particle diameter or size of the sediment,

Q_w is the water discharge,

and S is the slope of the stream.

If any of the above factors is changed without a corresponding change in the other factors, the regime or equilibrium of the river will be changed. Prof. Lane has given, for purposes of illustration, six classes of changes which take place in the profile of a river due to a change of one or more factors controlling the equilibrium. Of these six classes three classes are of particular significance in the analysis of regime changes in the river channels and floodways of the Indus rivers below the rim stations. They are reproduced in Figure 2.

Class 1 change will take place in a river in equilibrium with grade BCA if an increase in the sediment load Q_s occurs at a point C without changing the sediment diameter D or the water discharge Q_w . In order to reesstablish equilibrium, the slope S must be increased. The river between C and A cannot carry the increased load of sediment and some of it is deposited on the bed causing the bed to rise or aggrade to C_1 . At first this deposit may not exted to point A but may end at point E. As the deposit continues the river or aggradation may extend all the way to A and the bed level may increase to C_2 . If the new condition continues for a long enough time, final equilibrium will be established after the bed has risen to C_3 . The same class of change would take place if instead of the sediment discharge Q_s , the size of the sediment D is increased at C. The changes upstream of the point C will be represented by the profiles B_1 C_1 , B_2 C_2 and finally B_3 C_3 .

Class 2 change is similar to class 1 but results in lowering or degrading of the profile of the river due to a decrease in the sediment load Q_s or its particle size D or an increase in the water discharge Q_w .

Class 3 change occurs in the tributary rivers if the bed level of the main river degrades.

8. AFFECT OF NEW WATER DEVELOPMENTS ON THE REGIME OF RIVERS

Quantitative estimes of the effect of new water development projects that are being executed in India and Pakistan on the regime of Indus rivers can be made by means of the knowledge of sediment transportation now available if all of the factors affecting their equilibrium are known with sufficient accuracy. The method developed for the Middle Rio Grande by U.S. Bureau of Reclamation (Ref. 7) could be used for making such estimates. For this purpose the river is divided into convenient reaches which can be treated as units with similar characteristics within the reach such as slope, width, and river bed material. For each of the units, topographic surveys giving the river profile and cross sections, flow duration curves of the natural river and under the new conditions, sediment data of the reach, samples of bed material furnished by borings etc., are required. Using the formulae developed by Lane, Kalinske,Schoklitsch and Einstein, the estimates of inflow and outflow of sediment yields can be computed and the extent of aggradation or degradation determined.

The available data, however, is not sufficient for quantitative estimates and only qualitative estimates are possible. In arriving at these estimates the following information and data has been considered :—

(*a*) The experience of regime changes in the Indus rivers in the past.

(*b*) The experience of changes in the river regime in other countries, particularly in the United States, as a result of increased use and development of the rivers.

(*c*) The available data of flows and sediment loads of Indus rivers and their present characteristics of slope, width and bed materials in different reaches.

(*d*) The extent of changes in the water discharge Q_w and the sediment load Q_s that are introduced by the new water development projects on the Indus rivers.

On the basis of the above information and using Prof. Lanes' equation controlling equilibrium, a qualitative analysis of the many changes that are likely to take place in the Indus rivers can be made.

9. REGIME CHANGES IN THE PAST :

The changes in the phisiography of the river channels that take place in the alluvial plains have been discussed before. Even in their natural state, before irrigation developments, the Indus rivers were not in regime and were progressively aggrading. This is how the plains were formed. The various stages of the rise and fall, the caving action at the bends, the action of cut-offs are all processes which have been going on affecting the equilibrium of the rivers. Even if no Irrigation developments had taken place the aggradation process would have continued.

During the past 100 years there has been extensive irrigation developments in the Indus Basin. A series of 19 weirs and barrages were constructed on the Indus rivers, 4 of which are located to India and 15 in Pakistan, diverting some 300,000 cusecs for irrigating 31 million acres annually. Of the total average annual flow of 168 MAF at the rim stations the outflow at Kotri reduced to about 80 MAF (average of 1937-46). The weirs and barrages created large ponds changing the slope factor S in the vicinity. The equilibrium of the natural rivers was disturbed and aggradation started upstream of these barrages due to the deposition of sediment. The aggradation process continued for some time until some sort of a new equilibrium was reached. With the aggradation upstream which resulted in the reduction of Q_s, degradation in the river bed took place on the downstream side and this process stopped after equilibrium condions were reached on the upstream side. Subsequently the degradation process was reversed to aggradation because the factor Q_s remained the same while Q_w was reduced. The large diversions into the irrigation canals had the same effect on account of their selective sediment withdrawal. The losses in the river channels due to evaporation and seepage caused a significant reduction in Q_w while Q_s remained unchanged and contributed to the aggrading process. Thus on the whole aggradation in the natural rivers was accelerated with the development of irrigation. The increase demand for land use led to considerable deforestation in the uplands resulting in the deterioration of the water-sheds and increased the sediment inflow into the rivers and the aggradation process was further accelerated.

10. EXPERIENCE IN OTHER COUNTRIES :

The study of sediment problems of the Lower Colorado River (Ref. 8) in the Unietd States provides a useful guide for qualitative analysis of similar problems on the Indus river. The Colorado river carried an average annual sediment load of 160 million tons (103000 A.F.) at the Hoover Dam site. Bulk of the water and sediment carried by the river is derived from the drainage area above the dam. Below Hoover, the river flows through desert terrain where the only water and sediment reaching the river is derived from erratic and high intensity summer storms. In the valley flood plains the river meandered and changed course frequently. Before the construction of the Hoover dam in 1935 the river was slowly aggrading throughout most of its length below the dam. Within 6 months after opening of the dam, the river bed downstream degraded from 2 to 6 feet over a distance of 13 miles. By 1947 an average bed lowering of 6 to 14 feet had occurred throughout a 77 mile reach. As the finer particles were removed and coarser material, including solid rock ledges was exposed, stablisation became complete for ordinary flow releases. Subsequently developments in the lower reaches with the construction of Davis Dam (1950). Parker Dam (1938) and Imperial Dam (1943) introduced further adjustments in the channel profile. The whole reach between Hoover Dam and Davis Dam is in a canyan and is occupied by Lake Mohave. The clear water released from the Hoover, Davis and Parker dams has resulted in scour of the river bed and bank materials in the channel below the Dams with resultant aggradation in the back water reaehes of the next structure downstream. Degradation introduced a continual supply of sediment to the downstream aggradation areas and the bulk of the sediment in the river below Hoover dam is derived from the river bed and banks.

The study of sedimentation problems encountered on the Arkansas, Rio Grande, Missouri and Mississippi Rivers (Ref: 9) in the United States with the development and use of alluvial rivers is also helpful in predicting the nature of changes that will take place on the Indus rivers in future.

11. New Water Developments on Indus Rivers :

The new water developments on the Indus rivers including those recently completed are given in the following tables :—

TABLE NO. 1.

Storage Dams

Site	River	Gross Capacity (MAF)
Tarbela	Indus	8.4
Mangla	Jhelum	5.5
Pang	Beas	6.3
Bhakra	Sutlej	8.0
	Total :	28.2

Table No. 2. BARRAGES

Site	River	Site	River
Chasma	Indus	Qadirabad	Chenab
Taunsa	Indus	Sidhnai	Ravi
Gudu	Indus	Nangal	Sutlej
Kotri	Indus	Harike	Sutlej-Beas
Rasul	Jhelum	Mailsi (Syphon)	Sutlej

Table No. 3. IRRIGATION DIVFRSIONS

Canal	River	Diversions (cusecs)
Chasma—Jhelum Link	Indus	21,700
Taunsa—Panjnad Link	Indus	12,000
Taunsa Canals	Indus	18,000
Gudu Canals	Indus	36,600
Kotri Canals	Indus	41,300
Total	Indus	129,600
Rasul—Qadirabad Link	Jhelum	19,000
Marala—Ravi Link	Chenab	22,000
BRBD Link	Chenab	3,500
Qadirabad—Balloki Link	Chenab	18,600
Trimmu—Sidhnai Link	Chenab	11,000
Total	Chenab	54,100
Madhopur--Beas Link	Ravi	10,000
Balloki—Sulemanki Link	Ravi	18,500
Sidhnai—Mailsi Link	Ravi	10,100
Total	Ravi	28,600
Bhakra Canal	Sutlej	12,500
Bist Doab Canal	Sutlej	1,500
Rajastan Canal	Sutlej	18,500
Total	Sutlej	32,500

Before the construction of Taunsa, Gudu and Kotri barrages there have been diversions at these sites through inundation canals. The construction of the barrages, however, will increase the total volume of diversions at these sites. Some of the links transfer supplies to other links lower down during periods of short supplies. For example the Chasma-Jhelum Link transfers supplies to the Trimmu-Sidhnai and Sidhnai-Mailsi Links. The total diversion given for each river in Table No.3 above need not necessarily mean new diversions from that river in all periods.

12. **Changes in River Flows :**

The mean annual flow of the Indus rivers in India and Pakistan is 168 MAF. At the time of Partition the average annual outflow into the Sea below Kotri was 80 MAF (1936-46 average). The total historic irrigation diversions including river losses amounted to 88 MAF on the average. After the completion of the new water development projects mentioned above the outflow in to the Sea below Kotri; in an average year like 1944-45, will reduce to about 20 MAF. This means that the additional diversions taking into account estimated changes in river losses will be about 60 MAF on the average.

According to the Indus Waters Treaty between India and Pakistan, all the waters of the Eastern Rivers, Sutlej, Beas and Ravi, shall be available for the unrestricted use of India. Storage sites are available on the Ravi river which will enable India complete utilization of its surplus waters. There is no known storage project on the Ravi which is proposed to be constructed by India in the near future. Therefore, the Ravi river would be constributing some flows to the Indus System during the flood months, July and August, for some time. The storage capacity of Bhakra and Beas dams is more than the annual surplus flows available for development on the Sutlej and Beas rivers and except in very wet years, then will be no contribution from these rivers to the Indus system even during the flood season.

The hydrograhs shown in Figure 3 and the data in Table 4 give the historic and new flow conditions at some of the important stations on the Western Rivers.

The data relates to the water year 1944-55 which has been selected to represent the average conditions. Drastic changs in the river flows will occur below Mithankot, where the main tributary rivers join the Indus, with maximum changes below Kotri due to increased upstream diversions and reduced contributions from the tributary rivers. The Jhelum river below Rasul and the Chenab river below Qadirabad will have a new hydrograph pattern which will be quite different to the historic flows. Figures 4 and 5 show schematically the conditions of flow in the various reaches of the Indus rivers in Pakistan.

13. Changes in Sediment Inflow :

Studies of sedimentation of reservoirs in the United States have indicated that the trap efficiency of a reservoir is related to the ratio of annual inflow volume to reservoir storage capacity (Ref. 10). On the basis of this relationship both Tarbela and Mangla reservoirs are likely to have a trap efficiency of more than 90 per cent. The Tarbela reservoir will be some 45 miles long and nearly 400 feet deep in its deepest portions. The detention time in the reservoir even during the flood season will be about 15 days (Ref. 2). The Mangla reservoir also has similar characteristics. The suspended sediment load observed on the Indus river at Darband consists of 63 per cent sand, 29 per cent silt and 9 per cent clay. The corresponding percentages for the Jhelum river at Mangla are 52, 39 and 9 respectively. In view of high sand fraction in the sediment load and the large physical size of the reservoirs it appears that initially the trap efficiency of both Tarbela and Mangla is likely to be nearly 100 per cent. As the live storage

Table No. 4 CHANGES IN RIVER FLOWS (MAF).

Stations	Historic Conditions			New Conditions		
	Oct.-March	April-Sep.	Annual	Oct.-March	April-Sep.	Annual
INDUS						
Kalabagh	12.5	91.3	103.8	16.1	87.7	103.8
Taunsa*	11.9	81.3	93.2	9.6	64.3	73.8
Mithankot	12.4	110.0	122.4	9.5	60.0	69.5
Kotri*	7.7	78.7	86.4	...	20.3	20.3
JHELUM						
Mangla	3.6	17.8	21.4	8.0	13.4	21.4
Rasul*	0.8	16.3	17.1	...	3.5	3.5
CHENAB						
Marala	3.6	21.5	25.1	3.6	21.5	25.1
Qadirabad*	0.7	13.5	14.2	...	4.5	4.5
Trimmu*	1.3	27.5	28.8	...	4.1	4.1
Panjnad*	1.2	32.7	33.9	...	2.0	2.0
RAVI						
Modhopur*	0.2	3.4	3.6	...	...	...
Sidhnai*	0.2	1.9	2.1	...	...	...
SUTLEJ						
Ferozepur*	2.1	14.7	16.8	...	...	...
Panjnad confluence	0.1	8.2	8.3	...	...	...

*Flows below the barrages.

capacity decreased with time, the detention time in the reservoir will be shortened and the trap efficiency will be reduced. On the other hand, before the live storage capacity is substantially lost, other storages will no doubt be constructed on the river.

The Chenab and Ravi rivers would continue to bring the same sediment loads as in the past until storages are built on them. The Pang storage on the Beas river and the Bhakra storage on the Sutlej river have large enough capacities to regulate the river flows in most years and their trap efficiencies would be substantially 100 per cent.

After 1972 when the planned storages on the Indus rivers would be completed the total average annual sediment inflow into the Indus rivers would reduce by about 500 million tons as estimated below.

TABLE No. 5.

Sediment Inflows (Million Tons).

Station.	River.	Historic	New.
Tarbela	Iudus	360	—
Mangla	Jhelum	60	—
Marala	Chenab	80	80
Madhopur	Ravi	26	26
Mandi Plain	Beas	40	—
Bhakra	Sutlej	40	—
Total at rim stations.		606	106
Other rivers and hill torrents below the dams.		94	94
Total Inflow — Indus rivers		700	200

14. Change in sediment outflow at Kotri.

All the storages are located more than a thousand miles above Kotri. The sediment-free waters from the reservoirs will have ample opportunity to pick up new loads from the river beds and banks and by time they reach Kotri they will have, for all practical purposes, the same discharge sediment relationship as at present. On this assumption, the new sediment outflow at Kotri could be estimated using the present sediment rating curve for Kotri and the estimated new flows. Unfortunately the Writer could not obtain the daily sediment data from published records which are on the monthly basis. A rough estimate, however, is possible on the basis of the historic and new hydrograph conditions at Kotri shown in Figure 3 and the sediment data analysed in Appendix 3. Under the new conditions the total flow below Kotri would be 20.3 MAF and will occur only during the flood months July—August and the new hydrograph will have a pattorn intermediate between the historic pattrens for the periods April to June and

July to September (Figure 3). The historic ratio $Q_W : Q_S$ for the periods April to June and July to September is 1 : 2.9 and 1 : 3.8 respectively (Appendix 3). For the new conditions at Kotri a ratio of 1 : 3.5 can be assumed. On this basis, the estimated average annual sediment outflow below Kotri would be about 70 million tons. Of the total average annual sediment inflow of 200 million tons brought into the Indus rivers after the completion of the water development projcets the sediment outflow below Kotri would be 70 million tons and the balance 130 million tons would be deposited in the river channels between the rim stations and Kotri. A comparison of the historic and new sediment balance for the Indus rivers is given below.

TABLE No. 6

Sediment Balance (Million Tons).

	Historic.	*New.*
Sediment Inflows at rim stations	700	200
Scdiment outflows at Kotri	330	70
Sediment deposited in the Indus rivers.	370	130

The new rate of sedimentation in the Indus rivers will be substantially less than the historic rate and represents on overall improvement on the river system.

15. **Sediment problems in various reaches.**

Aithough the sediment inflows will substantially reduce after the construction of the reservoirs, it does not follow that the rate of aggradation in the river channels would reduce uniformaly. In the upper reaches immediately below the dams the present aggradation process would change rapidly into degradation. The lower reaches would continue to get, depending upon the flow conditions, as much sediment inflow as in the past, the new source of sediment being the erosion in river beds and banks in th upper reaches. The process of aggradation in the lower reaches, the efore, would continue as before and may even become worse owing to the large irrigation diversions.

Before the construction of the dam the river reach immediately below the dam was is equilibrium satisfying the relationship $Q_{s.} D = Q_W S$. After the completion of the dam, Q_s and D become zero and Q_W is decreased during the flood months on account of the filling of the reservoir and is increased during the remaining period on account of storage releases. The original equilibrium of the river is thus upset and in order to establish a new equilibrium the slope S must change. Class 2 change will occur (figure 2) and the original grade of the river CA will change finally to C_3 A. The vertical distances between CA and C_3 A will represent the extent of degradation at various points. After the river attained the final equilibrium grade C_3 A it will not be able to erode the bed further although the clear water from the reservoir will have a tremendous capacity to transport sediment. This will happen when all the sediment overlying the coarser material of the valley floor is eroded and a level is reached at which the size of the material is too large to be picked up and the factor D alone satisfies the equilibrium condition. The degradation in the reach will stop but the clear water will have ample eapacity to pick up new loads in the next lower reach where the bed materials are finer.

When the water loaded with the material picked up from the river bed in the upper reach enters the next lower reach it may be fully charged with course sediment but may still have a large capacity to carry sediment of finer size. The lower reach provides the finer sediment which is readily picked up and in the same process the coarser sediment brought from the upper reach is dropped on account of the changed values of S and Q_w.

In the equation for equilibrium mentioned above the sediment discharge Q_s is the coarser part of the sediment load or the bed material load in transport of sizes readily available in considerable quantities in the stream bed. In most cases, the quantity of the fine load of silt and clay sizes can change almost indefinitely without materially affecting the equilibrium (Ref. 6). In the Indus rivers the sediment of a given size D required to establish new equilibrium conditions will be available at a shallow depth in the upper reaches and will be deeper in the lower reaches. The extent of degradation therefore will increase with the distance below the dam unless this effect is off-set by the reduction in S and Q_w.

With the above general analysis, the sedimentation problems in the various rivers are discussed briefly in the following paragraphs.

16. Sedimentation Problems on the Indus River :

Below Tarbela the Indus river has a vide valley varying from two to three miles in width between low banks in which the river flows in many channels. The slope up to Attock, 29 miles below Tarbela, is 7 feet per mile. The stream bed is crossed at frequent intervals by shingle bars formed of gravel, cobbles, and boulders. Just above Attock the Kabul river joins the Indus bringing an annual load of 29 million tons (1961). Between Tarbela and Attock the river will receive almost clear water at its upper end and degradation of the present river bed would take place. As the final sands and silts are removed, the bed will resist further erosion. In view of the very coarse material available in the river bed the depth of lowering upto Attock will be relatively small but the degradation at Attock would cause class 3 change in the Kabul river and its slope will increase.

Below Attock the river has an average slope of 2.36 feet per mile in the 95 mile long reach upto Kalabagh in which the Haro and the Soan rivers join and contribute about 15 and 20 million tons of sediment respectively. The river will still have erosive power as its total load will be very much less than historic. The opportunities for sediment replanishment in this reach, however, are limited on account of the narrow valley. Any degradation that takes place in the main river will cause class 3 changes in the Haro and Soan tributaries.

As the river emerges out of the hill-ranges it enters the Kalabagh barrage pond where the coarser sediment is rapidly dropped. Below the barrage it will find itself in a broad valley with an almost unlimited source of finer sediment. Historically the river carried some 420 million tons of sediment annually at this station and it will soon pick up this amount of load. The coarser part of the load will again be dropped in the Chasma Barrage pond and the same process will be repeated at Taunsa. In course of time the whole reach from Kalabagh to Mithankot will be subjected to accelerated aggradation above the barrages and increased degradation below and the river bed will be armoured with coarser material. At Mithankot the Indus will receive a very weak Panjnad river than hithertofore with probably heavier concentration of sediment and because of the reduced Q_w and S and increased concentration of Q_s and D there will be accelerated aggradation lower down.

17. Sediment Problems on the Jhelum River :

Below Mangla, for a short distance, the river is crossed by a series of shingle bars formed of gravel cobles and boulders. Except in floods, the releases from the reservoir enter the river at Bong, 7 miles below the dam. Above Bong the river will be subjected to degradation only during the period of surplus flows through the spillway and because of the gravel formations the extent of degradation will be limited. From Bong to Rasul a distance of about 33 miles the river is wide and has a slope of 4 feet per mile. The clear water will have ample supply of sediment in the reach and degradation will take place. Its effect will be felt at the Jhelum road bridge and lower down. The barrage at Rasul, however, limits the extent of degradation in the reach. Most of the Jhelum water will be passed through the canals at Rasul and the escapage below Rasul will occur in July-August only (Fig. 3). But even in this short period the river will have sufficient erosive power to cause degradation lower down. The Chasma-Jhelum link joins the Jhelum river about 100 miles below Rasul and brings relatively clear water from the Indus. In the reach Rasul to Trimmu, therefore, the general trend will be degradation except above the Trimmu pond where the coarser material removed from the channel beds upstream, will be deposited. At Trimmu all the water is diverted into the irrigation canals and there will be no escapage below the barrage except for a short period in July and August (Fig. 3). This will cause rapid aggradation in the river channels above the pond.

During floods heavy movements of sediment will take place particularly below Rasul causing greater changes in the physiography of the river channels than in the past. For instance, during the flood of July 1959 the peak discharge in the river was 827,000 cusecs and in the 3 days of the flood from July 4th to 6th, the river carried a sediment load of nearly 122 million tons (twice the annual load) with a flow of 3.2 MAF. When such floods occur in future, the peak discharges below the reservoir will be almost as high as in the past and the clear water floods will have a tremendous capacity to pick up loads from the river beds. At such times great damage may be caused to river structures on account of heavy sediment movements.

18. **Sediment Problems on the Chenab River :**

In the absence of storages, the Chenab river will continue to bring the same load of sediment at Marala as in the past. In view of the very heavy additional diversions into the link canals between Marala and Qadirabad, the new flow below Qadirabad will reduce to 4.5 MAF against the historic flow of 14.2 MAF. All this flow will occur only during the months of July and August (Figure 3). The average ratio. $Q_w : Q_s$ for this period is about 1 : 5.5 (Appendix 3). On this basis the estimated average sediment outflow below Qadirabad under the new conditions will be about 35 million tons against the average inflow of 80 million tons at Marala. The difference of 55 million tons will be deposited mostly in the river channels between Marala and Qadirabad as the Irrigation links and canals will reject the coarser grades of silt which are harmful for their operation. The aggradation problems between Marala and Qadirabad will be severe and the rate of aggradation will be more rapid than on other rivers on account of the short reach (about 58 miles) in which the irrigation diversions are concentrated.

Sediment movements in the Chenab river are very heavy during floods. At the Alexander bridge the river carried 104 million tons of sediment (94 per cent of the total annual load) during July to September 1961 which gives a $Q_w : Q_s$ ratio of 1 : 6.6. During these 3 months the river had a discharge exceeding 150,000 cusecs for 9 days when it carried 55.7 million tons of sediment (50 per cent of the annual load and 54 per cent of the July-September load) with a total flow of 4.1 MAF. On a single day (19th July) the peak flood was 704,000 cusecs when it carried 35 million tons of sediment (32 per cent of annual load and 34 per cent of the July-September load) with a flow of only 1.4 MAF. Such floods will continue to occur in the Chenab in future and the sediment movements may be even heavy than in the past and may cause serious problems.

Below Trimmu the Chenab will have a new flow of 4.1 MAF against the historic flow of 28.8 MAF. This is a very drastic change and will result in accelerated aggradation. The new flow below Panjnad will be about 2 MAF, against the historic flow of about 34 MAF. The Panjnad river will no longer have any influence on the Indus and the latter will tend to move towards the east. Even today the Panjnad river has a longer meander belt above Mithankot as compared to the Indus and this tendency would increase further. The reach Panjnad to Mithankot will develop all the characteristics of a delta in course of time.

19. Sediment Problems on the Eastern Rivers :

The sediment problems on the Ravi river in Pakistan will be similar to those on the Chenab but will be less severe. The rate of aggradation below Balloki will be accelerated on account of reduced flows. There will, however, be improvement in the reach between tail Marala-Ravi link and Balloki due to additional inflows from the link without a corresponding increase in sediment.

Theoratically there will be no flow from the Sutlej and Beas rivers below Ferozepur. Occasional floods of short duration in wet year will continue to occur in the late monsoon season when there may be some spill below the reservoirs. The effect of clear water releases from the reservoirs will not be felt in Pakistan as all such releases, except during infrequent floods, will be diverted into canals in India. The river channels in Pakistan will deteriorate due to growth of shrubs and jungle which catch silt and build up the beds. They will lose capacity in course of time and the meandering trends will further increase.

20. Remedial Measure :

The foregoing analysis, although qualitative, indicates the trends of changes in the physiography of the river channels and the places where they are likely to take place after the completion of the Water Development Projects. They are shown schematically in Figure 6. It is important to foresee the problems and take preventive measures before than to solve the problems after they have occured. This possible if data of sediment transportation in the river channels and the factors affecting their equilibrium are known. The available data is quite inadequate. For a system as large as the Indus, it is necessary to have sediment data at all important barrages. The Water and Soils Investigation Division of WAPDA has done very useful work by initiating a programme of sediment measurements at some important rivers in the mountain catchments in order to estimate the hazards of sedimentation in the proposed reservoirs. This programme should be extended to the river channels in the alluvial plains so that the effect of the reservoirs on the regime of the river channels can be determined quantitatively. The programme will be expensive and the results will not be available for a long time but it is the only effective method to know the rivers and to appreciate the many problems that will be created in the future.

The present analysis shows that many of the sediment problems in the river channels can be prevented or their magnitude reduced if the sediment discharge Q_s is reduced or eliminated and the water flow Q_w is increased in the low flow period. The present reservoir projects will achieve the first objective to a very large extent but there will still remain some important rivers like Chenab, Kabul, Soan, Haro, Gomel, Kahan, Bunha Bhimber and many others which will continue to bring millions of tons of harmful sediment. The control of Chenab and Kabul rivers involves international problems which are difficult to solve. Reservoirs on the other tributarie may not be sufficiently attractive to receive priority. But no effective solution of the sediment problems is possible without providing some measure of control over these wild rivers.

The second solution of increasing the water discharge in the low flow period is partially achieved in some reaches. For instance the flow conditions on the Indus river between Kalabagh and Mithankot and on the Jhelum river between Mangla and Rasul will be improved with the present developments. But the conditions in the other reaches, which constitute a major part of the system, will become worse than historic on account of the very large diversions through link canals. It is not possible to avoid these large divertions as the primary object of development is irrigation. But with the extensive inter-river link system it is possible to utilize the clear waters available on one river to reduce the problems on the other. For instance, the Chenab river is connected with the Jhelum with links of a total capacity of about 27,000 cusecs. These capacities are utilized for irrigation only during periods when the supplies in the Chenab are short. Whenever there is surplus water in the Jhelum it will be useful to divert the supplies to Chenab through the links and escape them below Qadirabad. This will increase the flow and decrease the sediment intensity below Qadirabad and reduce the aggradation hazards. Similarly the Chasma Jhelum and the Taunsa-Panjnad links can be utilized for improving the problems in the lower reaches of the Chenab rivers between Trimmu and Mithankot.

The above measures will delay the aggradation process but will not avoid them. It will be necessary ultimately to take up protective measures. parttcularly in the lower reaches, in the form of flood embankments, river training works, drainage improvements, dredging etc., in order to solve the problems that will arise on the river channels.

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APPENDIX 1.

MEAN SLOPES OF THE RIVER AND DOABS IN THE INDUS BASIN

	River	Length (Miles)	Average slope (Feet per mile)
1. **Sind Sagar Doab :**			
Kalabagh—Mithankot	Indus	342	1.18
Sind Sagar Plains	...	...	1.17
Rasul—Trimmu	Jhelum	180	1.26
Trimmu—Panjnad	Chenab	189	0.81
2. **Chaj Doab :**			
Rasul—Trimmu	Jhelum	180	1.26
Plains of Chaj Doab	...	...	1.12
Khanki—Trimmu	Chenab	180	1.35
3. **Rechna Doab :**			
Khanki—Trimmu	Chenab	180	1.35
Trimmu—Panjnad	Chenab	189	0.81
Plains of Rechna Doab	...	...	1.25
Shahdara—Sidhnai	Ravi	304	0.72
4. **Bari Doab :**			
Shahdara—Sidhnai	Ravi	304	0.72
Sidhnai—Trimmu	Ravi—Chenab	79	0.35
Trimmu—Panjnad	Chenab	189	0.81
Bari Doab	...	...	0.89
Ferozepur—Suleimanki	Sutlej	79	1.01
Suleimanki—Panjnad	Sutlej	270	0.86
5. **Sind Plains :**			
Mithankot—Sea	Indus	621	0.47
Sind Plains	...	...	0.48

APPENDIX 2.

SEDIMENT DATA OF INDUS RIVERS

Station	River	Load in million tons		Source of Data
		Average annual	In any one Year	
INDUS				
1. Darband	Indus		483 (1960)	WASID
			383 (1961)	
2. Tarbela	Indus	360		TAMS Estimate
3. Kalabagh	Indus	420		Estimate
4. Sukkur	Indus	360		Indus Commission.
5. Kotri	Indus	330		Indus Commission.
6. Thapla	Siran		3 (1960) 7 (1961)	WASID
7. Nowshera	Kabul		29 (1961)	WASID
8. Risalpur	Kalpani		1 (1960) 2 (1961)	WASID
9. Chakdra	Swat		1 (1961)	WASID
10. Sanjawal	Haro		9 (1960)	WASID
			15 (1961)	
11. Makhad	Soan		20 (1955)	I.R.I. (June—Oct : Only
12. Jarma Weir	Kohat Toi		1 (1960)	WASID
13. Kot Murtaza	Gomal		28 (1960) 28 (1961)	WASID
JHELUM				
1. Mangla	Jhelum		61 (1960) 57 (1961)	WASID
		60		Estimate
2. G. Habibullah	Kunhar		6 (1960) 3 (1961)	WASID
3. Jhangi	Kanshi		5 (1960) 4 (1961)	WASID
4. Kotli	Poonch		10 (1961) 16 (1961)	WASID

APPENDIX 3 (1)

SEASONAL DISTRIBUTION OF SEDIMENT

	April-June	July-Sep.	Oct.-Mar.	Total
KABUL AT NOWSHERA				
1961				
Q_w	9.4	9.6	4.0	23.0
Q_s	13.3	13.9	1.8	29.0
$Q_w : Q_s$	1 : 1.4	1 : 0.4	1 : 0.4	1 : 1.3
Q_w %	41	42	17	100
Q_s %	46	48	6	100

Note : Q_w is in million acre feet. Q_s is in million tons.

APPENDIX 3 (2)

SEASONAL DISTRIBUTION OF SEDIMENT

	April-June	July-Sep.	Oct.-Mar.	Total
JHELUM AT MANGLA				
1960				
Q_w	8.6	7.7	3.9	20.2
Q_s	27.9	31.0	1.9	60.8
$Q_w : Q_s$	1 : 3.2	1 : 4.0	1 : 0.5	1 : 3.0
Q_w %	43	38	19	100
Q_s %	46	51	3	100
1961				
Q_w	8.7	8.0	4.1	20.8
Q_s	30.7	24.8	1.0	56.5
$Q_w : Q_s$	1 : 3.5	1 : 3.1	1 : 0.2	1 : 2.7
Q_w %	42	38	20	100
Q_s %	54	44	2	100

Note : Q_w is in million acre feet. Q_s is in million tons.

APPENDIX 3 (2)

SEASONAL DISTRIBUTION OF SEDIMENT

	April-June	July-Sep.	Oct.-Mar.	Total
CHENAB AT ALEXANDER BRIDGE				
1960				
Q_w	3.2	10.6	1.7	15.5
Q_s	5.5	47.2	0.9	53.6
$Q_w : Q_s$	1 : 1.7	1 : 4.5	1 : 0.5	1 : 3.5
Q_w %	21	68	11	100
Q_s %	10	88	2	100
1961				
Q_w	3.2	15.7	2.6	21.5
Q_s	5.5	103.7	1.4	110.6
$Q_w : Q_s$	1 : 1.7	1 : 6.6	1 : 0.5	1 : 5.1
Q_w %	15	73	12	100
Q_s %	5	94	1	100

Note : Q_w is in million acre feet. Q_s is in million tons.

APPENDIX 3 (3)

SEASONAL DISTRIBUTION OF SEDIMENT

	April-June.	July-Sep.	Oct.-Mar.	Total
HARO AT SAMJWAL				
1960				
Q_w	0.1	0.2	0.1	0.4
Q_s	0.3	8.3	...	8.6
$Q_w : Q_s$	1 : 4.9	1 : 34.6	1 : 0.3	1 : 20.0
Q_w %	15	55	30	100
Q_s %	4	96	...	100
1961				
Q_w	0.1	0.4	0.2	0.7
Q_s	0.4	14.8	0.2	15.4
$Q_w : Q_s$	1 : 4.3	1 : 42.4	1 : 1.2	1 : 25.3
Q_w %	15	57	28	100
Q_s %	3	96	1	100

Note : Q_w is in million acre feet. Q_s is in million tons.

APPENDIX 4

	Apr.-Jun.	July-Sep.	Oct.-Mar.	Total
INDUS AT KOTRI				
1902-1933				
Q_w	22.9	56.7	17.7	97.3
Q_s	79.4	255.3	20.9	365.6
$Q_w : Q_s$	1 : 3.5	1 : 4.5	1 : 1.7	1 : 3.8
Q_w %	24	58	18	100
Q_s %	22	70	8	100
1934-1940				
Q_w	21.0	49.2	8.0	78.2
Q_s	61.7	188.6	6.1	256.4
$Q_w : Q_s$	1 : 2.9	1 : 3.8	1 : 0.8	1 : 3.3
Q_w %	27	63	10	100
Q_s %	24	74	2	100

Note : Q_w is in million acre feet. Q_s is in million tons.

BIBLIOGRAPHY

1. Kirmani, S.S. ... ... Sediment Problems in the Indus Basin Part I. Sedimentation in Reservoirs Paper No. 336. West Pakistan Engineering Congress, 1959.

2. T. A. M. S. ...: ... Project Planning Report-Tarbela Dam, January, 1962.

3. Foy, Sir Thomas ... ... Regime Level Changes on the Indus System, Punjab Irrigation Branch No. 16, 1944.

4. Latif, A. ... ... Specific Discharge Gauges of Chenab River Sites Paper No. 319. West Pakistan Engineering Congress, 1956.

5. Dr. Nazir Ahmad ... ... Sedimentation of Reservoirs in Indus River System-Paper No. 325, West Pakistan Engineering Congress, 1957.

6. Lane, E. W. ... ... The Importance of Fluvial Morphology, in Hydraulic Engineering —Paper No. 745, Proc. ASCE July, 1955.

7. U. S. Bureau of Recalamation. An Estimate of the Magnitude of the Degradation which will result in the Middle Rio Grande Channel from the Construction of the Proposed Sediment Storage Basin and Constraction Works, Hydraulic Laboratory Report No. Hyd-290, U. S. Bureau of Reclamation, July 15, 1948.

8. Boreland, W.M. & Miller C.R. Sediment Problems of the Lower Colorado River—Journal of the Hydraulic Division, ASCE April, 1960.

9. Hathaway, G.A. ... ... Sedimentation Problems related to Floood Ways, Navigation Channels and Harbours Proc. of the Federal Inter Agency Sedimentation Conference, January, 1948.

10. Brune, C.B. ... ... Trap Efficiency of Reservoir Trans, AGU, June, 1953.

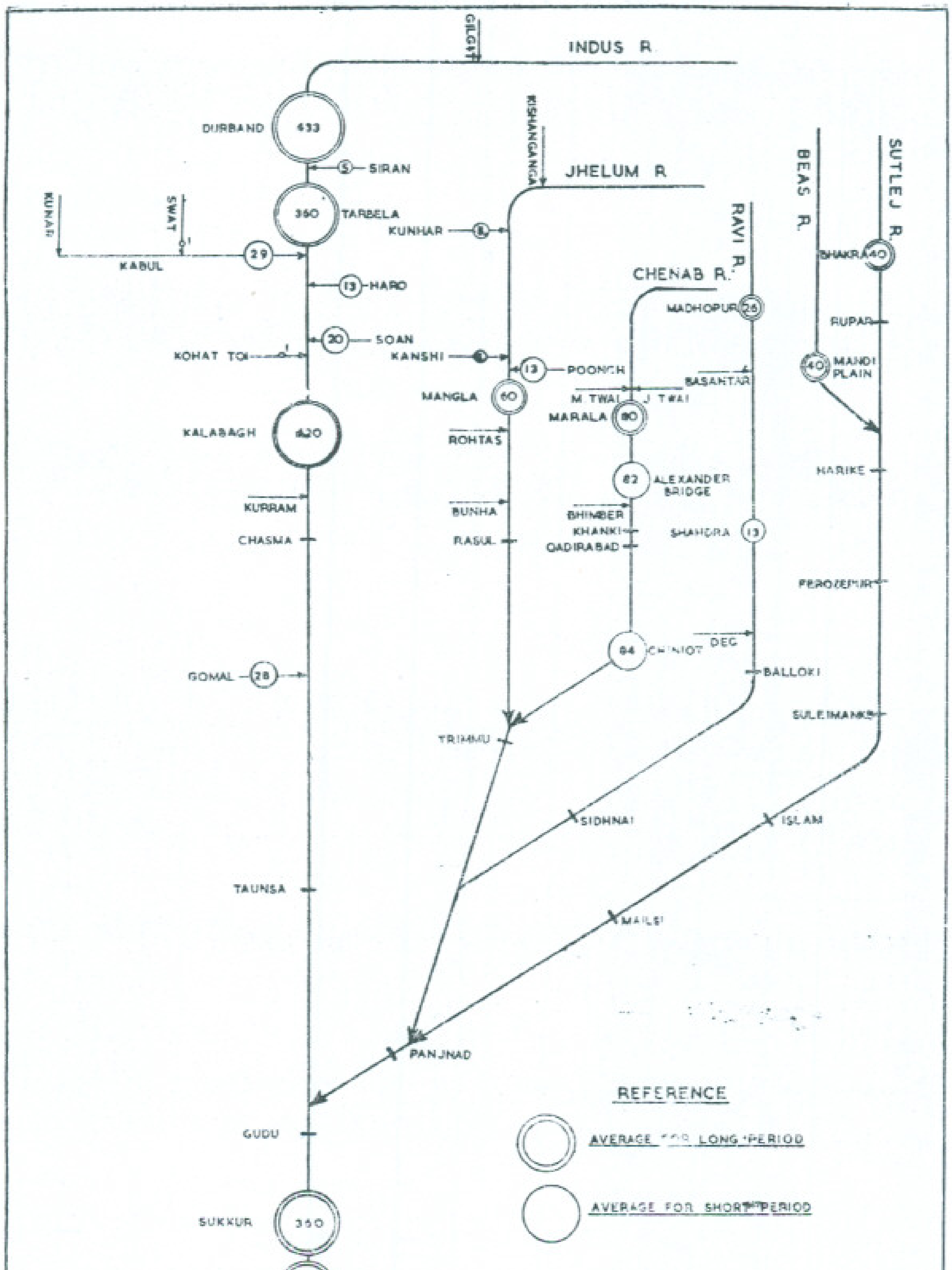


FIG: I SEDIMENT DATA OF INDUS RIVERS

(FIGURES GIVEN ARE IN MILLION TONS)

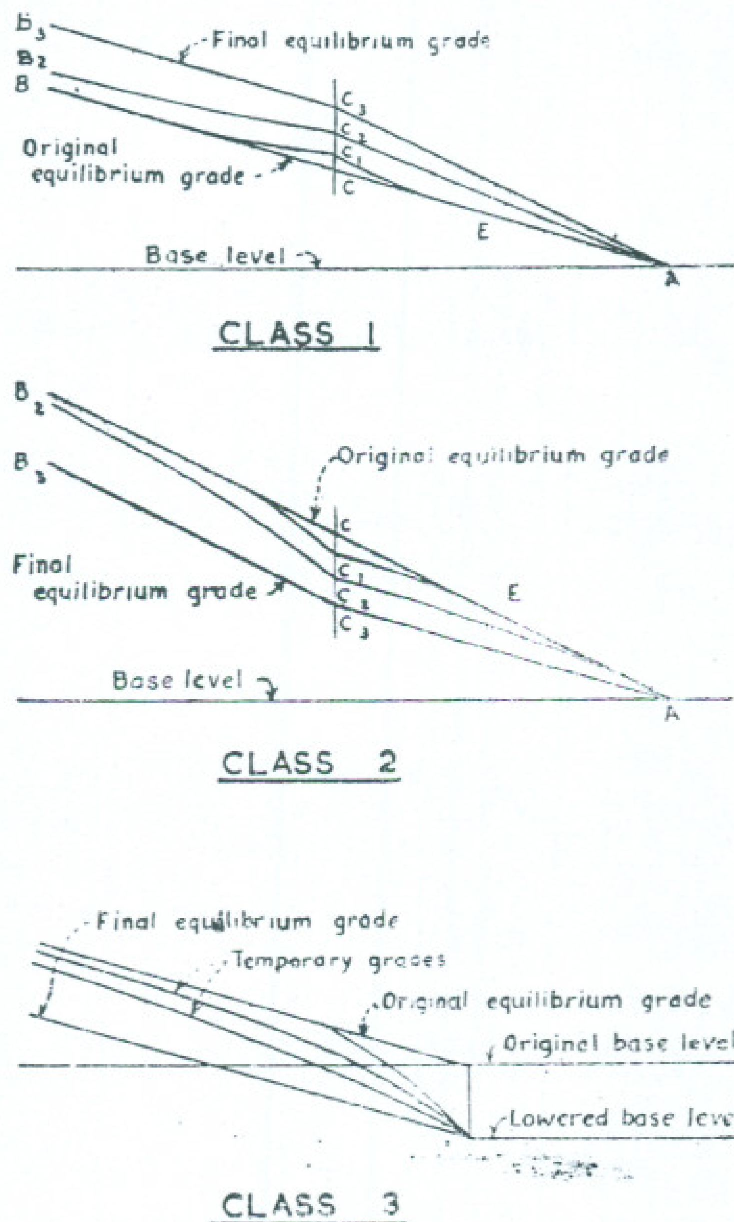


FIG: 2 CLASS OF REGIME CHANGES IN RIVER'S

FIG: 3.-SHEET NO: I

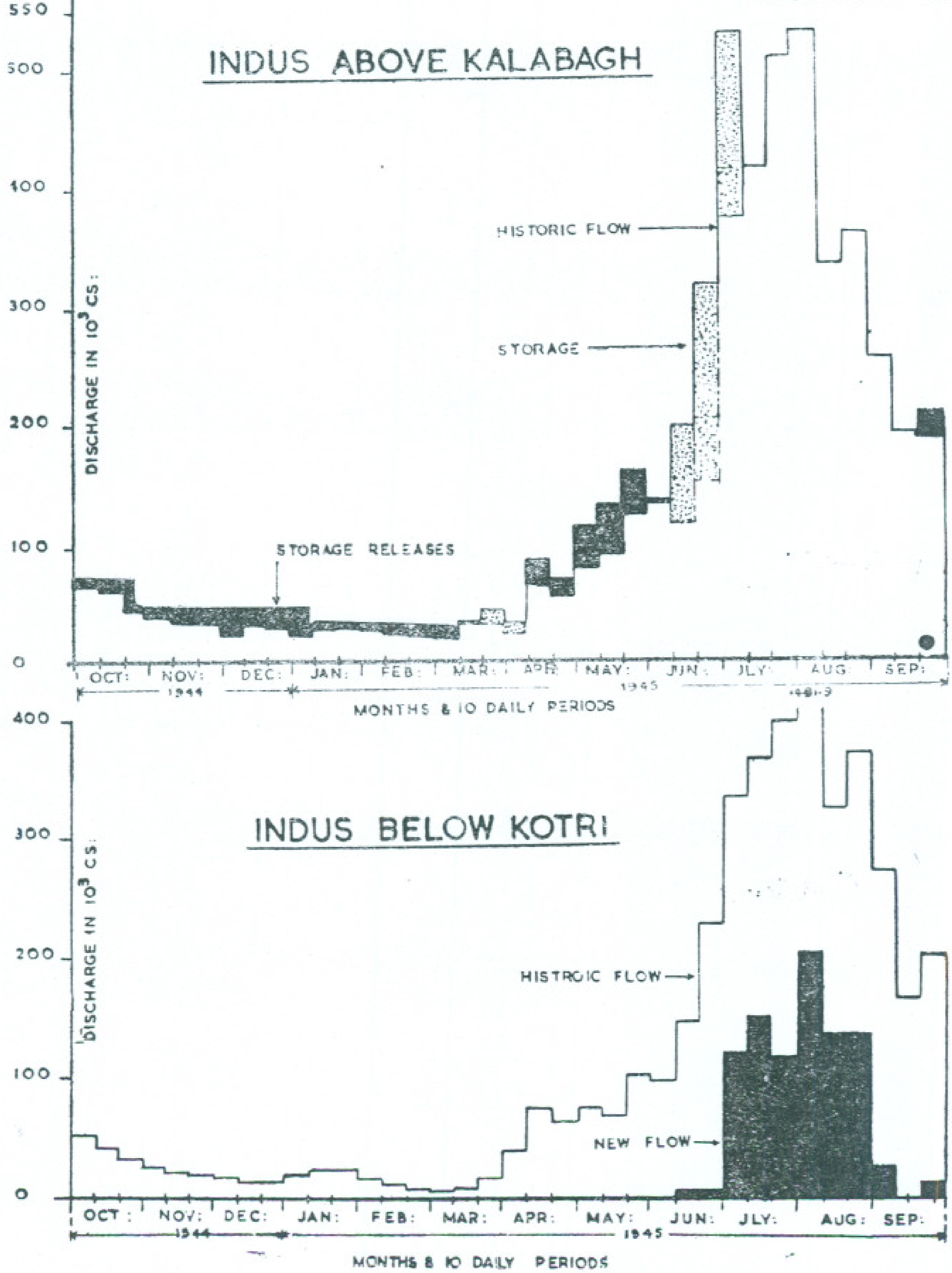
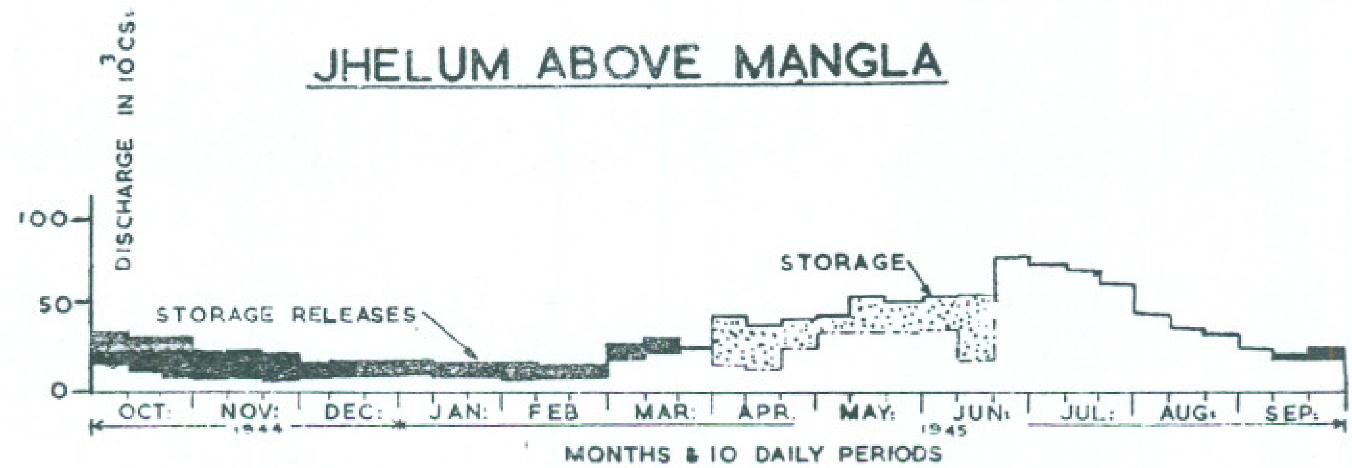


FIG: 3 - SHEET NO: 2

JHELUM ABOVE MANGLA



JHELUM BELOW RASUL

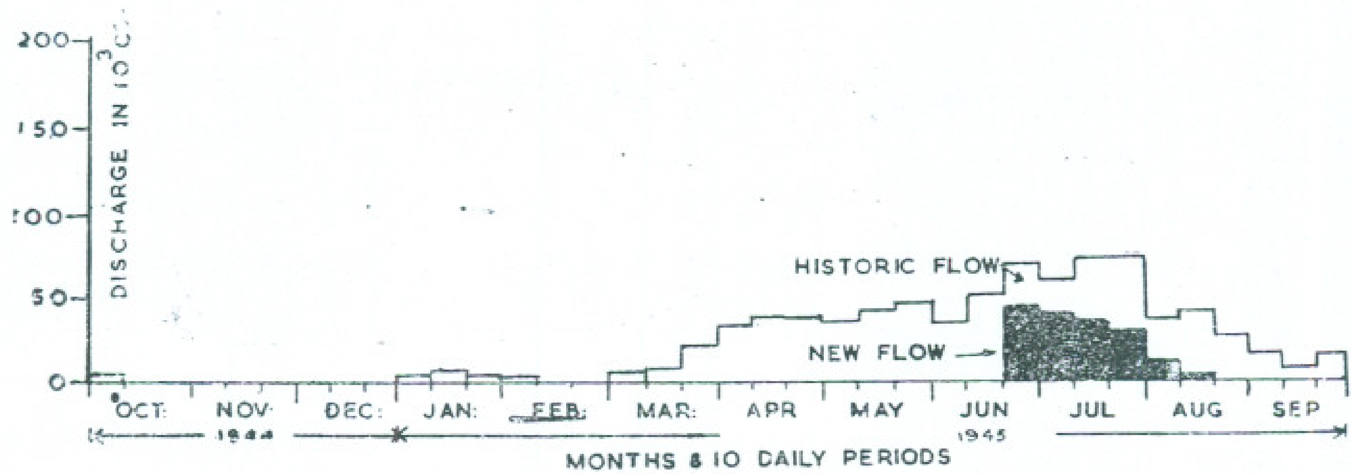
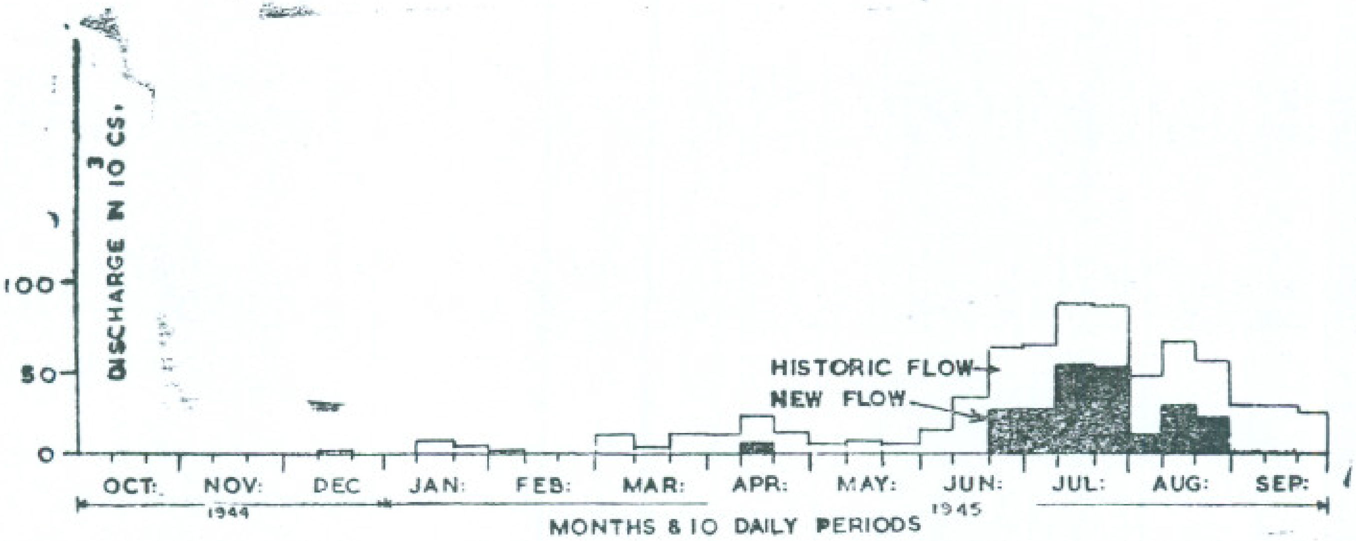
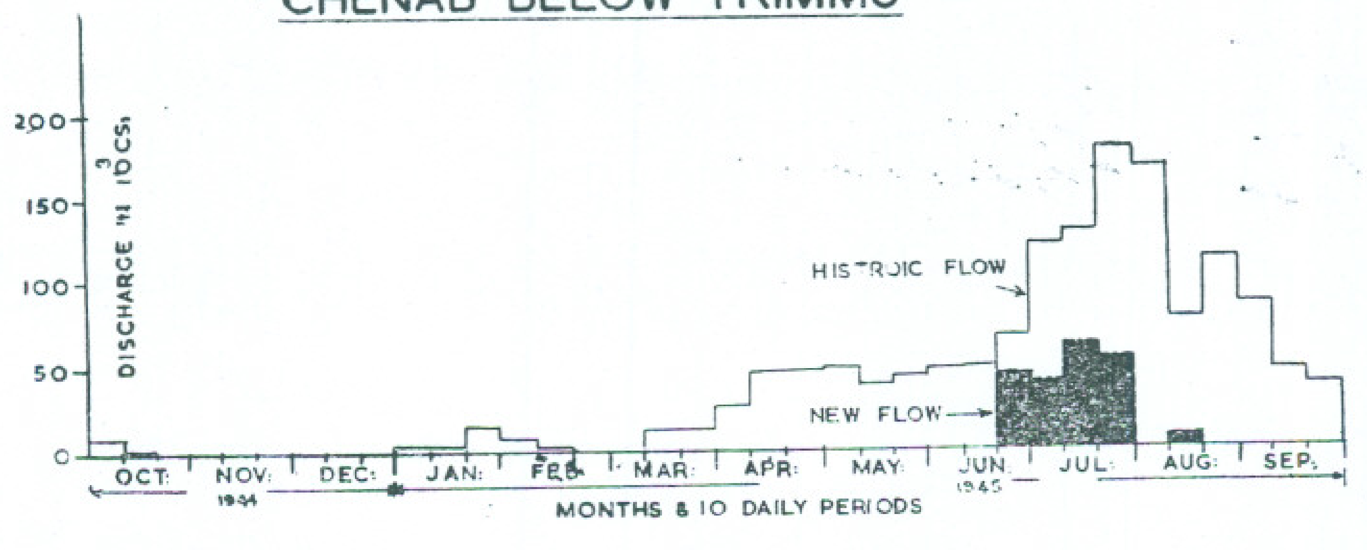


FIG: 3 - SHEET NO: 3

CHENAB BELOW QADIRABAD



CHENAB BELOW TRIMMU



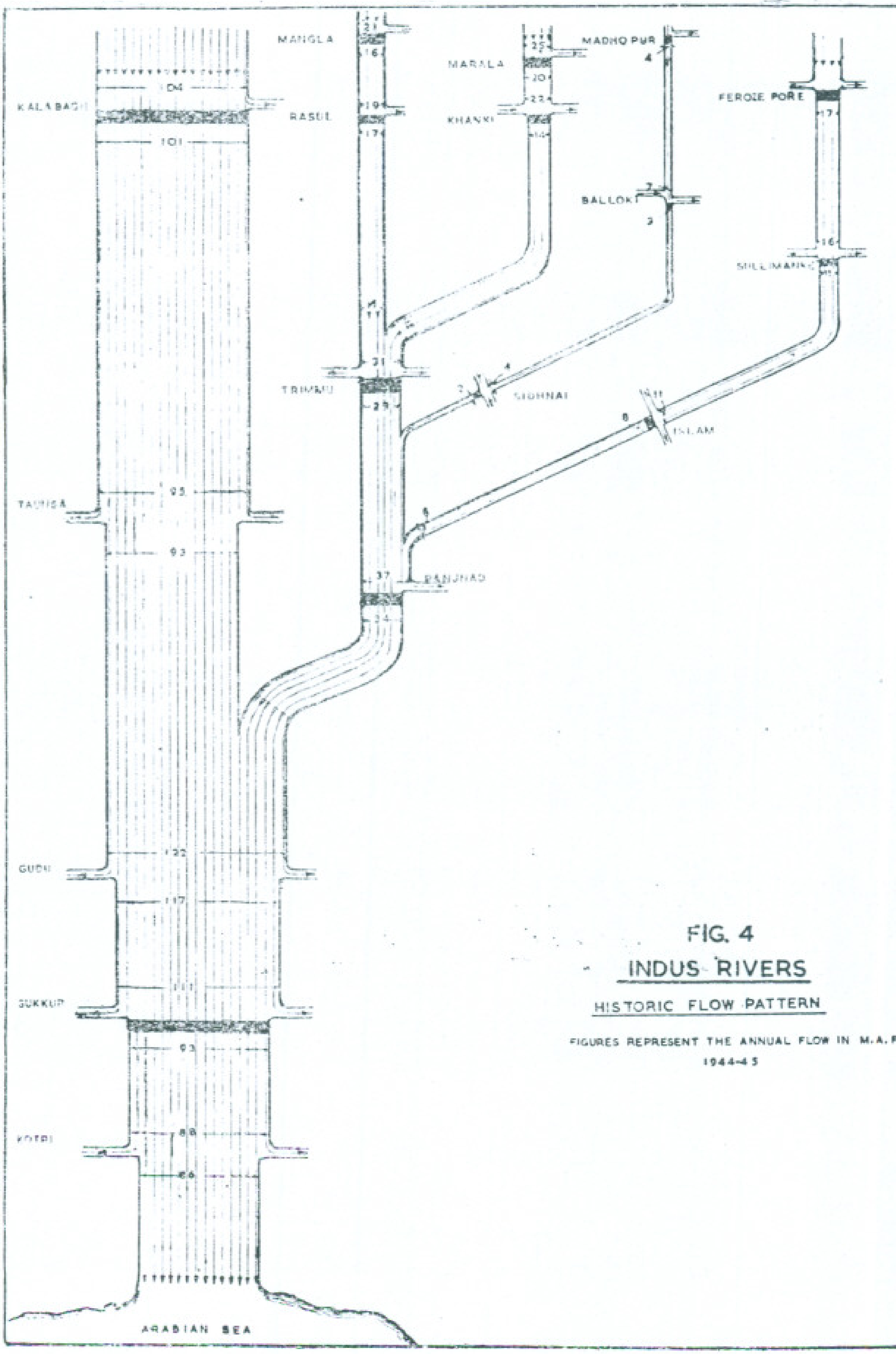


FIG. 4

INDUS RIVERS

HISTORIC FLOW PATTERN

FIGURES REPRESENT THE ANNUAL FLOW IN M.A.F

1944-45

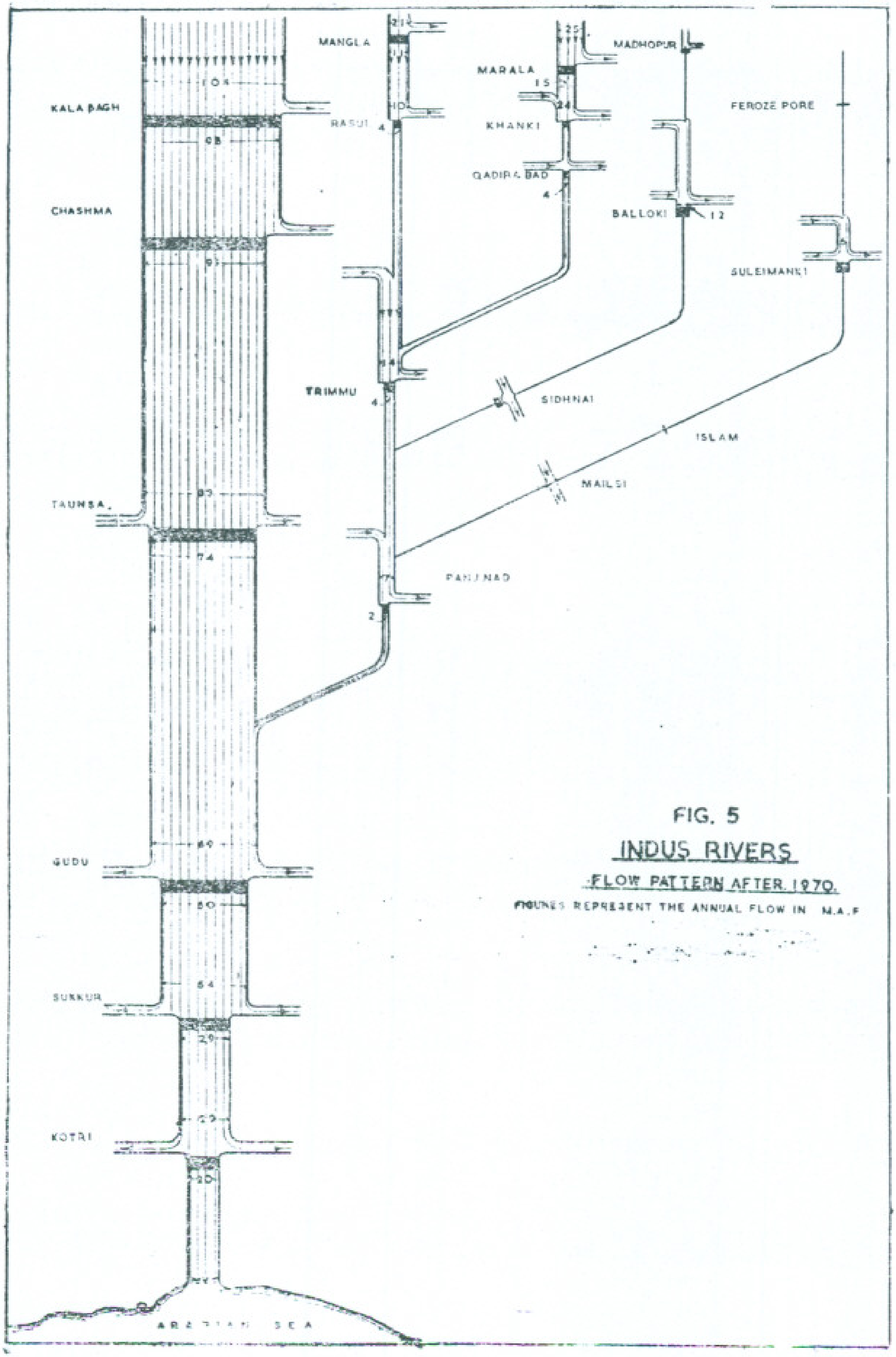


FIG. 5

INDUS RIVERS

FLOW PATTERN AFTER 1970.

FIGURES REPRESENT THE ANNUAL FLOW IN M.A.F

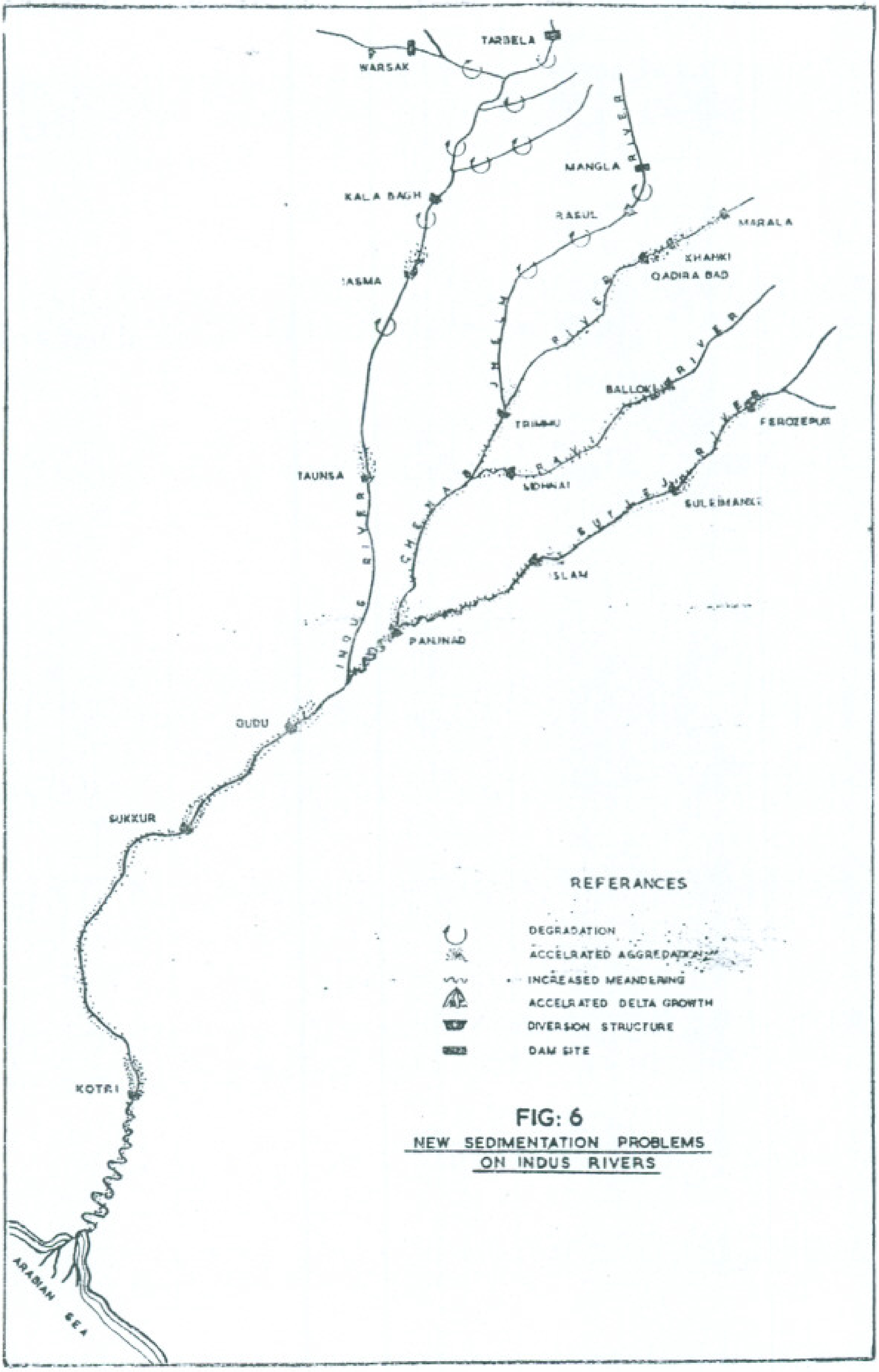


FIG: 6

NEW SEDIMENTATION PROBLEMS ON INDUS RIVERS