Paper No. 315—A

Studies in some Hydraulic Features of the Design of Taunsa Barrage

PART—I, ALIGNMENT AND LOCATION OF THE HEADWORKS.

By

DR. MUSHTAQ AHMAD*

Introduction.

For the design and construction of Taunsa Barrage on the mighty Indus, a very large number of investigations were undertaken in the Hydraulic Laboratories at Lahore and Hydraulic Research Station at Nandipur. It is one of the largest weirs under construction after partition. For its design a very close co-operation between research and design was maintained under the instructions of Mr. A. D. Ashraf, Chief Engineer (South). Full use has been made of the existing theories and known principles of design. In fact in some ways advances have been made on the existing theories and principles of design of weirs in alluvial rivers. Investigations on the alignment and location of weirs in alluvial rivers, estimation of maximum discharges and levels in Indus at Taunsa site on the optimum water-way, crest height and downstream floor level of the weir, on the alignment of guide banks, on optimum length of divide wall, on the effect of angle of approach of the current on the sediment exclusion, efficiency of still pond and semi open flow and on some design features of excluders and extractors have either been fully or partially completed. It is not possible to give the results of all these investigations in one paper yet each investigation is a part of the whole. More-over each investigation has been carried out in collaboration with a different person and sometimes with the help of more than one research worker. It is therefore proposed to discuss each investigation in a separate paper yet keeping it as a part of the whole study. An attempt will be made to prepare and submit separate papers on each investigation as and when they become ready. For the present a begining has been made and the results of only two studies on the alignment and location of weirs in alluvial rivers and estimation of maximum and minimum discharges and levels in river Indus at Taunsa are recorded.

* Dr. Mushtaq Ahmad, M.Sc., Ph.D., Hydraulic Officer, Irrigation Research Institute Lahore.

Alignment and Location of Headworks.

In Indo-Pakistan sub-continent the guide bank system of river training was first introduced by Bell in 1888 while constructing a bridge over River Chenab at Shershah. Spring who was associated with Bell in the first training works of the type, later in 1903 put together the principles and the experiences gained upto that time in his valuable paper[1] which even today remains the guiding light of the engineers on this subject. Since the inception of the idea, a large number of headworks and bridges have been constructed on the principle of the guide banks with marginal bunds on the two sides. The system was originally proposed for bridges but it has invariably been adopted for the barrages where the problems of pond creation, controlled flow, sediment exclusion and hydraulic jump are experienced in addition to those encountered in case of bridges It is time that we take stock of things. It was therefore planned to study the location of different weirs in the alluvial rivers and their future behaviour to assess the working of this system as far as the headworks are concerned.

Practice of Weir Construction and Considerations in Choosing the Site and Alignment of a Weir.

The usual practice in Indo-Pakistan sub-continent is to construct the barrage outside the main channel in a bye-river temporarily closed, or in an abondoned course or a creek which is dry in winter and the river is diverted to pass over the weir after its completion. Islam, Trimmu and Kalabagh weirs are some of the examples of this type of construction. The barrage can also be constructed in the main course of the river by putting coffer dams around the construction area and diverting the river during the course of construction.

The points that have to be kept in view while selecting the site of a weir are :—

(*i*) The site should be such as not to loose command in any area required to be irrigated.

(*ii*) It should be sufficiently near the commanded area to avoid long feeding channels.

(*iii*) In case the existing inundation canals are proposed to be converted into perennial channels, the site is limited to some extent by the position of the head regulators or the alignment of the existing inundation canals. Usually the inundation canals have to be fed, during the construction period.

(*iv*) In older weirs a well defined stable reach of the river with minimum width between the high banks was prefered.

(*v*) In case the commanded area locates the weir near about an existing bridge or a gorge, a weir site below the existing control point is preferred.

(*vi*) Easy haulage of material during the construction stage.

(*vii*) Easy protection of the ring bunds etc. during the construction period

(*viii*) Easy diversion after the construction period.

(*ix*) Attainment of approach to the barrage after diversion may be good for sediment exclusion from the canals.

The first three considerations fix the general locality of the weir in a wide area. The sites of Rupar and Rasul weirs were selected mainly from the fourth consideration. Such a site will however reduce the length of irrigation channels to be constructed in filling in the river Khadir. The fifth consideration will eliminate some of the future training works. Examples of this type of weir locations are, Ferozepur weir below railway bridge, Sukkur (Lloyds) barrage below Lansdown bridge and Bukher Island and Kalabagh below Kalabagh bridge. The sixth consideration will sometimes impose preferential choice of site nearer to the river bank which is connected by rail or road, Taunsa weir is a case of this type. It has rail and easy road connection only on the left bank. If the site is approachable from either bank equally easily, it is preferable to locate the barrage as far as possible in the middle of the high banks between which the river is likely to meander.

The last three considerations for selecting the weir site, *viz*, protection of the ring bund during construction, easy diversion after construction and attaintment of good approach for sediment exclusion, impose conditions which require a very judicious location of the position of the weir with respect to :—

(*a*) general direction of the river or the river axis.

(*b*) the river loops in the vicinity of the selected site.

To study the above problem, it was decided to examine the effect of different placements of the weir on the future behaviour at the Headworks for the 14 weirs that have since been constructed in the meandering alluvial rivers of the Indus basin.

Position of weirs in relation to the generai axis of the River.

In making an analysis of the problem the following terms were coined and are defined as below with reference to fig. 1.

Khadir axis—is a line passing centrally in the river course between the two high banks for a length to which back water effect goes.

Weir axis—is a line along which the crest of the weir is laid.

River axis—is a line parallel to the Khadir axis at the centre of the weir axis between the abutments.

Headworks axis—is a line perpendicular to the weir axis at the middle of the weir between the two abutments.

Angle between the river and Headworks axes.

The angle between river axis and the Headworks axis is a measure of obliquity. In this analysis the angle is considered to be positive both upstream and downstream of the weir if river axis is to right of the headworks axis and negative if it is to the left of the weir axis.

Asymmetrical weir shift.

The perpendicular distance S between the Khadir and river axis is a measure of asymmetrical placement of the Headworks in the Khadir.

To fully appreciate the behaviour of the river with respect to the river approach it is necessary to understand the function of the guide banks. In case of a weir the functions are :—

(*i*) To pass the flood normally over a weir to secure a straight run.

(*ii*) To pass the flood as uniformly as possible over the weir.

(*iii*) To obtain approach for good sediment exclusion conditions into the offtake.

(*iv*) The marginal bund protecting the canal should not be threatened by the river forming a loop behind any of the guide banks.

There are three important river stages *viz* low winter discharge stage, the bank-ful discharge stage and high floods. In the first two stages the river keeps within the banks and its approach to the headworks is controlled by the meanders. In the flood stage the river spills over the banks and obviously if the angle between weir axis and river axis is large the general river appaoach will be oblique to the upstream noses of the guide banks. Under such conditions of oblique approach, uniform flow over the weir cannot be attained. Formation of uniform channel has not been attained upstream of any of the weirs of Indus basin. Evidently whenever the river axis makes an appreciable angle with weir axis as in fig. 1. a shoal will appear by the side of right or left guide bank according as the river axis is on the right or left of the headworks axis, simply due to oblique approach in floods. It will also be noted that for a given positive value of θ, the more we shift the weir to the left of the Khadir axis *i.e.* the greater the asymmetric weir shift distance S, the greater will be the tendency to form a shoal along the right guide bank

On a large scale plan of River Indus and its tributories, the river axis, the weir axis and the headworks axis for the fourteen weirs were marked with respect to the North line. The angle between the river axis

and the headworks axis for different weirs are recorded in table I. It was noted from the study of the placement of the weirs and their future behaviour in forming an island within the guide banks that wherever this angle is positive and its magnitude large there is a tendency for a shoal to form along the right guide bank simply due to the reasons of oblique approach. It should be noted that the trouble increases when the angle increases. For a full discussion of the subject a distinction has to be made for the three types of handworks built under different conditions.

These are :

(*i*) Weir located at sites where the river enters from the hilly area or 'pubbies' into the alluvial plains.

(*ii*) Weirs located in alluvial plain not below the confluence of two rivers.

(*iii*) Weirs located below the confluence of two rivers.

The first type comprises Madhopur, Rupar, Mangla, Rasul and Kalabagh. For such cases the river upstream is confined and emerges from the foot-hills to enter the plains. Such weirs have been constructed rather loose and the approach is therefore not in a single channel but shoals and belas split the river and therefore the wrong orientation of a weir does not make itself so acutely felt as in the case of a tighter weir where the river meanders between its Khadir more freely and approaches the weirs in a single channel generating a single island within the guide banks.

Headworks in plains.

The weirs in plains such as Ferozepore, Sulemanki, Islam and Balloki show that where difference between the headworks and river axes is more such as at Islam, the trouble is acute. At Sulemanki the angle between axis of the river and axis of the headworks downstream of the barrage is large hence the trouble is experienced on the downstream side. On River Ravi at Balloki Headworks, the river axis is again located on the right side of the headworks axis with the result that an island appears on the right and flow concentration is experienced on the left. At Sidhnai, the angle is positive but is not very large, $\theta=(+13°)$; and there are islands or berms on either side with a central channel.

Headworks below the confluence of two rivers.

The headworks under this class are Trimmu below Chenab and Jhelum, and Panjnad below Sutlej and Chenab. Obviously for such a case any position of weir immediately below the confluence of two rivers meeting at an angle, knowing that generally the two weirs are not simultaneously in spate, can not satisfy the conditions of straight approach. In locating the Trimmu weir, it appears that greater weight has been given to Jhelum river, as the headworks axis makes a bigger

angle with axis of River Chenab than it does with the axis of the river Jhelum. Actually Chenab being the dominent of the two rivers has created a bad approach to this weir and the river concentration is completely on the right side and heavy embayment has occurred above the right guide bank nose.

From this study it is concluded that the weirs should be located at some distance downstream of the confluence so that the river may approach the weir as one, and the individual effect of gbliqus approach of the two rivers is not felt within the headworks limit.

Position ef weir in relation to river loop in the vicinity of selected site.

Experiments on the design and behaviour of spurs by the author[2],[3] have conclusively shown that whenever a spur or a guide bank head is located in an alluvial stream approaching it in a perpendicular or at an oblique angle, a scour at the nose and a shoal at its back invariably make their appearance. For a straight approach to the weir the island can be made to form any where between the guide banks with the help of regulation but if the approach is oblique to any guide bank, control will be lost and island will form behind the attacked guide bank whether we like it or not. In case of bridges an island within a guide bank adversely effects only the two functions of guide banks namely passing of flood normally and uniformly under the work, but in case of a weir a suitable curvature of flow is essential for sediment exclusion[4] from off-taking channels. The realization of correct flow curvature depends on the formation of islands at the correct place which in turn depends to a great extent on correct river approach

It has to be noted that apart from the consideration of alignment of headworks axis with respect to river axis, the location of a weir with respect to the river loop is also responsible for the approach to the weir for a number of years after its opening and determines the need of training works upstream. This is particularly true for our usual practice of constructing the weir in dry or dried creek and later diverting the river over the weir, Suppose three possible sites at A, B and C with respect to a river loop in (fig 2) where probable river courses after the diversion are also shown. Evidently for site A, the diversion will be easy as the cuts take off from the outside of a curve, the approach, to start with, will be straight, and any loop behind a guide bank head will only appear when upstream meanders slowly travel down by progressive caving of the outer bank. This will take long, perhaps a decade or so, affording a long spell of care free period in which no immediate training works are needed. For a weir at site B, the approach, from the very start will be very oblique, forming a shoal behind the guide bank immediately after the diversion resulting in heavy silting in the right bank canals, if any. The weir at position C will behave still worse. The locations of Panjnad and Islam headworks with respect to river loop (fig.3) correspond to positions A & B and the river approach after diversion

supports the conclusion. Above Islam an immediate need of spurs was felt and Murphy spur was constructed, but at Panjnad no spur has yet been needed.

Location of Taunsa Barrage.

The conclusions from the above studies are summarised below :—

1. When-ever the angle θ between Headworks axis and river axis is great, invariably we get trouble in the form of concentration of flow on the one side and island formation on the other within the guide banks. Islam, Sidhnai and Balloki are examples of this type where oblique approach due to the difference in the axis of the headworks and river axis have caused the trouble.

2. It is also noted that if the river axis is to the right of the headworks axis the concentration of flow is generally on the left side with tendency to form an island on the right and vica versa.

3. When Headworks are located below the confluence of two rivers these should be located sufficiently below the confluence. It has to be kept in view as to which of the two rivers is dominant and due weight must be given to that river in locating tne weir line.

4. In case of only one river, the alignment of the weir should be such that the angle between headworks axis and river axis is minimum, This will give good approach condition to the barrage in floods.

5. Location of the barrage on one side of the centre of 'Khadir' will increase spill area on one side of the weir thereby enhancing the tendency to form a shoal along the guide bank on that side. The greater the asymmetric weir shift distance S, for a given angle θ, the greater will be the tendency to form a shoal.

6. The most suitable position of weir when constructed dry is below the outer side of a convex bend upstream of which the river is straight for some distance.

7. An in-opportune site on the inside of a convex bend will give oblique opproach to the guide bank head forming an island along it within the guide banks and will considerably increase sediment entry into the canal taking off from that bank.

To satisfy the conditions of minimum angle between Headworks axis and the river axis angle of 10° with the north line as shown in fig. 4 was recommended for Taunsa weir. It will be seen that the location is on the

outside of the convex bend, the river above which is straight for some length. The weir is located towards the left of the Khadir axis in the left arm of the river which was closed by bunds leaving enough waterway to pass the floods during construction period through the central and the right arm of the river. This position was also suitable due to reasons of the only existing rail and road connection from the left bank. The greater spill area on the right which shall result from the asymmetric placement is proposed to be corrected by some training works.

Acknowledgments

The author considers it his duty to thank Mr. A. D. Ashraf Chief Engineer with whom he had enlightening and thought provoking discussions on the subject at the Field Hydraulic Research Station. The investigation was initially started after discussion with Mr. R. F. T. Farrant who not only allowed the investigation to be taken up, but also took keen interest by giving guidance and help at different stages of the study. I am indebted to him for that.

TABLE I

S. No.	Name of Headworks	Name of River	Angle between Headworks axis and River axis		Remarks
			U/S	D/S	
1	Rupar (Bharat)	Sutlej	+33°	+43°	
2	Ferozepur (Bharat)	,,	+12°	+ 2°	
3	Sulemanki	,,	—11	+37	
4	Islam	,,	+32	+ 5	Large shoal (bela) on the right side within the guide banks
5	Panjnad	,, Chenab	—31 } +33 }	—10	
6	Madhopur (Bharat)	Ravi	+17	—43	
7	Balloki	,,	+25	+ 7	Large shoal (bela) on the right side within the guide banks
8	Sidhnai	,,	+13	+ 6	Bela on the right
9	Marala	Chenab	+12	+ 1°	
10	Khanki	,,	+ 6	+ 9	
11	Trimmu	, Jhelum	—33 } +16 }	—18	
12	Rasul	Jhelum	+18	0	
13	Kalabagh	Indus	—36	—15	

REFERENCES

1. **Spring F.** ... River Training and Control, Government of India Publication, Paper No. 153, Simla.

2. **Mushtaq, A.** ... Experiments on design and behaviour of spur dykes. Proceedings Minesota International Hydraulics Convention. I.A.H.R. & A.S.C.E. 1953

3. **Mushtaq, A.** ... Spacing and Projection of spurs for bank protection, Civil Engineering and Public Works Review, March & April 1951.

4. **Mushtaq, A.** ... Some aspects of design of Headworks to exclude sediment from canals. Proceedings International Association for Hydraulic Research, Fourth Meeting, Bombay 1951.

413

PAPER NO. 315-A

FIG: 1

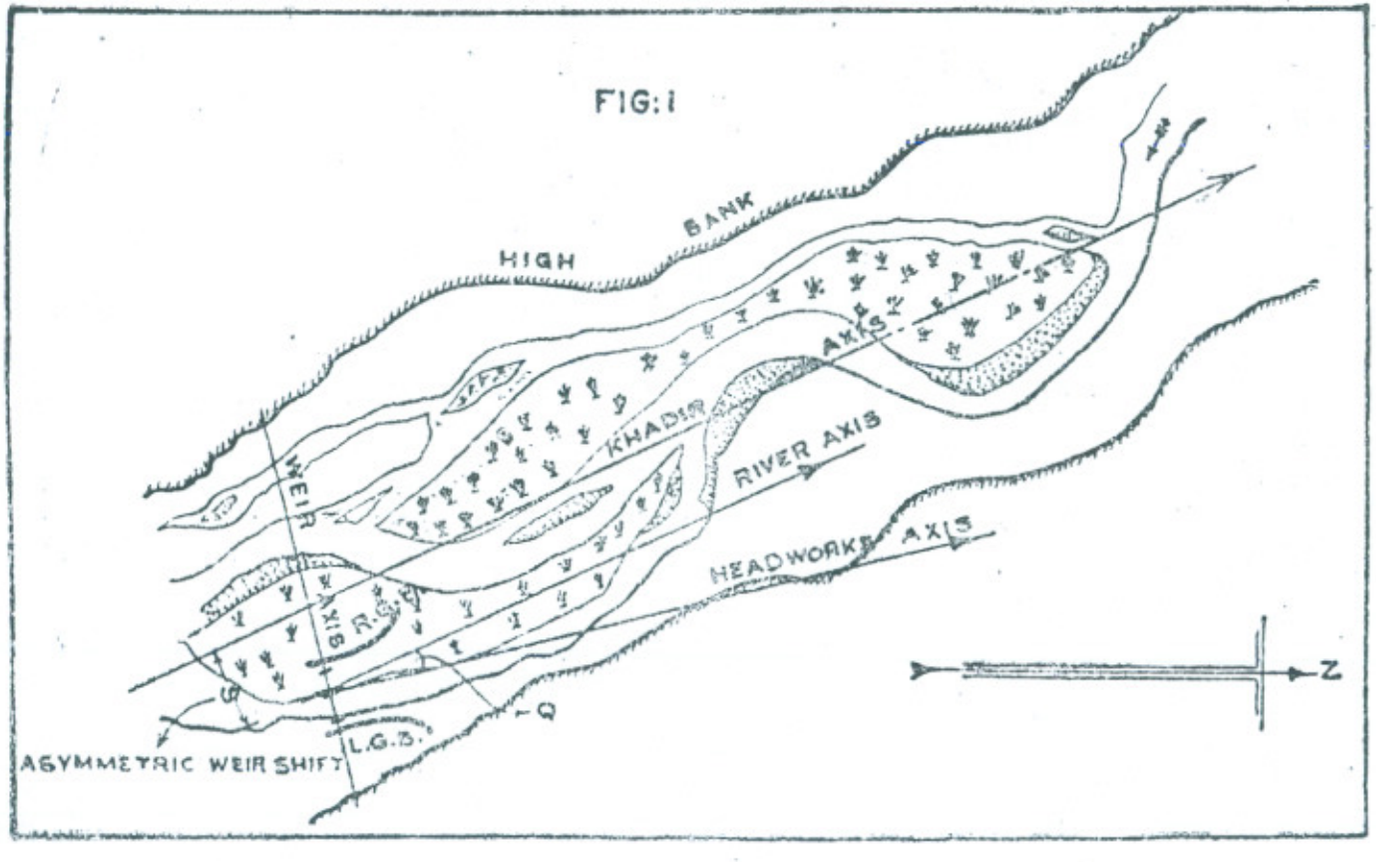


FIG: 2

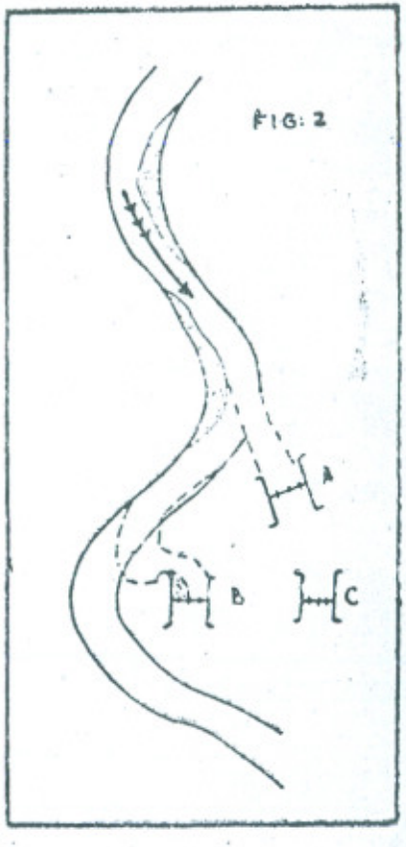
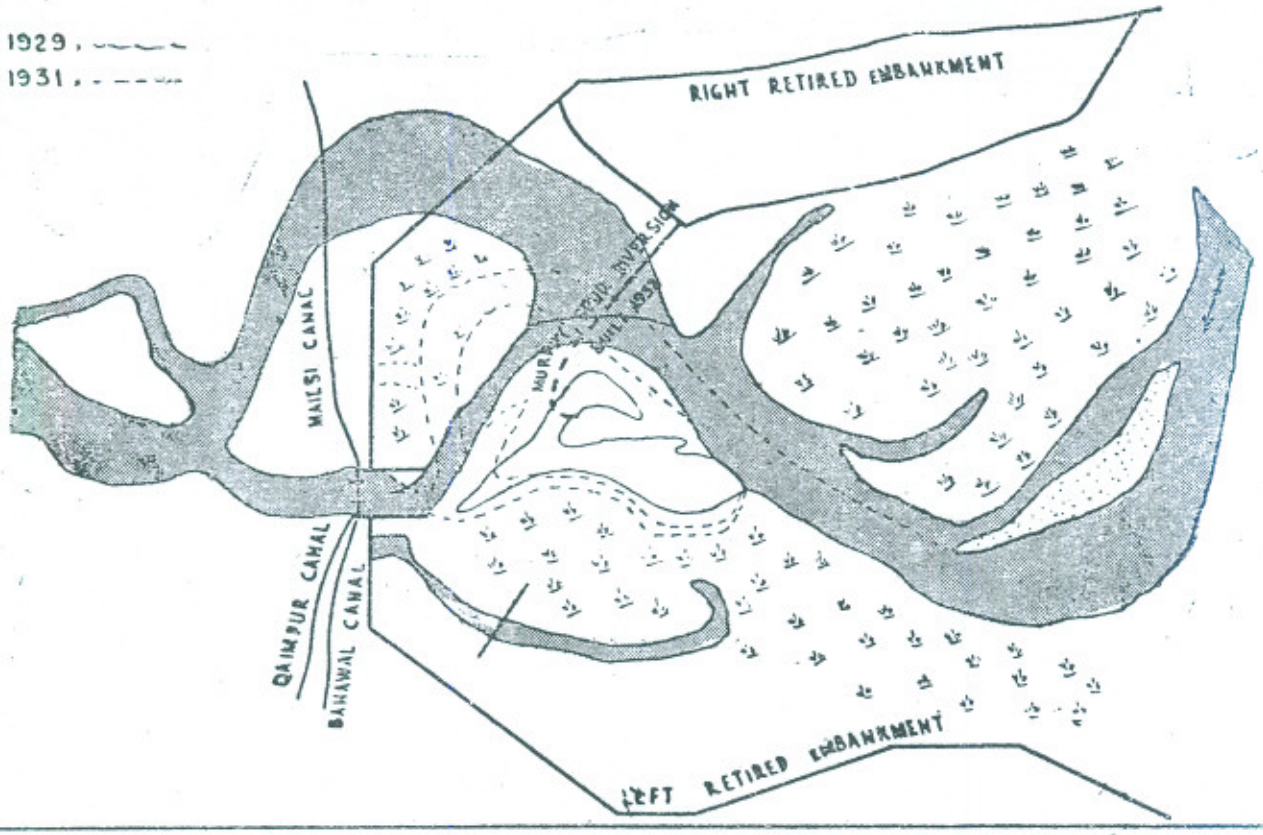


FIG.3

PAPER NO. 315-A

SURVEY PLAN OF RIVER SUTLEJ AT ISLAM HEAD.WORKS



SURVEY PLAN OF SUTLEJ RIVER AT PANJNAD HEAD.WORKS.

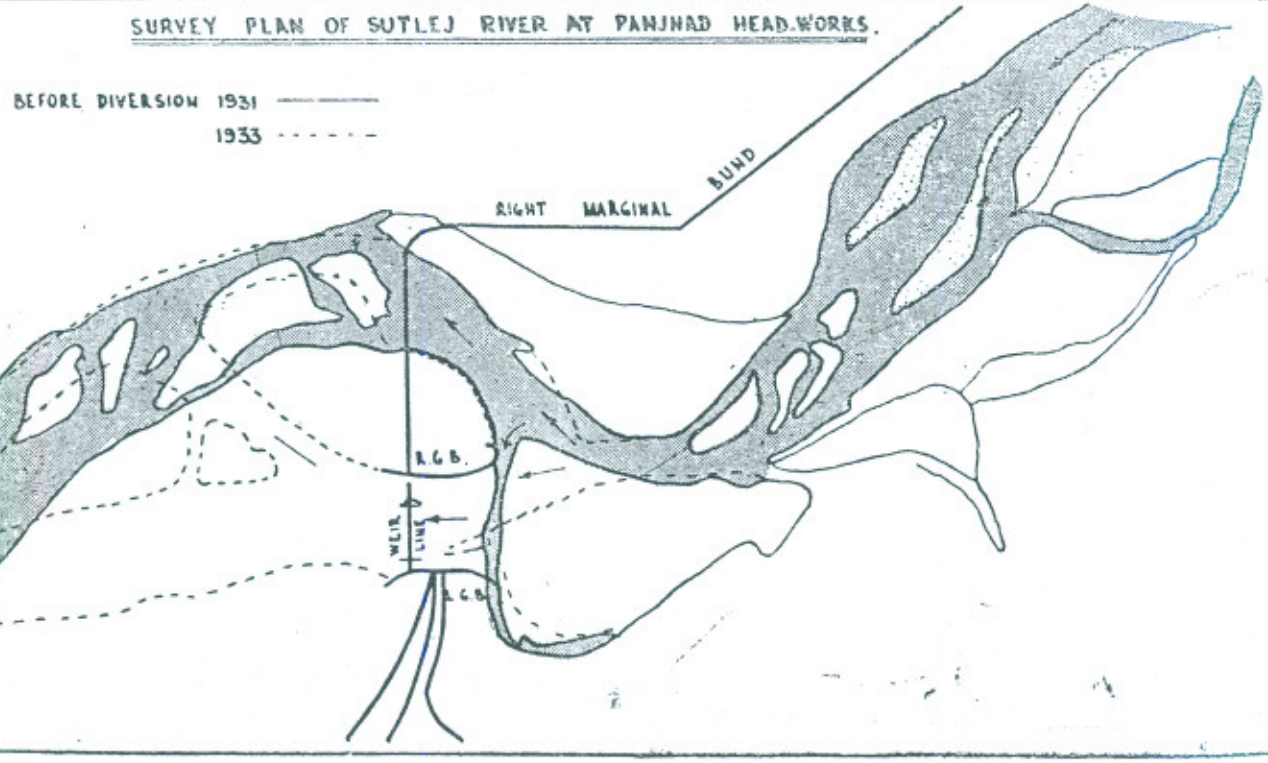


FIG 4

PROPOSED TAUNSA BARRAGE AT RIVER INDUS

