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TRAINING WORKS, RIVER CONTROL AND METHODS OF REGULATION AT RUPAR, KHANKI, MERALA AND RASUL.

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Introductory.

The alluvial rivers of Northern India flow through comparatively flat country, and the river valleys or *khadirs* in which these rivers flow, vary in width from a mile or two in the case of the Ravi, to as much as 16 miles in the case of the Indus. The usual practice in the Punjab is to construct the weir or barrage outside the main river channel, in some minor creek which is dry in the winter, and then to divert the main river channel through it. Moreover, the weir as constructed is generally much narrower than the river width during floods, and the wandering river has to be trained so that it may flow between the two abutments of the weir.

The training works generally consist of Bell's or guide bunds upstream and downstream of each abutment equal to or as much as twice the length of the weir upstream and from 500 to 1000 feet or more downstream.

In addition to the guide bunds, it sometimes becomes necessary to protect the river banks upstream or downstream by means of spurs, which may considerably affect the direction and location of the river channels.

After the river has been trained, it can be controlled by the manipulation of shutters or gates in different parts of the weir or sluices, so as to regulate the distribution of discharge along the weir and the water surface levels upstream.

The two fundamental requirements at every canal headworks are:—

(*a*) to pass floods over the weir, normal to it, as uniformly as possible and

(*b*) to keep the canal open as long as needed without causing it to silt, and the methods adopted for river training, control and regulation must necessarily satisfy both these requirements. The first is necessary f o he safety of the weir so as to prevent any portion of it being over-strained and the second is necessary to give the zamindars an uninterrupted supply of water free from harmful silt.

Most of the troubles of irrigation engineers are due to coarse silt finding its way into the canals and this makes silt exclusion at the head-works very necessary.

It is the purpose of this Paper to describe and discuss the existing training works and methods of river control at the four shuttered weirs in the Punjab, *viz.*, Rupar, Khanki, Rasul and Merala, the steps taken at each of these weirs from time to time to exclude silt from the canal, and to find out the best methods to be adopted in future, consistent with the safety of the works during floods.

Historical.

Rupar Headworks, Sirhind Canal.—The Sirhind Canal was opened in 1882 and had not been running for more than twelve months when a steady deposit of silt and weed growth were noticed in the first 15 miles of its bed. The canal could not be fed and it was decided in 1885 to raise the masonry crest of the weir, which was originally constructed at R. L. 865, by 1·5 feet, over its whole length and surmount it by falling shutters 3·0 feet in height. The undersluice gates were also raised, so that supply at the regulator could be headed up to the top of shutters, R. L. 869·50. In 1888, the height of the shutters was further increased by 2·5 feet, by adding a collapsible flap and the undersluice gates were simultaneously raised, so that the river could be headed up to R. L. 872·0.

From this time, the greater part of the regulation of the river was done by means of the undersluices, owing to the difficulty and time involved in raising the shutters by hand power, the only means then available.

The evil results of the system, which led to the gradual silting up of the head reach of the canal, were not at the time realized, and by 1892, matters had reached such a stage that complete blocking of the canal by silt was greatly feared.

The canal head regulator was originally constructed with its cill at R. L. 859, *i.e.*, at the same level as the canal bed and only 2·0 feet above the undersluice floor.

The first officer who realized that the silting trouble was due entirely to faulty methods of regulation, was Lt.-Col. Ottley, R. E., who in a note dated 24th January, 1893, laid down the principle that in order to exclude silt from the canal, the water should be drawn in over as high a raised cill as possible from a still pond or silting tank. His first measure was to remodel the regulator. The water way was increased from 195 to 273 feet, the permanent masonry cill was fixed 7·0 feet above the floor of the Regulator, *i.e.*, at R. L. 766·00 and in addition a sliding cill 2·25 feet high, working behind this, was provided.

The second important part of Col. Ottley's preventive measures was the formation of a still pond or silt trap in front of the regulator from which water, free from the heavier grades of silt, could be drawn off for the canal supply. To obtain this, he proposed a divide groyne running from the right flank of the undersluices paralell to the face of the regulator to a distance of 1000 feet upstream. This was constructed but the length was reduced to 710 feet.

These remedial measures were carried out in 1894, but do not appear to have been fully made use of in the manner intended by Col. Ottley until 1901, and in the interim the silt trouble continued.

At this very time, the tendency of the river above the headworks to eat away its left bank first attracted serious notice, and the advisability of checking such action was considered, mainly as an aid to the solution of the silting difficulty in the canal, which was then in an acute stage.

Nothing, however, was done, and further erosion continued until in 1897, the possibility of the headworks being outflanked, and of the silt question (which was considered to have been largely solved in 1894) being reopened, led to the construction of Spurs Nos. 1, 2 and 3 (see Plate I).

These three spurs protected a frontage of 2 miles above the weir and are said to have secured excellent results in directing the left river channel straight down to the undersluices. But erosion continued above Spur No. 3 and as no attempt was made to check it, the result was that the left channel was deflected towards the right and large shoals were thrown up between Spur No. 2 and the canal regulator.

It was not until 1901 that definite orders were laid down that the regulation should all be done by means of the shutters on the right flank of the weir and that the undersluice gates were to be kept completely shut, except when used for scouring out the pocket, or when the canal was closed during passage of big floods. This system of regulation, in accordance with which the shutters on the right flank of the weir are dropped first and raised last, is said to have been rigidly adhered to, in spite of periodical proposals from the local officers to modify the rules to the extent of working the shutters in the other bays, chiefly to control the silt deposits above the weir; all such alterations were fortunately vetoed by successive Chief Engineers on the ground that the existing method, by keeping the main stream of the river away from the regulator and drawing the canal supply across the width of the river from the right to the left flank, provided an extensive silt trap and ensured clear water entering the canal, and that since the latter object was attained, no alteration seemed either necessary or desirable.

By this method, the river developed two deep channels, one on either flank and in 1922 a high shingle bar was noticed opposite Bays 1 to 4. With the object of trying to keep down the height and width of the shoal, the system of regulation was modified to the extent of dropping the shutters in the order 4, 3, 6 and 5 and raising in the reverse order. The result was not satisfactory and the original system of dropping the shutters from the right flank was reverted to.

The still pond system of regulation was abandoned at the end of 1930 and *the undersluice gates were lifted on the 27th August* 1930 *with the canal in flow, for the first time since* 1901.

The chief reasons for this change were :—

(1) that the time lost in cleaning the pocket was detrimental to irrigation, in that it disorganized the regulation, when demand was keen, and

(2) that if the shutters were dropped with only a small surplus in the river, the standing wave formed below the downstream protection of the weir and damaged the toe wall.

In 1930, the result of this change was reported to be highly satisfactory, but, in 1931, it was reported that more silt entered the canal during the period of its trial than had entered in the 3 preceding years. In 1932, a reversion to the old system was ordered, subject to the modification that the undersluices were to be kept open so long as the downstream water level at the right flank was below a certain level, and ultimately in 1933, a reversion was made to the still pond system as it existed prior to 1930, this being the system found most suited to the Sirhind Canal.

Training Works.—As stated above, Spurs Nos. 1, 2 and 3 were constructed in 1897, with the twofold object of stopping the erosion on the left bank and helping in the solution of the silt trouble in the canal. A new spur, No. 4, was added in 1901.

The tendency of Spur No. 3 to deflect the stream away from the regulator was noted by Messrs. Bird and Laurie in 1911, and they had Spur No. 3 shortened in consequence, but the result was further erosion of the bank upstream.

The tendency of the river to eat away its left bank continued and became more pronounced till in 1913, it was decided to construct Spurs Nos. 4, 5 and 6, shown in Plate I.

Thus briefly speaking, the measures adopted at Rupar for silt exclusion consist of :—

(1) Raising the pond from R. L. 865·0 to R. L. 872·0 or by 7 feet, and raising the canal cill by the same amount.

(2) Adding a long divide groyne between the undersluices and the rest of the weir.

(3) Adopting the still pond system of regulation and passing the surplus river discharge by means of the shutters on the right flank of the weir, and

(4) Constructing spurs along the left bank of the river to deflect the main channel away from the canal head regulator.

The effect of these various measures will be discussed later.

Rasul Headworks, Lower Jhelum Canal.—

The Rasul weir and the headworks of the Lower Jhelum Canal were completed in 1902.

The level of the weir crest varied, rising by 0·15 ft. in each bay from left to right. Hinged shutters 4·0 ft. high and 6·0 ft. wide were provided over the weir, with their top at a mean level of 711·80, but in order to prevent these from being overtopped by sudden floods, the limit fixed for heading up was R. L. 710·0.

The undersluice floor was at R. L. 701·0, which was also the floor of the regulator and the bed level of the canal, the crest of the cill being at R. L. 704·00. The regulator floor was designed at R. L. 699·00, but owing to the high spring level in the river bed, it was decided to raise it by two feet, and as a consequence the slope of the canal was increased from 1/6666 to 1/4348 to absorb this difference of two feet.

There are no training works at Rasul except the stonefaced embankment (Bell's Pattern) connecting up with the right river bank upstream and downstream. (See Plate II, fig. 1).

The left bank of the river is high and is pitched with stone for a length of 2890 feet above the regulator.

The silt troubles of the canal were " a source of constant complaint and administrative inefficiency, from the opening of the canal onwards. As early as 1903, it was a cause of anxiety to the engineers in charge."

As the water level above the weir was limited to R. L. 710·0, the shutters were dropped early in the summer and were downthroughout the flood period and the river flowed over the weir uncontrolled. Under these circumstances, as the average bed level of the river was 709·4, silt up to this level was found everywhere, and the canal silted up in the first 3 miles and on occasions it was not possible to pass full indent over the silted bed.

The rules of regulation of supply were first drafted in 1905, and provided for passing the river's surplus flow over bays Nos. 5, 6, 7 and 8 of the weir, i.e., at the end of the weir furthest from the canal head, in imitation of the Rupar practice.

By January 1907, the shutters in the two left flank bays of the weir had to be increased in height from 4 feet to 6, with the result, it is said, that silt was excluded from the canal by scouring the sluice pocket, and the canal bed was scoured to a depth of 3 feet below designed level in its first mile.

In June 1907, a big flood occurred, all the weir shutters had to be dropped, and the canal silted up. Later on the shutters were raised again and the canal scoured out.

In August, the canal again silted up, but in September the shutters were erected once more, and the silt disappeared.

By the end of 1907, the shutters of the four left hand bays of the weir had to be increased in height from 4 feet to 6.

All went well thereafter, till 1910, a year of good supply in the river (though no high floods), which necessitated the dropping of the shutters. Silt troubles were again much in evidence, but on the subsidence of the river in September, the weir shutters were erected and the silting of the canal reduced.

In 1911-12, Tee spurs were constructed on either flank downstream of the weir, with the object of contracting and deepening the stream.

The regulation rule regarding the order of dropping the shutters as drafted in 1905 was modified in 1912 and it was laid down that these should be dropped in the order 7, 6, 5, 4, 3, 2, 1 and 8 and raised in the reverse order. In 1915, it was further modified to 5, 4, 3, 6, 8, 2, 1 and 7 by way of keeping the main stream as much as possible towards the centre of the weir. The rotation subsequently recommended by Mr. Woods was 2, 3, 4, 1, 5, 6, 7 and 8.

The headworks and weir were thoroughly remodelled during the period 1914-21. The remodelling of the weir consisted of dismantling the steel shutters, 6 feet high, which had previously been hinged to the masonry crest of the weir, and of raising the masonry crest of the weir from its original (mean) level of 707·80 by 3·7 ft. to R. L. 711·50. The remodelling of the canal head regulator consisted of dismantling the masonry crest wall, the top of which was 3·0 ft. above the level of the floor (701·0) and of substituting for it a reinforced concrete crest wall at a level of R. L. 707·67.

The main object of remodelling the headworks, as described by Mr. Woods in the preface to Irrigation Branch Paper No. 22, was to keep the perennial stream of the river flowing past the canal head; the surplus flow of the river, over and above the requirements of the canal, being passed through the weir sluices up to the discharging capacity of the latter; while further surpluses, representing the excesses of floods, were left to spill over the level masonry crest of the weir, at its new level of R. L. 711·50.

The canal head regulator gates were designed to skim off the top water of the river's flow, at the lowest practicable velocity, carrying with it a minimum of coarse silt into the canal.

An examination of the survey plans attached to Punjab Irrigation Branch Paper No. 22 will show that, during this period, the main channel of the river was on the right and the canal was fed from right to left, and this continued up till 1928. Plate II, fig. 1 is typical of the period before 1921 and fig. 2 of the same plate of the period after 1921.

All went well till the big floods of 1928 and 1929, when the weir was badly damaged. During 1929, the river had two main channels, one on the right flank and the other on the left, the left bank channel flowing approximately along the edge of the high *bela* upstream of the weir, as shown dotted in Plate III, fig. 1. There was also a small creek between the *bela* and the left bank, which did not flow during the cold weather.

In this year (1929), the river developed its right bank channel owing to the crest being removed in Bays 7 to 8 of the weir. It also obliterated the left bank channel entirely and instead of it developed the creek, as shown in firm lines in fig. 1, Plate III.

Shutters in Bays Nos. 3 and 4 were erected in 1929-30 and those in Bays Nos. 5 and 6 in 1930-31, when the crest in Bays 7 and 8 was also restored. It was hoped that a main central channel would develop, but the river kept to two channels, one near either bank, which carried off equal discharges during the flood season. The regulation rules laid down that shutters should be dropped in the order 6, 5, 4 and 3 and raised in the reverse order, which was done. At the end of the flood season when the river commenced to fall, it was found that the right channel was carrying a greater discharge than the left, and a sand *bela* formed adjacent to the main *bela* in the middle, and extended to within 100 feet of Groyne No. 4. The discharge of the left channel decreased considerably and it was feared that the left channel might silt up and the right channel might be cut off from the undersluices and regulator by the sand *bela* joining up with Groyne No. 4. To cut this *bela* back the order of dropping and raising the shutters was reversed. The result was that water was pushed towards Bays 3 and 4 and the sand *bela* was cut back by water being pushed through between Groyne No. 4 and the *bela*. When all shutters were raised all the supply in the river was passed through the regulator and the undersluices. This caused the left bank channel to develop and this became the main channel of the river.

In 1932, during high supplies approximately 50% of the discharge approached the weir from each of the right and left channels.

The shutters were dropped in the order 3, 4, 5 and 6 and raised in the reverse order.

Towards the end of August, 1932, the left channel immediately upstream of the weir developed and was ultimately carrying the entire cold weather supply.

It was feared that if further erosion of the left bank developed to a serious extent, it would result in the river approaching the undersluices direct and it might become necessary to forcibly develop the right channel by connecting the upstream *bela* to Groynes 2 or 3 in a manner similar to that adopted at Khanki.

The still pond system was tried during this year and its adoption resulted in less silt entering into the canal.

During high supplies, due to the rising of the downstream levels, lack of afflux became a matter for serious attention and it was decided to raise the crest in the shutter bays, Nos. 3 to 6 by 2·0 feet.

The work was done during 1932-33. The increased afflux obtained made it possible to allow a heavier silt deposit in the pocket before having to close the canal for sluicing, with the result that sluicing closures became less frequent.

During 1934, the river in high supply showed a greater tendency to divide just below line 7-8, as shown dotted in Plate III, fig. 2. About 70% of the total supply passed down the left channel and the balance through the right, which was augmented by about 20% flowing through the diagonal channel above the *bela* on line 11-12. This diagonal channel silted up considerably as the season proceeded.

An important change took place on line 13-14, the central *bela* extending considerably to the right. All attempts made by variations in method of shutter regulation such as keeping the shutters in Bay 6 down in low supplies, etc., proved useless in scouring this extension to the *bela*.

The waterway between upstream Groyne 4 and the central *bela* became very restricted.

During 1935, in high supplies the river bifurcated above section line 9-10, but the right channel took only 1/10th to 1/20th of the total discharge. Below 25000 cusecs, the right channel at this point ceased to flow.

Lower down, between section lines 11-12 and 13-14, the left channel again bifuracted and about 50% of the supply was reported to be passing down each channel to the weir, the flow in the left channel being direct to the undersluices.

At the beginning of the monsoon season of 1936, the right approach channel to the weir silted up badly, with the result that the river developed a set to the left which was not only inimical to the safety of the undersluices, but which resulted in fairly severe cross flow from the left channel along the upstream weir aprons and into bays 5 and 6 thereby threatening damage to the weir and connected works. In order to check this set of the river and in order to restore the equal distribution of discharge in each approach channel, the following measures were adopted :—

(*a*) A leading cut about 50 feet wide and 300 feet long was made from the right channel to the main stream at a point about $2\frac{1}{2}$ miles above the weir, as shown in fig. 2, Plate III.

(*b*) A divide bund was constructed from the upstream face of pier No. 4 of the weir to the central *bela* also shown in fig. 2, Plate III, to prevent flow taking place from the left channel into the right hand bays.

During 1937, the shutters in Bays Nos. 5 and 6 were kept down and a high level maintained on the left side of the river and the right channel developed rapidly, so much so that a silt bar formed in the left channel and at the end of the flow season in October, the canal had to be fed by means of a temporary gunny bag bund in Bays 7 and 8.

The same trouble was experienced during 1938, but a 4-day scouring closure of the canal replaced the gunny bag bund of the previous year.

To sum up, the measures adopted at Rasul consist of :—

(1) Raising the pond from R. L. 710·0 to R. L. 711·5 and raising the cill of the canal regulator from R. L. 704·0 to R. L. 707·67.

(2) Adoption of still pond system of regulation in 1932-33.

(3) Manipulation of shutters, and

(4) Division of the river into two channels in 1936 by means of a bund.

The effect of the different measures will be discussed in detail hereafter, but it may be stated that the problem at Rasul is yet far from solution.

Merala Headworks, Upper Chenab Canal.

The canal was opened in 1912. The weir crest was constructed at R. L. 800·0 with shutters 6·0 feet high fixed over the crest.

The undersluice floor was at R. L. 792·1 and the permanent cill of the head regulator at R. L. 795·23 which could be raised to R. L. 799·23 by means of a rising gate.

There were no training works except the left marginal bund and guide bank and the right guide bank as shown in Plate IV.

During construction, the fact that the weir was built from left to right had caused the main stream of the river to leave its more or less central position for the extreme right bank.

In the cold weather of 1912-13, the passage of the whole river through the undersluices, while the weir was under examination and repairs, developed a channel downstream and parallel to the weir from left to right.

The first big flood occurred on 24-9-17, but this caused very little change upstream. The river settled down into two branches, one from the main river hugging the right bank to the upstream right guide bank nose and thence along the weir, the second from the Eastern Tawi to Bays Nos. 1 and 2 of the undersluices.

Alterations in the river upstream being slight and being all on the right bank, had no effect on the silting or scouring of the canal.

During 1921-22, the scour on the river bank above the upstream right guide bank increased at the beginning of the monsoon, but the deep channel moved more towards the centre after the August flood and the bank erosion stopped.

During 1922-23, the erosion of the upstream right river bank continued. The river also developed a branch channel just above the *bela*, some 2000 feet above the weir, reducing the supply in the right main stream. With a low level in Jammu Tawi, the river in high supply was drawn to the left, resulting in erosion of the bed and large quantities of silt being carried into the undersluice pocket and the canal. Before the cold weather, the river returned to its old channel from right to left along the upstream of the weir. It is stated that the usual procedure of dropping weir shutters from right to left and raising them in the reverse order could not be adhered to this year due to changed river conditions. Different bays were dropped to suit these conditions and prevent silt entering the pocket and the canal, and to maintain a clear channel upstream of the weir.

During 1923-24, there was a marked change in the river.

The River Survey Plan for 1923 is shown on Plate IV, fig. 1. The junction of the main river and the Eastern Tawi, shifted up and the combined channel split into 3 branches, one of the main branches hugging the right bank upstream of the guide bank ran diagonally to the weir, the second branch to the central bay, and the third to the first and second bays. The left channel was wholly blocked by a flood in the Eastern Tawi late in August and a new channel opened to Bays Nos. 1 and 2, blocking the direct approach to the undersluices.

In this year the river was markedly unstable, and the question of raising the weir crest to ensure better control was seriously taken up.

The raising of the crest was taken in hand during the winter of 1924-25 and was completed in Bays 5 to 8, as a result of which the right channel shoaled and the left channel developed further. The second branch to the central bay, formed in 1923-24, disappeared.

According to the policy laid down by the Chief Engineer, regulation during 1926-27 was to be done with a view to bringing the main channel on to the left bank and for this purpose the left weir bays were worked most of the time.

As a result of these measures the whole river supply came down the left channel, along the foreshore in front of the left upstream guide bank, as shown on Plate IV, fig. 2.

It was considered at the time that a contributory cause of this silt trouble was the raising of the weir by 2·0 feet, without at the same time remodelling the regulator gates to work overshot, and consequently the remodelling of the gates was decided on and the work vigorously pushed on.

As for the river, it was finally decided, after careful consideration, that, for purposes of silt exclusion, it was best to keep the main channel on the right and a subsidiary channel on the left.

During 1927-28, by judicious regulation, the main channel was diverted to the right bank and approached the weir in front of bays 5,6 and 7 (Plate IV, fig. 3). A subsidiary channel on the left bank leading directly into the pocket was maintained, and it was reported that this change in the course of the river had been very beneficial in excluding coarse silt from the canal.

The approach channel to the undersluices was treated as a canal, a constant discharge being maintained, the canal proper taking the indent supply and the balance passing through the undersluices.

"The pond level in the pocket was also kept constant for long periods to suit the river supplies and the silt-charge conditions. With these conditions of steady flow and constant water levels, the tendency to scour or erode was minimized, so that there was little rolling silt to be picked up and transported to the canal."

There was no change in the river course and this system worked satisfactorily till 1929.

Silting of the Upper Chenab Canal in 1930.

Towards the end of September 1929, there was only 0·2 feet of silt in the first mile of the canal which increased to 2·3 feet by April, 1930 due to several winter freshets, which had to be passed through the undersluices with the canal open, on account of the extensive repairs in hand below the weir.

This caused heavy deposits of silt in the approach channel, a good deal of which found its way into the canal, in spite of the regulator cill gates being fully up.

With the approach channel silted and the open flow system of regulation, large quantities of coarse silt passed into the canal in May.

To make matters worse, on the evening of 11th May, the pond level was lowered, the discharge through the undersluices increased by 5000 cusecs, and the cill of the canal regulator lowered by about one foot. This caused extraordinarily heavy silting of the canal.

Another heavy dose of silt was pushed into the canal on the 26th of June, when the discharge through the undersluices is said to have been again considerably increased (from 5000 to about 20,000) without completely closing the canal.

The result of mean silt soundings in May and June is given below. On one day over 30 lacs cu. ft. of silt passed into the canal and were deposited in the first mile :—

R. D.	Date.				
	10/5	12/5	14/5	25/6	26/6
250 ..	5·28	7·66	6·67	6·35	7·8
1000 ..	3·53	7·42	6·63	4·73	6·3
2000 ..	2·63	3·62	7·1	4·37	5·7
3000 ..	1·43	2·70	3·13	2·07	4·1
4000 ..	1·32	1·78	2·41	1·83	4·0
5000 ..	2·23	2·41	1·97	1·76	3·9

During 1931, the question of silt exclusion from the canal at the head assumed major importance. In June and September, months of keen demand, the supply level in the Main Line Upper showed a dangerous rise of 1·7 feet at mile 10 and 1·0 foot at mile 16, over that of the previous year. In June the gauge at the head had to be raised to 3·7 feet above the designed level in order to meet the indent.

It was decided to give the Still Pond method of regulation a tria and this was introduced in May, 1932 and resulted in a marked decrease in the silt drawn into the canal from June to September.

The mean surface slope from head to mile 10 which was 1 in 4010 in 1930 flattened to 1 in 5900 in 1932 and was 1 in 5950 in September, 1933.

Briefly, the measures adopted at Merala to keep out silt from the canal consisted of raising the pond level from 806·0 to 808·0, keeping the main river channel on the right and adopting the still pond system of regulation.

Khanki Headworks, Lower Chenab Canal.

The Khanki weir, sluices and canal head regulator were completed in March, 1892. The weir was originally constructed with its crest wall sloping up from R. L. 722·23 on the left to R. L. 723·05 on the right. The undersluice floor was constructed at R.L. 715 and was fitted with 3 tiers of gates such that the pond level could be raised to R. L. 728·0.

The regulator as originally constructed had 12 main bays of 24·5 feet subdivided into 3 equal small bays of 6·5 feet by jack piers, with the crest wall at R. L. 717·0, 2·7 feet above the floor of the undersluice pocket.

In the work as originally constructed, the only attempt at a divide groyne, was a short loose stone groyne in extension of the right upstream wing of the undersluices.

In the winter of 1898-99, this was replaced by a divide groyne of a design similar to those constructed at Narora and Rupar, "to prevent silt deposit immediately in front of the Regulator."

In 1908, owing to heavy silting in the main canal in the previous flood season, proposals were submitted for remodelling the Khanki weir on the lines of Rupar, but before the original regulator could be altered, it was necessary to provide a subsidiary head regulator. This was constructed in 1910-11, and consisted of 6 spans of 24·5 feet with the permanent cill at R. L. 721·0.

In the working season of 1911-12, the old regulator was remodelled, the permanent cill raised to R. L. 721·0 and the jack piers removed to give a clear span of 24·0 feet in each bay.

During the hot weather of 1910, serious difficulty was experienced in maintaining the supply in the canal and working the undersluices owing to the large shoals of silt up and down-stream of the left of the weir. As the river fell at the end of the monsoon, control of the river was lost, so much so, that the canal supply had to be passed over the weir on the right flank along the downstream face of the weir and back through the undersluices into the canal regulator.

Along with other remedial measures, Bays Nos. 4, 5 and 6 were raised by 2 feet in 1910-11 with a view to making the river flow in two channels on either side of these bays and to improve command, as the shutters could be kept up until the river rose to R.L. 729·2 on the left and to R. L. 730·0 on the right, while previously they had to be dropped as soon as the river rose to R. L. 727·2 on the left and 728·0 on the right, because due to the fear of a sudden rise in the river the water surface was kept about 1·0 foot below the top of shutters. During 1912-13, a one-foot flap was added at the top of these shutters.

In the summer months of 1916, the silt trouble at headworks was still acute, despite all that had been done to remedy matters. In June, the canal indent could not be met and there was fear of the complete silting up of the aproach to the canal owing to the lack of command, etc., in the river. In this year (1916) in the presence of one of the members of this Congress, a beldar walked across the river upstream to

Groyne 3, then back along the river downstream of the weir and undersluices and then across the canal.

In the winter of 1916 the weir crest was raised further to R. L. 724·65, and the gates of Bays 1 to 7 of the undersluices were increased in depth to enable the pond level upstream to be increased from R. L. 728·0 to R. L. 730·0, the remaining gates could not be increased due to difficulty in obtaining the iron work.

As the trouble continued, the weir crest was raised to its present level of 726·5 in Bays 1 and 2 and 727·0 in the remaining Bays in 1920-22.

At the same time, both gates of the regulators were altered so as to allow of their being used as cills working one behind the other, the maximum cill level thus obtained being 730·0.

The old gates in the undersluices were replaced by new gates 14·0 feet deep, which enabled the water to be headed up to R.L. 729·0.

Finally the whole weir, undersluices and canal regulators were reconditioned in 1933-35, as fully described in Paper No.195 presented to this Congress in 1936. Briefly, the changes made were :—

(*a*) Bays 4 and 8 were gated with the crest depressed to R. L. 715·0.

(*b*) The top of gates in Bay 4 and 8 was kept at R. L. 733·0, the same as that of the shutters in Bays Nos. 3, 5, 6 and 7.

(*c*) A silt excluder was constructed in front of the old or main regulator, the permanent cill level of which was at R. L. 726·0, and

(*d*) The top of the gates in the left undersluices was kept at R. L. 732·0 against 733·0 in Bays 3 to 8 and 732·5 in Bays 1 and 2.

In 1938, the top of the gates in the left undersluices was raised to R. L. 733·0.

Thus the measures adopted at Khanki to keep out silt from the canal consist of :—

(1) Construction of a divide groyne,

(2) Raising the pond level from 727·2 to 732·5,

(3) Raising the cill of main regulator from R. L. 717·0 to 726·0 and constructing tunnels in front, to exclude the heavy bottom silt, and

(4) Gating of Bays 4 and 8 of the weir.

The effects of these changes will be discussed in their proper place.

We shall now proceed to discuss the training works at Khanki, the construction and maintenance of which has cost a fortune, but the utility of which has been often questioned.

River Training Works at Kkanki.

A clear and comprehensive description of the development of the training works at Khanki is given in Part X, pages 36—50 of the printed History of the Khanki Headworks.

The training works constructed at different times are shown on the attached survey plans for different years (Plates V to VIII).

The training works originally constructed along with the head-works in 1889-92 consisted of a stone pitched river slope downstream of the left undersluices extending for a distance of 1000 feet, a Bell's bund extending about 5500 feet upstream on the right and a similar bund downstream about 1200 feet long and a retired embankment about 3½ miles long connecting the right abutment of the weir with the high land on the Gujrat side, which was extended 2½ miles in 1894 by a marginal bund along the high bank of the river as far as Chuhamal village. In 1893-94, the left protection bund, 4 miles long, was also built from the left abutment of the canal head along the left bank of the weir, and the upstream Bell's bund above the regulator was constructed about the same time.

The idea of constructing the extensive training works in existence at present originated with Mr. Beresford, Chief Engineer, in 1897. His reasons for so great an addition to the training works are not on record but his successor stated that the object to be aimed at was to bring the river from Alexandra Bridge in a uniform channel straight on to the weir, as had been done in the case of the Narora Weir on the Lower Ganges Canal. To do this he proposed to run out a series of spurs or groynes from the high bank, so that their heads were in a line connecting the left abutment of the undersluices with the right abutment of Alexandra Bridge. At this time the islands above the weir had become more or less permanent and obstructed the approach to the weir.

An examination of the river survey plans from year to year (Plates V to VIII) and the silt statement at Appendix 1, leave no room for doubt that the silt trouble in the canal at Khanki increased whenever the main river shifted to the left except in years of low discharge.

The course of the river was considerably affected by the various training works and we will now examine the Survey Plans for certain years in detail to gauge the effect of these works.

Spur E was the first to be constructed in the year 1899-1900, followed by spurs G, H, I, J and K (see Survey Plan for 1903 at Plate V).

These were designed to prevent further encroachment by the river on its bank which had caused embayments in places between Khanki and Wazirabad to a depth of nearly a mile, which not only led to the loss of valuable land but endangered the right flank of the retired embankment.

During 1899-1900, the main river was on the right. In 1900 the monsoons were normal. In 1901 they were sub-normal and in 1902 there were no floods, and practically no change occurred in the course of the river, the main channel persisting on the right (see Plate VII, Fig. 1).

Spur A was constructed in the winter of 1901-02 with the two-fold object of checking the erosion along the face of the Bell's bund and forcing the stream to scour away islands formed upstream of Bays Nos. 6 and 7 of the weir which were considered a standing menace to it and interfered with the regulation of the supply to the canal. Spur W was constructed in 1902-03, 5000 feet downstream of the weir to prevent the draw of the river to the left bank.

At this time the Still Pond system of regulation was in force.

Although Spur E was seriously damaged in the high flood of July 1903, the survey plan for 1903-04 (Plate V) clearly shows that both spurs E and A, along with the other spurs higher up, were the cause of the river moving towards the left.

A statement is attached (Appendix I) showing the maximum quantity of silt in the first 8 miles of the Lower Chenab Canal in any one month in each of the years 1905 to 1938.

During the years 1904 to 1907, the main stream of the river kept well away from the right. In the year 1907 considerable quantities of silt were deposited in the canal. Mr. Benton wrote as follows in his inspection note dated 2nd December, 1907.

" There is far more silt in the main line of the canal than there has been at the same time of the year on previous occasions. The river by proceeding direct tothe undersluices (see Plate VII, fig. 2) has carried an unusually large quantity of silt into the canal in spite of precautions being taken to avert this evil."

It was considered that the silting of the canal was due to the river coming to the left and in 1908, the river was approaching so much to the left that the Palkhu Bund was constructed. This was converted into a Spur in 1910-11, as shown in fig. 3, Plate VII.

However, silting in the canal was worse than ever and this was ascribed to the embayment upstream of the left Bell's Bund, caused by the Palkhu Spur.

During 1908, as a result, it was thought, of the construction of the Palkhu Bund, the main river shifted towards Spur E and flowing along the right to Spur A, cut straight across to the canal head.

The order of dropping the shutters before 1906 is not known but from 1906-1909 they were dropped in the order 8,7,6,5,4,3,2, and 1.

In his inspection note, dated 3-11-1909, the Chief Engineer, Mr. W. B. Gordon, wrote as follows :—

"The right or Spur E channel which is still the main stream not being called upon to supply the canal or drawn upon by the undersluices found its way in a more direct course over the weir. There has been some erosion of the right bank between Spur E and A. and Spur A, which perhaps extends a little too far into the stream, has to some extent interfered with the direct course of the stream across the weir.

"As regards the state of the works, by far the worst feature of the year is the heavy deposit of silt in the main canal. The deposit appears to be due to the long duration of a high river, to the steady demand for water which prevented closures and the working of the undersluices, these not having been fully opened owing to the danger of drawing the main stream into the Palkhu Channel.

"If we could regulate or limit the supply through the Palkhu Channel, it would probably do more good than harm, its water would be fairly free from silt, and it would tend to check the diagonal draw from the main stream across the weir. But as we cannot regulate or limit its discharge at any reasonable cost, it will be better to close it altogether, else it may become the main stream, and we should then have increased silt difficulties in the canal and serious shoaling along the length of the weir."

In 1910 the set of the main stream of the river was to the right and there was no silt trouble, but in his note dated 20-11-11, Mr. Scratchley, Chief Engineer, wrote as follows regarding the proposal for the construction of a guide Bank :—

"In the year 1910 the set of the main stream of the river between Spurs E and A altered to such an extent as to set up erosion on the right bank above Spur A. The erosion continued throughout the season of 1911 and serious attack on this spur commenced, which attained its climax in July and August, and it was only by strenuous efforts and the constant addition of large quantities of stone that it was possible to prevent its being swept away. The maintenance of Spur A was absolutely necessary because during the cold season of 1910-11 the Bell's bund upstream of the spur had been stripped of stone.

" The shoaling which is now apparent on the left side of the river, and the recent troubles consequent on the embayment between Spurs E and A, go to show the retirement of Spur E in the year 1900 was a mistake as it is to a great extent the key of the position."

The subject was fully discussed with the Inspector General of Irrigation and it was decided to build a new guide bank in advance of the existing right Bell's bund. This was constructed in 1912, and is shown in fig. 4, Plate VII.

The construction of the guide bank had the immediate effect of diverting the river to the left as will be seen from the survey plan of 1912-13, (Plate VII, fig. 4) and the extension of the right bank training works in 1915-16 pushed the main river over entirely to the left bank.

The survey plan for 1920-21 (Plate VI, fig. 1) shows the course that the river maintained from 1916 to 1926 and that before the extension of the right bank spurs has been shown dotted.

The monsoons in the years 1914 and 1915 were normal and no trouble was experienced but 1916 was a year of abundant flow and silt trouble became once more acute. In June the canal indent could not be met and there was a fear of complete silting up of the approach channel.

This state of affairs was attributed by local officers to the loss of afflux owing to the construction of Spurs O and P downstream of the weir and the defective design of the Palkhu Spur in that when the main river flowed along the left bank it was deflected to the right, causing dangerous shoaling above the canal. It is interesting to note that 20 years later, Bay 4 was depressed for this very purpose, i.e., restoring the curvature of flow.

Late in August, permission was obtained to work the undersluices with the canal open and this is said to have produced an immediate improvement.

The Inspector General, Mr. Nethersole, was of opinion that the silt trouble was mainly caused by the building of the training works for the Upper Jhelum Canal. He thought it was temporary and would be remedied by raising the weir crest. He agreed to the gapping of the Palkhu Bund so as to provide a regime channel to the undersluices, and this was done in 1917-18, as shown in fig.1, Plate VIII—a great mistake according to modern theories of silt exclusion.

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Conditions in August 1917 were as bad as in August, 1916.

The so called regime channel which was expected to form in 1917-18, by gapping the Palkhu Bund, did not materialize, as it was found only to flow when the river rose and brought down heavily silt laden water. It was accordingly decided to remove the old head of the bund in the hope that the island formed behind it would erode and result in a main channel coming straight into the pocket instead of round the divide groyne, with the Palkhu as a subsidiary. This work was carried out in 1924.

These measures were successful and it was reported that by August 1925, the island had disappeared and there was considerable improvement in the direction of the approach of the river to the pocket.

In 1924, Spur A was also dismantled as it was considered superfluous.

The year 1918 was remarkable for the early occurrence of floods in March and April, as a result of which the right channel again developed to some extent. But in the years 1919 to 1924 the river was low and floods were few and the right channel was completely blocked by 1925 and the whole river was flowing straight along the left, as shown in Plate VIII, fig. 2.

Some efforts were made to develop the right channel but with little success and in 1927 the Chief Engineer found it practically dead, because when the discharge of the river was about a lakh cusecs only Bay 8 was drawing water from it (the right channel). All the other bays were being fed with water from the left channel and at Bays Nos. 6 and 7 the flow was almost parallel. He was of opinion that the efforts being made to pull the river across from the left to the right would not be of much avail and decided that the order of opening and closing the weir shutters should be 8, 1, 7, 2, 6, 3, 5 and 4, which might be changed as found suitable. Also that when the river first rose, shutters in Bays 8 and 7 should be opened first so as to give their right bank channel a chance of scouring out a bit, with the help of the bund that was being built from groyne No. 6 to the island upstream.

In August, 1928, the Chief Engineer agreed that supplies in excess of the capacity of the canal and requirements of the undersluices for regulation purposes might be passed over the weir by opening the bays in the following order, viz. 8, 1, 5, 2, 6, 3, 7 and 4.

The big floods of 1928 and 1929 cleared all the *belas* in the left channel as shown in Plate VI, fig. 3, which is a survey plan for the year 1929-30 and there was not much trouble till 1930-1931 when the problem of silt in the canal again became acute. The right channel did not develop to any great extent with the result that the left channel carried all the discharge.

In 1931, the river remained persistently high during the month of August, and the discharge was in excess of one lakh cusecs for 15 days.

The trouble was considered to be due chiefly to the fact that the main stream of the river hugged the left bank and the canal drew directly from it. It was thought desirable that the right bank creek should be developed so as to be capable of carrying the main river and the channel feeding the canal should be the smaller of the two. With this end in view, a temporary bund was put upstream of Bay No. 5 connecting the weir shutters with the *bela* and the sequence of lowering the latter was altered to 8,7,6, 3,4,2,1, and 5.

The Still Pond system was again tried this year, but given up.

Since 1931, the bund in Bay No. 5 has remained intact and the right bank creek has gradually developed into the main arm of the river. Figs. 3 and 4 of Plate VIII and Fig. 3 of Plate VI show the development of the right channel.

The working of the right half of the weir was somewhat restricted during 1932 and 1933 due to heavy works in progress but by June, 1933, it was carrying a discharge of 30,000 cusecs and it passed 105,000 cusecs during the flood of 10.7.33, when further development was checked by closing Bay No. 6 and part of Bay No. 7.

Ever since the construction of the spurs along the right bank, most of the engineers connected with the Khanki Headworks have expressed the opinion that whenever the main stream of the river shifted to the left, silt trouble in the canal became acute, the degree of acuteness depending on the river discharge.

The deflection of the river to the left has been generally ascribed to the training works, but the fact is that the effect of these works in this respect was only temporary, because the river very tenaciously adheres to the right bank training works, on account of the deep channel along them. However, lower down below Spur E, the course of the river is decided more by regulation than by the effect of spurs. The frequent scouring closures of the canal, when the river-approach to the left under-sluices is scoured, particularly at the beginning and end of the flood season, assure a deep channel along the left bank and the river has a tendency to stick to this deep channel. It was, therefore, decided that the right channel could only be developed after putting a bund connecting Bay 5 to the permanent *bela* upstream.

Method of Regulation at Khanki.

The present system of regulation at the Khanki Headworks was introduced in 1932 in connection with the reconditioning of the Headworks and its essential features as described in a note dated 20-4-33 by the late Mr. H. W. Nicholson, C. I. E., are given below :—

The first essential stated by Mr. Nicholson was "to draw a reasonable portion of the flood discharge of the river away from the left bank of the river to the right, while maintaining a channel to the left bank with certainty."

He stated that the conditions under which the main-stream of the river crossed from the right to the left bank were very favourable, and stressed the desirablity of maintaining these conditions by protecting the upstream nose of the *bela*. But this suggestion was not accepted.

He further stated that "the splitting up of the river into two channels, in addition to equalizing the distribution of flood discharge over the weir, will have a very beneficial effect on "silt control." He thought that the channel to the right flank of the weir will take off at an angle from the main stream and thus tend to draw a greater proportion of silt, leaving the main-stream with a lower silt charge and that when the river was in flood, the slope in the left channel will be increased by the undersluices and the gated bay of the weir having a much lower crest level than that of the right half and that this will result in a tendency for the right channel to silt up and become obliterated.

"The selection of Bay No. 4 for gating was decided on to facilitate the maintenance of curvature of flow in the river upstream of the undersluices which is so desirable a condition for silt control.

"At the end of the cold weather, assuming that there will be little silt capacity left in the river channel in the approach to the undersluices, with a steady rise in the river there would be a definite tendency for silt to be moved into the undersluice pocket, unless the pond level could be raised or the undersluices opened and the channel upstream scoured out.

"Appreciating the fact that it is undesirable on a rising river, after a period of steady flow, to allow an increase in discharge to approach the canal regulator without raising the pond level, it would probably be best to arrange to pass the increase in discharge down the right channel to the 8th bay of the weir, which will be gated.

"This should be done with a slight increase in gauge above the head regulator.

"When the supply passing down the right channel increases and further raising of the pond level on the left flank to prevent silt moving in the approach to the head regulator is not desirable, then the canal would be closed, the whole of the gates in the undersluices and Bay 4 cleared and, if necessary, the shutters dropped in Bays 1-3, and the right half of the weir closed. The whole of the supply in the river would thus be suddenly passed down the left channel with a steep slope and high velocity which would clear out a fair silt-free channel.

"On opening the canal again, water in excess of canal requirements would be passed over the right half of the weir as before or through Bay 4 of the weir, which will be gated.

"Which of the two latter methods is the better will be found from actual experience and depend on the amount of water it will be necessary to pass over Bay 4 in order to establish conditions of curvature of flow upstream of the undersluice pocket."

Bay 4 was completed during 1933-34 and came into action on the 14th of June 1934 and Bay No. 8 was completed during 1934-35 and came into action on 4th July 1935, and since then the method of regulation advocated by Mr. Nicholson is being followed, with certain minor modifications to suit prevailing circumstances.

During 1934, the right part of the weir was opened for the first time in the season on the 23rd June, but did not develop any further as the river remained rather low that year.

During 1935, the right half of the weir remained closed up to the end of June, four floods occurred during July and the right channel developed to such an extent that during August, 1935, it was considered necessary to place a check on its further development, by maintaining the water surface upstream of the right half of the weir between R. L. 733 and 734 the water overtopping the shutters in Bays 5, 6 and 7.

During May 1936, the average discharge at Alexandra Bridge was 80,000 cusecs against an average of 31,500 cusecs for the previous 12 years. As a result of this there was an increased discharge in the left channel, and the silt in the pocket went up from 1·96 to 2·94 feet on the 26th. The canal began to silt on the 27th, when the gauge on the right side was lowered considerably to re-establish greater flow in the right channel.

Throughout the month of June, 1936, the right arm carried more than half of the river supply and attempts made to divert more water into the left arm did not meet with any marked success.

The year 1937 was one of low river and no trouble was experienced.

However, during 1938, the river rose very early in the season and the right undersluices were opened on the 3rd of March with a discharge of 3316 cusecs.

By the 8th of April the river above Khanki rose to 49,075 cusecs of which 32,037 was passing through the left arm and 17,038 through the right, the silt intensity in the canal having risen to 5·42 cu. ft., per cusec-day.

Experience during the last two years has shown that the silt intensity of water entering the canal and consequently the silt and scour in it depend mainly on the discharge in the left arm. A curve showing the relation between the discharge in theleft arm and the silt intensityi n the canal is attached (Plate IX, fig. 3). This curve is very significant. It shows that up to a discharge of about 35,000 cusecs the silt intensity increases in a straight line, but for higher discharges the increase in silt intensity is very rapid, being as much as 30 cu. ft., per cusec-day for a discharge of 45,000 cusecs.

It is, however, noticed that as soon as the undersluice pocket or approach channel gets silted up, the silt intensity is much in excess of that shown by this curve.

Another curve showing the relationship between the silt intensity in the canal and the river slope from the Palkhu Spur to gauge No. 13 has also been plotted and is attached (Plate IX, fig. 4). This shows that the silt intensity increases gradually up to a slope of 1 in 5000, but as the slope becomes steeper, the increase in silt intensity is very rapid and the canal invariably starts silting up. In practice this curve has proved to be more reliable for purposes of regulation, than the discharge curve.

Past experience also shows that the Lower Chenab canal at its head can carry water with a silt intensity of between 4 and 6 cu. ft., per cusec-day without silting, which corresponds to a discharge of about 35,000 in the left arm. As the river discharge increased in May, the object in view was to restrict the discharge in the left arm to about 35,000 cusecs as so to maintain the slope from the Palkhu Spur to gauge No. 13 flatter than 1 in 5000, and pass the balance through the right channel.

On the 27th May, the river discharge above Khanki was 92,554 cusecs of which 34,038 was passing in the left and 58,516 cusecs in the right arm and the canal remained clear of silt.

In order to prevent over-developing of the right channel of the river, the revised regulation rules (1937) providethat "Asthe river rises in May, the ratio of discharge taken in left and right channels should be about 1 to 1 for a total discharge of 60,000 cusecs. This ratio may be increased to 1 to $1\frac{1}{2}$ or even 1 to 2, but on the approach of the flood season it is desirable to revert to a ratio of $1\frac{1}{2}$ to 1, because the flood discharge capacity of weir in the left channel is the greater and because when the river is in flood, the right arm has a tendency to overdevelop."

Accordingly, after the middle of June the discharge in the left arm was gradually increased and the ratio of discharge was gradually altered from 1:1·7 at the beginning of the month to 1:1 on the 27th.

The high river persisted throughout July and although the ratio of left to right was generally 1:1·2, the discharge in the left arm remained in excess of 35,000 cusecs from the 6th to the end of July, and the canal suffered from silt, the average depth of scour in the first mile having reduced from 2·25 on the 3rd to 1·87 on the 14th and to 0·76 on the 22nd July.

But in spite of all the efforts to restrict discharge in the right arm, this channel overdeveloped and during the flood of 24th July, a discharge of 1,62,000 cusecs passed into the right arm out of a total discharge of 2,64,000 cusecs above Khanki.

The right half of the weir, with the exception of a few shutters in Bay 5 had to be fully opened and even then, the gauge upstream rose to 734·6, while the gauge on the left was 3·1 feet lower at 731·5. Bays 1, 2 and 3 of the weir were not opened as the two sets of undersluices easily passed the discharge of 1,02,000 in the left channel. With a pond level of 734·6 upstream of the weir on the right, water flowed over across and the central *bela* in many places. From the experience gained in this flood, it is evident *that a flood of over 4 lacs will wash out the bund in front of bay No.5 but before doing so any of the weir bays no. 4 to 7 may be seriously damaged.*

The highest flood on record in the River Chenab at Khanki occurred on the 29th of August, 1929, the calculated discharge of which was reported to be 7,97,000 cusecs.

The maximum gauges recorded upstream of the weir for this flood as well as the discharge in each Bay are given below for both Khanki and Merala :—

	Left Under-sluices	Bay No.							
		1	2	3	4	5	6	7	8
Khanki Guage	737.9	741·6	742·0	741·7	739·5	737·7	736·5	733·5	735.7
Discharge	96868	87245	115755	111519	100110	85872	72265	62425	57557
Merala Gauge		815·6	815·75	815·85	815·9	816·0	815·9	815·3	813·9
Discharge	64378	82000	79000	79890	80320	81190	80320	75690	63690

The above figures show that the distribution of supply at Merala during the record flood of 1929 was much more uniform than at Khanki. where the discharge was mostly conncentrated on the left side. An inspection of the survey plans for Khanki (Plate VI fig. 2) and Merala (Plate IV, fig. 3) for the year 1929 will at once show the cause of this remarkable difference.

At Merala the river approached the weir at an angle from the right side, masking only Bay No. 8 whereas at Khanki immediately above the weir, the main stream hugged the left bank and the right half of the weir was almost entirely masked.

The gauges and discharges recorded at Khanki during 1938 with a discharge of only 2,64,000 cusecs are as below :—

	Left Under-sluices	Bay No.						
		1 and 2	3	4	5	6	7	8
Guage	731·5	732·0	731·7	731·4	732·5	733·0	734·6	733·3
Discharge	55514	..	..	46082	10677	23213	34885	93633

It is very difficult to foretell what the actual distribution of discharge will be if we get a record flood of about 8 lacs in the present condition of the river but they would be no more favourable than in 1929.

It appears that the late Mr. H.W. Nicholson visualized a much greater measure of control at the upstream nose of the central *bela* than is found possible in actual practice, and he did not foresee the heavy masking of Bays 3, 4, 5 and 6 that has resulted from the central bund. Moreover his hopes that the right channel would draw a greater proportion of coarse silt and therefore remain silted up have also not come true.

The present conditions could perhaps be improved by cutting short the central *bela* and moving the point of bifurcation nearer the weir, as this will give the greater control that is needed and may remove the masking of Bays 4 and 3 but this will again necessitate the protection of the nose of the bund at the point of bifurcation which will be both difficult and expensive in the middle of the river and all the objections raised against the "*Parting Bund*" proposed by Mr. Nicholson will hold in this case.

It will thus be seen that in spite of the vast sums of money spent from year to year, the trouble at Khanki is yet far from over.

The alterations carried out at the different Headworks and their effect on silt exclusion.

The alterations carried out and the methods adopted for silt exclusion at the four headworks discussed in this Paper have been described above.

These fall under the following headings :—

1. Raising the pond level and keeping it constant.
2. Raising the cill level of the regulator.
3. Adding a divide groyne.
4. The Still Pond system of regulation.
5. Training works.
6. Manipulation of shutters.
7. Methods of feeding the canal :—

(*a*) by means of a direct channel to the undersluices, surplusing the supply over the right flank.

(*b*) by artificially dividing the river into two channels and regulating the distribution of discharge in these, to obtain optimum conditions.

(*c*) By feeding the canal from right to left.

1. *Raising Pond Level* :—We have seen that the pond level at Rupar was gradually raised by 7 feet after the opening of the canal, at Rasul by 1·5, at Merala by 2·0 and at Khanki by about 5·0 feet.

The immediate effect of raising the pond is to reduce the river slope upstream with the result that it becomes incapable of transporting the coarse silt which is harmful to the canal. This coarse silt must either desposit as a silt bar at the point of bifurcation, or be carried away by the river if the channel carrying the surplus water is sufficiently steep.

If the silt deposited at the bifurcation is not carried down with the surplus water, frequent closures of the canal become necessary to remove it.

The river is so sensitive to pond level, that any changes are immediately reflected in the silt conditions in the canal. Raising the pond level in a rising river checks the shoal from advancing into the pocket. Lowering of the pond causes this shoal to move into the pocket and silting results. Moreover, lowering the pond considerably steepens the surface slope in the immediate vicinity of the headworks and all the silt in the approach channel is washed into the canal. It is, therefore, essential that the pond level should either be lowered very slowly and with great caution or it should be lowered after closing the canal.

At Khanki under ordinary conditions the pond is generally lowered at the rate of 0·2 foot per day during winter and 0·1 foot per day during the summer. At the close of the monsoon, about the middle of September, when the pond level has to be dropped by several feet, the canal is closed before lowering the pond and the pocket and approach channel are thoroughly flushed for about 24 hours before reopening the canal.

Similarly, at Merala there is a short 12-hour closure in the middle of October for this purpose, whenever necessary.

2. *Raising cill level*:—The raising of the cill level in itself cannot have any appreciable effect on silt exclusion and this was the opinion expressed by Kennedy after watching the effect of raising the cill of the head regulator at Rupar by 7 feet.

When the water in the river is flowing with a high velocity, most of the silt is in suspension and must necessarily be drawn into the canal. It follows that the other changes made along with the raising of the cill, viz., the raising of the pond, adding a divide groyne or adopting the Still Pond system of regulation are the real causes of silt exclusion, which is ascribed to the raised cill.

As long as the head regulator is protected by a suffciently long divide groyne, the cill level can make very little difference, for whatever silt has once entered the pocket, must pass on into the canal.

However, in the absence of a divide groyne a raised cill may be of some use.

But the main advantage of a raised cill is that it makes regulation foolproof, to the extent that to feed the canal it becomes necessary to maintain a high pond level in the river, which is very effective in excluding silt, by flattening the slope in the approach channel.

3. *Adding a divide groyne*:—The advantages of a divide groyne have been proved experimentally at the Hydrodynamic Research Station near Poona, as described in Bombay Technical Paper No. 52.

The divide groyne at Khanki is shown in plan in fig. 1 of Plate IX. It extends to the end of the main regulator, but does not cover the subsidiary head regulator, and it is found to have no effect on the working of the latter. Whenever the subsidiary regulator is opened during a high river, it draws very heavy silt and results in silting the canal.

This shows that a divide groyne should extend at least to the upstream end of the upper canal.

The extension of the groyne to only two-thirds of the distance of the canals from the weir, as recommended on page 31 of Bombay Technical Paper No. 52, does not appear to be sufficient in view of the experience at the Khanki Headworks.

4. *Still Pond System*:—It has now been established both experimentally and practically that this system by which the undersluice gates are kept closed as long as the canal is flowing, is very effective in silt exclusion.

The opening of the undersluices when the canal is in flow, increases the discharge and, therefore, the velocity and slope of water approaching the canal head. The result is that due to the higher velocity of flow at the entrance to the pocket, a high proportion of silt is drawn into the pocket, and due to the higher velocity of water through the pocket, most of the top water flows on, straight through the undersluices, while a large proportion of bottom water flowing with low velocity is deflected into the canal.

The advantages of the still pond system have been thoroughly expounded by the experiments in Bombay, described in Bombay Technical Papers No. 45, 46 and 52, and need not be elaborated here. The silting of the Upper Chenab Canal during 1930, as described above, is an instance in point of the evil effects of open or semi-open flow.

5. *Training Works. Guide bunds or Bell's bunds*:—

These bunds which are constructed for the purpose of restraining the stream within the limited length of the weir consist of two artificial banks protected by means of stone aprons. The length of the bund upstream is made sufficient " to prevent the formation of a bend of the river above and behind the guide banks, circuitous enough to breach the main embankment."

In Technical Section Paper No. 2-b, Mr. Bell recommended that the guide banks should be brought closer together at their upstream ends than at the site of work, so that the area at the narrowest part near the upper end may approximate to the clear waterway of the weir. He thought that narrowing of the artificial gorge at its upper end improved the current's chances of flowing straight, instead of obliquely, through the work.

The guide banks constructed above weirs discussed in this Paper are straight except at Khanki, where instead of converging at the upstream end, they diverge.

The effect of this divergence upstream is that the river is forced directly into the undersluices, which is detrimental to silt exclusion.

On the other hand a straight guide bank protected at its upstream end would help to push the river away from the undersluices towards the middle of the weir.

It would thus appear that straight parallel guide banks are better than diverging ones for river training at sites of weirs.

Spurs Downstream :—Two spurs, O and P, shown in fig. 3 Plate VII, were constructed at Khanki in 1910-11 at the suggestion of Sir John Benton, Inspector General of Irrigation, for contracting the river channel downstream of the weir with a view to stopping the " general rise of the bed of the river".

Similar spurs were constructed at Rasul in 1911-12 about half a mile below the weir, with the object of contracting and deepening the stream.

At both weirs, the object sought was not attained and the local officers have from time to time recommended abandoning them, but as they were not doing any harm, they have been allowed to remain.

Single Spurs :—The effect of a single spur projecting out into the river, is to push the main stream away from it, a minor channel running along it.

Considering that surface water flows with a greater velocity than bed water, a spur should mainly push out the bed water and the channel running along the spur should carry surface water.

In course of time, erosion sets up immediately upstream of the spur, and the bank caves in till it approaches a semi-circle. As caving increases, the curvature pushes the main channels more and more to midstream and the small creek flowing along the spur taking off outside the curve, continues to draw clear water, till a stage is reached when the stream is deflected right out as depicted in fig. 2 of plate IX. At this stage the curvature of flow is reversed and the subsidiary channel flowing along the spur head, taking off from the inside of a sharp curve, starts drawing bed silt and may consequently silt up in no time.

It may, however, take a long time after the construction of the spur before this stage is reached, the length of time depending mainly on the soil and the direction of the river upstream.

At Rupar, Spurs Nos. 1, 2 and 3 were constructed as early as 1897; erosion is said to have set in above Spur No. 3 soon after and continued, but the tendency of Spur No. 3 to deflect the stream to the right was noticed in 1911 and became so pronounced in 1913 that it was decided to construct Spurs Nos. 4, 5 and 6. The result of this deflection of the left channel towards the right is stated to have been the shoaling up of the river between Spur No. 2 and the canal regulator. Similarly, Spur A was constructed at Khanki in 1901-02, but the embayment above it did not fully develop till 1910-11. On the other hand, the construction of the guide bank at Khanki in 1912 had immediate effect in pushing the river to the left, as will be seen from the survey plan of 1912-13 at Plate VII, fig. 4.

We can, therefore, conclude that in order to obtain permanent good results it is necessary to support a single spur by others higher uptill we reach a place where the river course is more or less stable, as is the River Sutlej at Patial above the Rupar Headworks or the River Chenab at Alexandra Bridge above the Khanki Headworks.

Finally, the embayment may extend further and attack the shank behind the groyne head.

The effect of a series of spurs is however quite different and we cannot do better than reproduce the following description from Technical Paper No. 153 by Spring, wherein he quotes an extract from a report dated 23-9-1892, on the Chenab Wazirabad Training Works by Mr. F. Wooley Dodd :—

" By making a series of spurs, deep holes are scoured at each of them, and if the spurs are near enough to one another, a continuous channel is thus formed. It is believed that this will take place when spurs are half a mile part, if there are no obstacles in the way. At the upper part where, so to speak, the river has to be caught and collected in one channel the spurs must of course be closer."

As stated above, Spur E was the first to be constructed at Khanki in 1897. In 1899, it was heavily attacked along its shank and was bayonetted in the threatened lengths. In 1900, the four Spurs G, H, I, J and K were sanctioned and Spur E was reduced in length to its present position.

The effect of Spur E on the river course is clearly seen from the river survey plan for 1901-02, (Plate VII, fig. 1). It pushed the main stream to the middle of the weir and a small channel flowed along the right Bell's bund, big shoals forming in between.

In 1903-04, Spur A was constructed with the object of clearing these shoals (Plate V), but as already stated, as a result of the upper spurs coming into action, the river shifted altogether towards the left (Plate VII, fig. 2) and the main stream kept well away from the right, till the Palkhu Bund was constructed in 1909-10.

The closing of the Palkhu Channel by means of a bund was proposed by Mr. Benton as Chief Engineer, as early as 1903 and was again suggested by him as Inspector-General in 1907, but by 1908, the channel had ceased to run except during floods and the Chief Engineer, "refrained from closing it," because, he said, "there was then no immediate necessity for adopting a measure which was bound to cause the temporary diversion of the Palkhu stream over to the right side of the weir, already occupied by the main stream, and with the whole river passing through a few bays on that side, a serious deposit of silt was inevitable on the left half of the weir between the canal head and the main stream, from which the canal would have to depend for the bulk of its supply. When, however, the main stream threatened to occupy the Palkhu Channel, the closure of that channel became essential. Had it not been closed, we should have been exposed to the danger of heavy silt deposits in the canal even during low floods, and of serious shoaling above the central and right hand bays of the weir."

In 1910, high shoals of silt were deposited below the Palkhu Island extending down to the weir and masking Bays 1, 2 and 3 (Plate VII, Fig. 3).

The cutting back of the Palkhu Bund was proposed, as the bund with the island on which it abutted, formed a spur with an abnormally large head. The island turned the river stream off to the right in the direction of Bay 5 of the weir and erected a shoal above Bays 1 and 2 of the weir, blocking the stream which flowed parallel to the weir and causing a great deal of trouble at the beginning of September, 1910, when the canal had to be fed from below the weir, as already described.

So in 1910-11, the Palkhu Bund was converted into a spur by extending back its shank to the left protection bund, its head was retired to the Palkhu edge of the island and the stone nose being considered insufficient protection, a strong head was provided.

The trouble during 1916, was attributed to the defective design of the Palkhu Spur in that when the main river flowed along the left bank it was deflected to the right, causing dangerous shoaling above the pocket.

The Inspector-General agreed to the gapping of the Palkhu Bund so as to provide a regime channel to the undersluices.

Accordingly the Palkhu Bund was gapped for a length of 500 feet between the old head and shank, the old head was retained and further revetted so as to form a permanent island, and a new T-head was built on the left side of the gap. This is shown on the survey plan for 1917-18 at Plate VIII, Fig. 1. However, this regime channel did not materialize, as it was found only to flow when the river rose and brought down water heavily laden with silt, and it was accordingly decided in 1923 to remove the old head of the bund in the hope that the island formed behind it would erode and result in a main channel coming straight into the pocket, instead of round the divide groyne nose, with the Palkhu as a subsidiary.

By August 1925, the island had disappeared and there was a considerable improvement in the direction of the approach of the river to the pocket, but the canal head gauge had to be increased by 3·0 feet to pass full supplies into the canal.

We have thus seen that the effect of constructing the Palkhu Bund was to shoal up the river downstream, as seen on Plate VII, Figs. 3 and 4, although these shoals are said to have consisted of fine silt.

The shoal behind the horse-shoe bund (Plate VIII, Fig. 1) persisted and only washed away after this bund was removed, but the whole river shifted to the left once again, as shown in Fig. 2, Plate VIII.

Reverting to Spur A, in 1910, due to the construction of the Palkhu Bund, the set of the main stream altered to such an extent as to set up erosion on its right edge above this spur. This erosion continued during 1911 and commenced a serious attack with the rising river in April and attained its climax in July and August. The survey plan for 1911-12 (Plate VII, Fig. 3) shows the embayment upstream of this Spur, which was saved from destruction by strenuous efforts and considerable expense.

The effect of the embayment on the course of the river is clearly seen in Plate VII, Fig. 3, which shows the main stream, continuing in the path of the curvature of the embayment and a subsidiary channel along the right bank, with a shoal in between masking Bays 5 and 6 of the weir.

The construction of the guide bank in 1912, pushed the main stream further towards the left (Plate VII, Fig. 4) and resulted in further masking of the weir bays. The embayment upstream of the guide bank and the shoals downstream are significant.

The construction of the series of spurs upstream on the right, resulted in a deep channel being formed along them, as will be seen from the survey plan for 1903-04 (Plate V), but the extension of these spurs in 1915, pushed the weir to the left as will be seen from the survey plan for 1920-21 (Plate VI, Fig. 1), on which the course of the river before the extension of the spurs has been shown by dotted lines. This effect was, however, temporary and gradually the river shifted back to the right and as expected, it now tenaciously sticks to the right bank training works (Plate VI, Fig. 2, and 3).

A series of spurs were also constructed upstream of the headworks of the Sirhind Canal at Rupar to check the erosion along the left bank, which have already been described, and are shown in Plate I.

The river clings to the upper spurs which lie on a quadrant of a circle, *viz.*, Nos. 6 to 3.

Cross sections of the river at different points have also been shown on the attached survey plan for 1938, (Plate I). These cross sections show that opposite Patial, which is upstream of the first Spur (No. 6) the river section is normal, opposite Spurs Nos. 6, 5, 4 and 3 there is a distinct deep channel along the spurs, the other side being shallow.

Opposite Spur No. 2, the river divides into two channels which are about equal, and gradually the right of these two channels continues to develop till opposite Spur No. 1, the right channel becomes much bigger and makes straight for the central bays of the weir, while the smaller channel along the left feeds the canal. These conditions are ideal for silt exclusion.

In flowing along the quadrant from Spur No. 6 to No. 2, the water acquires a circular motion which persists even beyond Spur No. 2, and results in the division of the river into two channels, that feeding the canal taking off from outside the curve.

6. *Manipulation of shutters of gates*:—

The regulation rules for almost every headworks lay down the order in which the shutters are to be dropped or the gates opened to escape the surplus water as well as for raising the shutters and closing the gates as the river falls.

The order of dropping and raising the shutters during different years at the four weirs discussed in this Paper has already been stated above, when describing the various head-works.

The manipulation of shutters gives only limited control, because the river persists in following the deep channel wherever it may be situated, and if the shutters or gates opposite the deep channel are kept closed, the river continues along the deep channel till its course is stopped by the shutters or gates, after which it takes a course parallel to the weir.

The only periods during which the river is amenable to some control by the manipulation of shutters or gates are April to May before the river rises very high and from the middle of August to the middle of September after the river has fallen, as during these two periods, there is a surplus available to be passed down below the weir and the current is not very strong.

During the monsoon months, all attempts to divert the course of the river by the manipulation of shutters or gates are usually unsuccessful, due to the force of the current, which must continue in its path along the deep channel formed during the previous month unless obstructed in this path. Once a deep channel has developed at the required place either by the construction of spurs or other means, it is comparatively easy to maintain it on its course by the manipulation of gates and shutters, but to change this course is both difficult and slow.

As the canals at all the four weirs, discussed in this Paper, take off on the left, the usual practice is to pass the surplus water over the right or middle bays, the bays next to the undersluices being invariably kept closed.

The effect of opening these latter bays is practically the same as that of opening the underslucies, *viz.*, increasing the discharge and slope in the approach channel and the results are, therefore, similar.

7. *Methods of Regulation*:—

The two primary considerations at every canal headworks are the safety of the weir and an assured supply in the canal.

For the safety of the weir it is necessary to pass the flood discharge as uniformly as possible over the weir, so that no particular part is subjected to unnecessary strain and this can be achieved either by having the main river stream running centrally or by having the river running in two channels, one at either flank.

For an assured supply in the canal we require a clear channel from the river to the canal head, such that it does not carry much silt, as otherwise the canal may silt up and it may become impossible to feed it.

Both these considerations are equally important but we will consider the latter first.

As stated previously, the quantity of coarse silt carried by the supply entering the canal at Khanki depends mainly on the discharge in the left approach channel and the condition of its section.

It follows that any methods which can reduce the discharge approaching direct to the undersluices, thereby flattening the surface slope in the approach channel, are likely to succeed in solving the silt trouble.

This can be achieved by one of the three following methods :—

(*a*) The Rupar Method. By dividing the river into two channels, one at either flank, and further subdividing the left channel in the vicinity of the weir, so that all the surplus discharge passes straight on to the weir.

The conditions of the River Sutlej above Rupar were described as follows in a note dated 8th September, 1893 by Mr. T. Higham.

" The whole of the River Sutlej is confined in a single channel with well defined banks at a point four miles above the headworks, immediately below which a side channel is thrown off which hugs the right bank of the river until it passes over the right flank of the weir. The cold weather current in this channel is not considerable, but it remains open with remarkable persistency, and is a valuable relief channel in seasons of flood.

" The main stream of the river, however, hugs the left bank as far as the village of Kotli (about one mile above the headworks), the two streams being divided by a high island most of which is under cultivation and is topped only in extraordinary floods. At Kotli this main stream again divides into two, one of which, keeping to the left bank, passes down to the canal head and undersluices, while the second and generally the larger stream turns off to the right, and makes for the middle of the weir.

" When the Sirhind Canal was opened in 1882, the head of the left or undersluice channel was obstructed by a heavy shoal of shingle, which was cleared out in 1882-83.

" The present bed opposite Kotli after a month's scour is about 7 feet above the floor of the undersluices ; the bed level immediately above the undersluices is four feet *above this floor*. When the undersluices are closed, however, the channel silts very considerably, and cannot be relied on to carry the whole of the canal supply, part of which only passes down this channel, the balance flowing down the right and central channel until deflected by the shutters on the weir into a direction parallel with it, when it passes on towards the regulator round the nose of the short masonry groyne (38 feet in length) on the right flank of the undersluices."

The advantages of drawing the supply through three different channels as recorded by Mr. Higham are :—

" By allowing the supply to pass down three different streams as at present, the area of silting basin is immensely increased, and surplus water passing down the right and central channels can be discharged over the weir before reaching the undersluices. A too great development of the left channel would not only tend to throw too much work on the undersluices during high floods, but would render it necessary to regulate by working the undersluices. It is found by experience that the working of the undersluices when the canal is open leads to silting in the canal, owing to the velocity induced in the approach channel which tends to stir up the silt in the bed of the channel."

Reverting to the survey plan of the River Sutlej at Rupar for 1938 (Plate I), the effect of spurs along the left bank has already been described under training works, where it was shown that the water in passing round the curve from Spur No. 6 to Spur No. 3 acquires a circular motion, which persists for a certain distance beyond and due to the draw of the canal on one side and the weir on the other side, it results in the formation of two separate channels, opposite Spur 2.

The advantage of these favourable conditions which enable supply to be drawm through three different channels is not due to the immense increase in the area of silting basin as stated by Mr. Higham, but to the flattening of the slope in the approach channel as a result of the reduction in discharge at the point of bifurcation. The coarse silt is all carried in the main stream which has the capacity to deal with it, being larger and steeper.

(*b*) The Merala Method. The second method of silt exclusion at the headworks is the one which has been followed so successfully at Merala for the last 25 years and was practised at Rasul some years ago, and given up. This consists of feeding the canal from right to left.

The main supply of the river in excess of the undersluice requirements was passed over Bays Nos. 4, 5, 6, 7 and 8 while the discharge of the Jammu Tawi was passed over Bay No. 3, when the canal was in flow and through the undersluices and Bays Nos. 1, 2 and 3 in flood.

According to the printed history of the Merala Headworks for the year 1928-29, the approach channel to the undersluices was treated as a canal, a constant discharge being maintained, the canal proper taking the supply and the balance passing through the undersluices. The pond level in the pocket was also kept constant for long periods to suit the river supplies and the silt charge.

With these conditions of steady flow and constant water levels, the tendency to scour or erosion was minimized, there being little rolling silt to pick up and transport to the canal. This system worked very satisfactorily.

Due to reasons already stated above, the question of silt exclusion from the canal at Merala became one of critical importance and it was decided to give the still pond method of regulation a trial to the extent possible. A modification of the rules was approved in May, 1932.

The Marala method of regulation is very efficient, because only the canal supply approaches the pocket and this limited supply is incapable of transporting the coarse silt. What actually happens is that at each bay, the discharge approaching the canal is reduced and on account of this sudden reduction in discharge, the water drops some of its burden of coarse silt, particularly the coarsest particles which form a silt bar opposite the groyne on the left of the bay. Similarly, silt bars are formed on the left groyne of each working bay. Soundings are frequently taken and the weir bays are worked backwards and forwards, as necessary, to keep the river upstream of the weir, clear of these bars, and in this manner the canal remains clear of silt.

As stated above, at Khanki, a discharge up to 35,000 cusecs in the left arm does not bring much harmful silt. Similarly at Marala, there is a rule that the canal should be closed when the discharge in the Jammu Tawi is more than 30,000 cusecs.

With no water in the Jammu Tawi, the canal is fed from the right and the canal discharge being about 12,000, the coarse silt intensity does not generally exceed 2 cu. ft. per cusec-day. The Khanki method of regulation consists of restricting the discharge in the left arm and has so far been quite successful.

A survey plan of the river at Merala, showing river conditions after the big flood of 1929 is attached (Plate V, Fig. 1).

The efficiency of the Merala method of regulation, *i.e.*, feeding the canal from the right to left lies in the fact that the approach channel carries a discharge just sufficient to feed the canal and, therefore, the slope is as flat as possible.

The gauges recorded at Merala show that the slope from the last working bay to the canal regulator is very flat, in fact there is generally a rise due to the heading up caused at the left side on account of the velocity of approach.

(*c*) Dividing the river into the channels by means of a bund as at Rasul and Khanki :—

At Rasul, up to about 1932, the system of control of the river in force was that whereby a constant flow was maintained through the undersluices. The Rupar system of keeping the weir sluices closed normally, so as to form a still pond upstream, had not been practised at Rasul, except occasionally for short periods, and it is recorded that whenever it was tried the result was to shoal up the sluice pocket and silt up the canal.

In 1919, Mr. Woods expressed the opinion that the Rupar system of surplussing the greater part of the river's flow, normally over the end of the weir furthest from the canal head, having been found by experience to be inapplicable to the works at Rasul, there was no sense in keeping the river flowing in two separate channels, by keeping one bay of the weir at a low level, controlled by shutters.

The survey plans attached to Irrigation Branch Paper No. 22 show that in 1903 (Plate No. VIII), the river approached the weir in two well defined channels as at Rupar with a shoal in the middle,but the right channel bifurcated again, one branch going to Bay 3 and the other to Bay 4. By 1905 (Plate No. IX) the right channel developed further and the left channel dwindled somewhat and this process continued till the left channel got choked. After 1920, the whole of the winter discharge passed through the right channel, and the canal was fed from right to left as in the Merala system.

However, the undersluices were not kept closed and silt entry into the canal continued unabated.

After the big floods of 1928 and 1929, the river developed on the right, but was gradually brought back to the left by manipulation of the shutters and in 1934, about equal discharge passed over the two sides of the weir in high supply, but as the season proceeded, the right channel silted up considerably, the central *bela* extended to the right and the waterway between the upstream groyne No. 4 and the central *bela* became very restricted (Plate IV, figs. 2 and 3); and ultimately in 1936, it silted up badly so much so that the safety of the undersluices, weir and connected works was considered in danger.

The Still Pond system was adopted in 1932 and has been in force since then. The river has been divided into two halves as at Khanki, by connecting the central *bela* with groyne No. 4.

The present conditions at Khanki and Rasul appear to be very similar, as at both headworks there is a central *bela* connected with groyne No. 4 by means of an earthen bund. However, the conditions at the two headworks are actually quite different.

Due to the much shorter length of the central bela at Rasul, which is only ¾ths of a mile as compared with about 2 miles at Khanki, the control over the distribution at the nose of the *bela* at Rasul is much greater, in spite of the absence of shutters in the right bays. At Khanki only remote control is possible over the distribution of discharge in the right and left channels, since adjustment of pond level on either flank of the weir, particularly on the left, does not result in any similar variation in the discharge ratio of the two branches, until some days have elapsed.

This important fact is well illustrated by events at the end of June 1936, when the canal was closed for six days.

The pond gauges and discharges are tabulated in the attached statement (App. II).

During the closure period the pond level was three to four feet lower on the left side than the right, but no appreciable change occurred in the ratio of the discharges on the two flanks.

During the 10 days, 16th to 25th June, the pond level on the left was about 1·5 feet lower than on the right, but the ratio of discharge increased from only 0·75 to 1·0.

The river slope from the Palkhu Spur to the canal head at Khanki is generally 1 in 5000 or steeper during the monsoon months, while the slope at Rasul is much flatter even in a high river, the usual slope being 1 in 10,000 or less.

At Khanki, this slope does not alter much if the undersluices are opened, but at Rasul the effect is immediate and the slope increases to as much as 1 in 4000 or even steeper.

This difference is due to the river at Khanki flowing direct to the undersluices (Plate VI, Fig. 3) while at Rasul, the curvature above the left guide bank pushes the main river towards Bay 3. (Plate III, Fig. 3). So far this method of dividing the river into two channels has given good results as far as silt exclusion is concerned, but the safety of the weir is much more important and has to be given first consideration.

The right channel at Khanki being much shorter in length its over-development during years of abundant flow cannot be controlled, with the result that in a big flood the right half of the weir is likely to be over-strained.

The method adopted at Rupar ensures both a uniform distribution of discharge across the weir and silt exclusion from the canal. It has the additional advantage of absolute stability, but it cannot be applied at this stage to the other three headworks dealt with in the Paper, except at prohibitive cost.

The Merala method has proved a success and also ensures a very uniform distribution across the weir and silt exclusion from the canal. It does not involve any extra expense, and is known to be stable.

It, however, involves parallel flow upstream of the weir which may not be suitable at other places.

At Rasul, this method was blamed for damaging the weir during the big floods of 1928 and 1929 due to the diagonal flow causing swirls at the noses of the upstream groynes.

There are no pier groynes upstream of the weir at Merala and those at Rasul and Khanki could be dismantled to suit the Merala conditions. However, the river sand at Marala is coarse, and the sand at

Rasul and Khanki is much finer, and may not be found suitable to stand the diagonal flow caused by adopting the Marala methods.

The drawbacks of the method at present employed at Khanki and Rasul are the lack of sufficient control on the distribution of discharge between the two branches and the danger of oblique flow and uneven intensity of discharge over the weir in high floods.

Conclusion :—

The ideal method would appear to be to distribute the river into two branches, the main channel flowing straight to the middle of the weir and a smaller but certain channel feeding the canal, but it is almost impossible to obtain such distribution in practice because either the main channel may overdevelop, thereby choking the other channel feeding the canal, or else the smaller channel may develop too much and cause trouble. For these reasons, this method is very unstable, and this is amply proved by the history of the Palkhu Bund at Khanki.

The most suitable course appears to follow the Marala method and to strengthen and alter the weir upstream to stand the diagonal flow, the effect of which can be greatly mitigated by training the main channel towards the middle of the weir.

APPENDIX I.

MAXIMUM QUANTITY OF SILT IN ANY ONE MONTH DURING THE SUMMER EACH YEAR.

Year.	Quantity of silt in lac c. ft.	Month	Remarks
1905	42·3	September	Low river.
1906	34·9	August	Abundant flow during July and August.
1907	77·2	October	Abundant flow in July and August.
1908	37·9	September	
1909	63·5	do	
1910	77·2	October	
1911	62·7	do	
1912	84·0	do	Guide Bank constructed.
1913	34·9	do	
1914	31·6	July	
1915	39·4	August	
1916	84·2	October	Year of abundant flow, with no big floods.
1917	66·0	September	
1918	33·9	August	
1919	51·4	September	
1920	45·0	do	
1921	52·4	do	
1922	54·7	do	
1923	32·6	August	
1924	32·0	do	
1925	36·5	do	
1926	33·6	do	
1927	26·7	do	Up to end of June discharge below weir did not exceed 30000. There was good supply in the latter half of July and 1st half of August but canal was closed 6 times to pass freshet.
1928	50·7	September	
1929	41·9	do	Pond level gauge No. 13 maintained at 732·5.
1930	131·05	June	Gauge No. 13 kept very low, viz., between R. L. 729 and 730·5 and fluctuating. Also high river at end of June.
1931	173·25	September	High River and fluctuating Pond level. Pond lowered from 732·8 to 731·8 on 8.8.31 when discharge was 117898 cs. of which 90000 cs. was passing in Left arm canal silted to the extent of 2·39 by 18.8.32. Low pond in September.
1932	155·52	August	Silting caused by fluctuating Pond level, which was lowered from 731.5 on 14.7.32 to 730.2 on 15/7 when discharge in left arm was 85000 cs. River in August was also high.
1933	104·23	July	
1934	77·8	September.	
1935	— 2·62	August.	
1936	81·59	do	
1937	—83·16	do	
1938	—73·84	do	

APPENDIX II.

STATEMENT OF POND LEVELS AND DISCHARGES BEFORE AND AFTER CANAL CLOSURE.

Date.	Pond Level Gauge No. 13.	Right U/S Gauge No. 5.	Discharges.		Ratio Col 4. / Col. 5	Fall Spur S.E.			Fall Palkhu to left flank	
			Left Channel.	Right Channel.		To right flank.	To Left flank.	To Palkhu.		
1	2	3	4	5	6	7	8	9	10	
26-6	731·5	733·0	26500	27300	0·97	1·5	3·0	1·85	1·15	
27	731·5	733·0	19746	18815	1·05	1·1	2·6	1·25	1·35	
28	731·5	732·5	18744	23097	0·81	1·5	2·5	1·5	1·0	
29	731·65	733·0	21675	25223	0·86	Gauge Spur E not given			1·0	
30	725·95	729·2	22397	31830	0·70	4·6	7·85	2·8	5·05	Canal closed for repairs and to pass flood.
1.7	726·20	730·0	25303	37208	0·68	Gauge Spur E not given			4·1	
2	726·8	731·5	28620	27678	1·04	2·3	7·0	3·1	3·9	
3	727·6	731·5	31569	31524	1·00	Gauge Spur E not given			3·5	
4	729·0	732·0	35338	36236	0·98	3·2	6·2	3·7	2·5	
5	730·8	733·2	87142	83012	1·05	2·1	4·5	1·85	2·65	
6	731·0	732·5	54367	51556	1·05	2·5	4·0	2·55	1·45	
7	731·8	732·2	77992	68265	1·14	Gauge Spur E not given			1·2	
8.7	731·4	732·0	55400	50200	1·13	2·4	3·2	1·55	1·65	

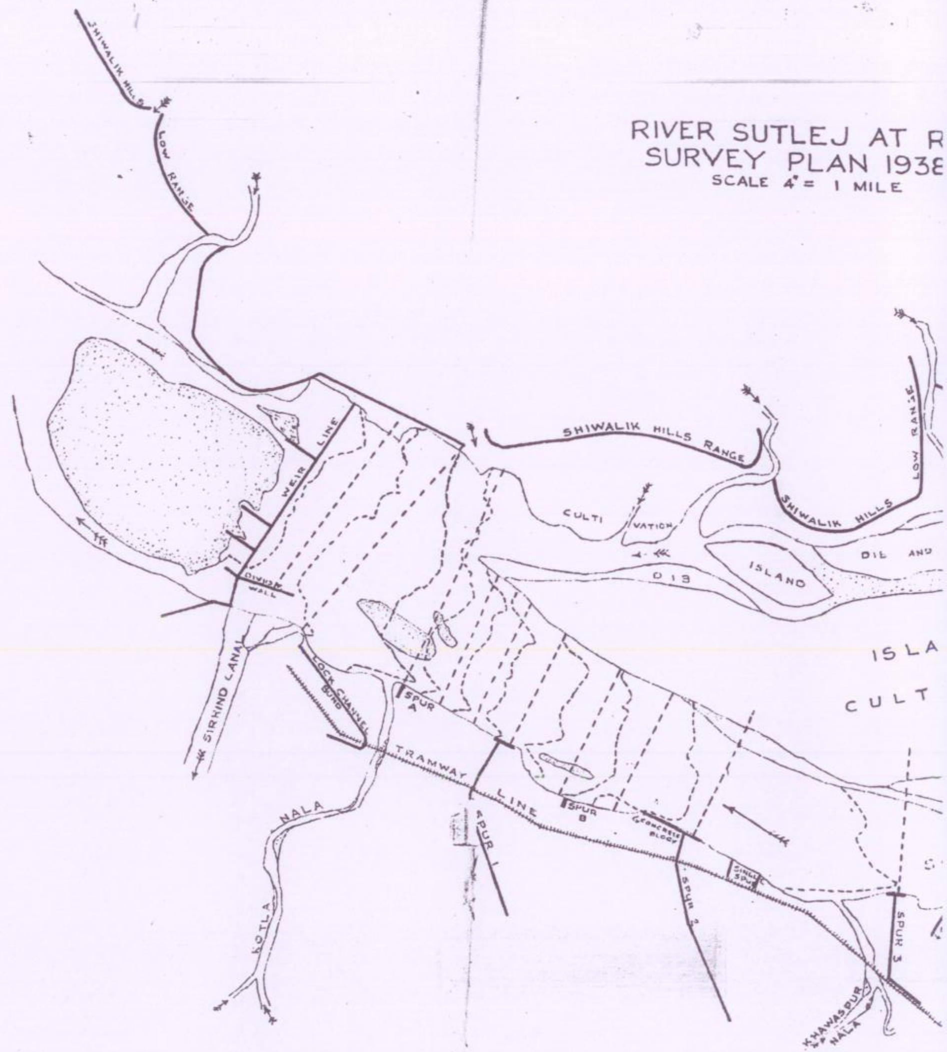
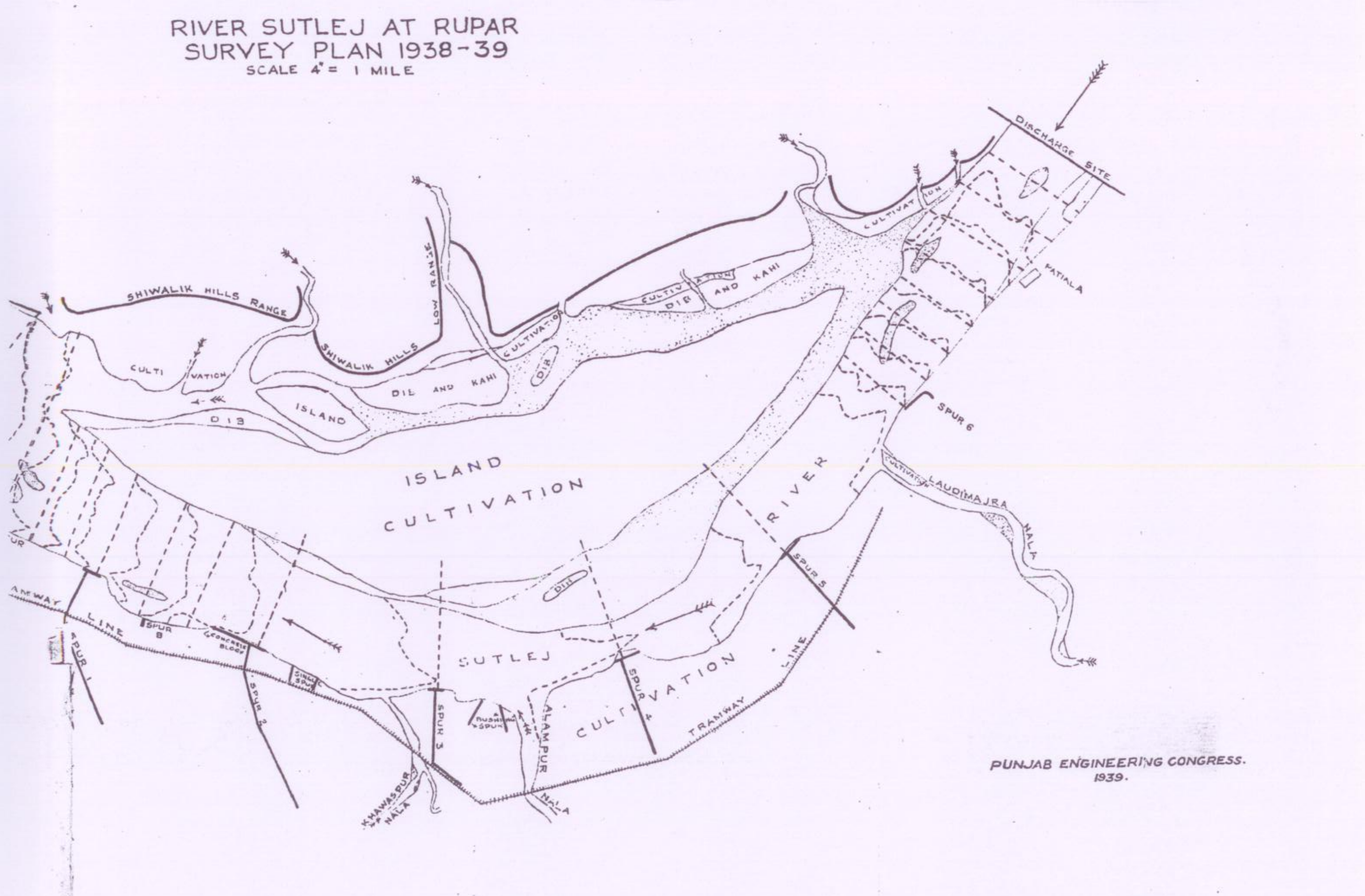

RIVER SUTLEJ AT R
SURVEY PLAN 1938
SCALE 4" = 1 MILE
SHIWALIK HILLS
LOW RANGE
SHIWALIK HILLS RANGE
CULTI VATION
DIB
ISLAND
DIL AND
ISLA
CULT
WEIR LINE
DIVIDE WALL
SIRHIND CANAL
LOCK CHANNEL BUND
SPUR A
TRAMWAY LINE
SPUR 1
SPUR B
SPUR 2
SPUR 3
NALA
KOTLA
KHAWASPUR NALA

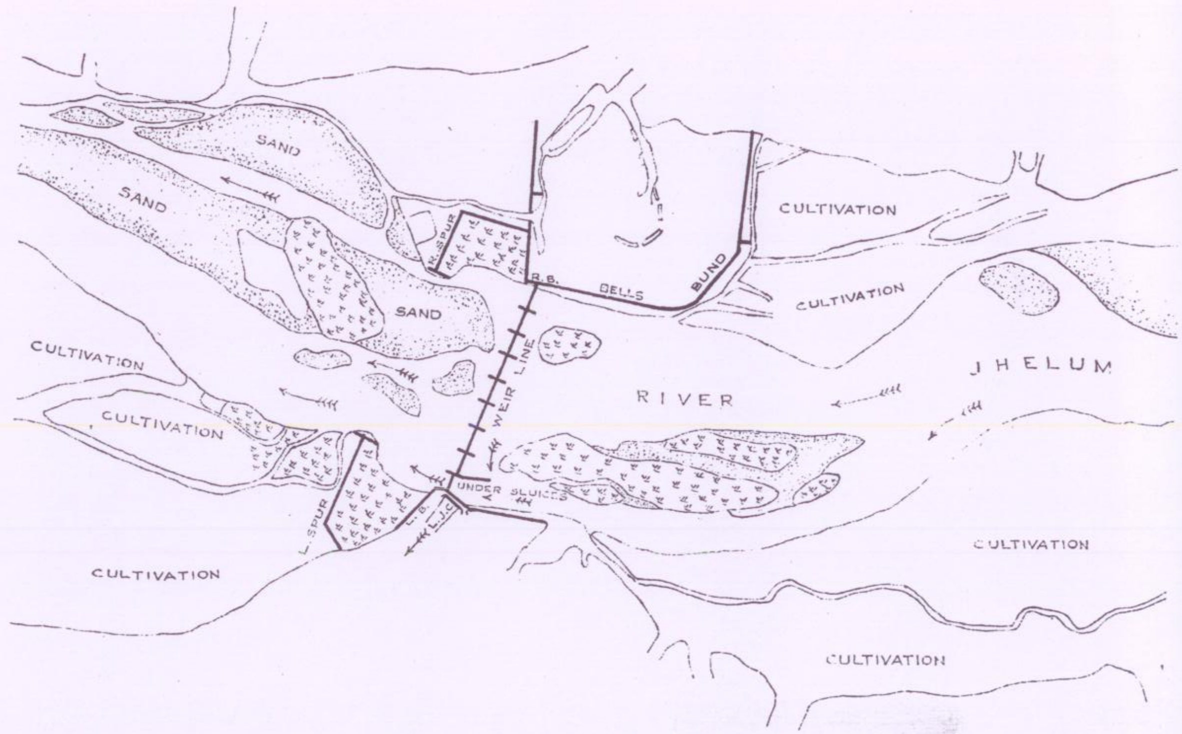
PLATE I

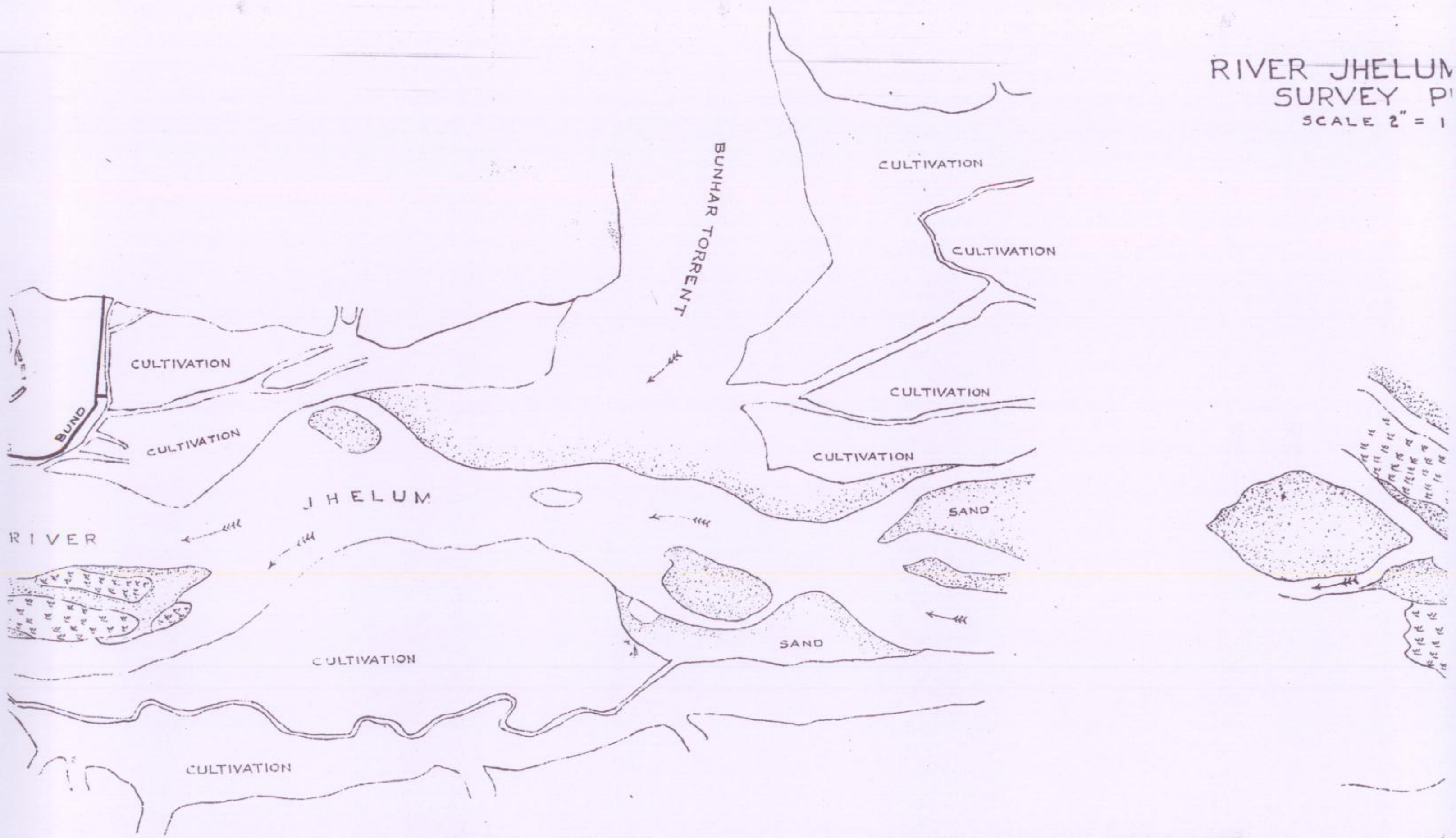
PAPER NO. 226



PUNJAB ENGINEERING CONGRESS.
1939.

FIG. 1
1916-17

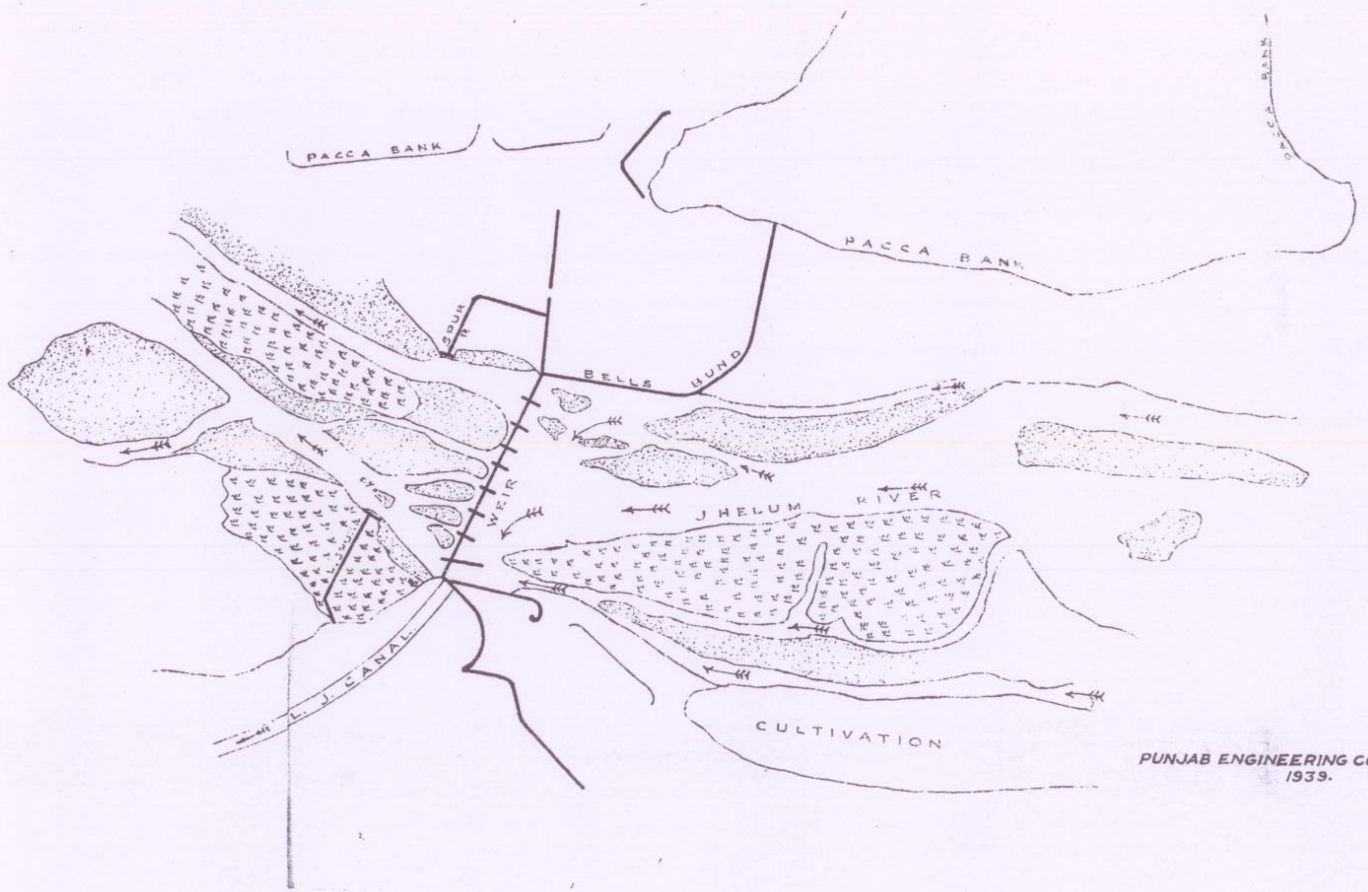

SAND
SAND
SAND
R. SPUR
R.B.
BELLS
BUND
CULTIVATION
CULTIVATION
CULTIVATION
CULTIVATION
JHELUM
RIVER
WEIR LINE
UNDER SLUICES
L.B.
L.J.C.
L. SPUR
CULTIVATION
CULTIVATION
CULTIVATION


RIVER JHELUM
SURVEY P
SCALE 2" = 1
BUNHAR TORRENT
CULTIVATION
CULTIVATION
CULTIVATION
CULTIVATION
SAND
SAND
CULTIVATION
CULTIVATION
BUND
JHELUM
RIVER
CULTIVATION
CULTIVATION

RIVER JHELUM AT RASUL
SURVEY PLANS
SCALE 2" = 1 MILE

PLATE II
PAPER NO. 226

FIG. 2
OCTOBER 1927



PUNJAB ENGINEERING CONGRESS.
1939.

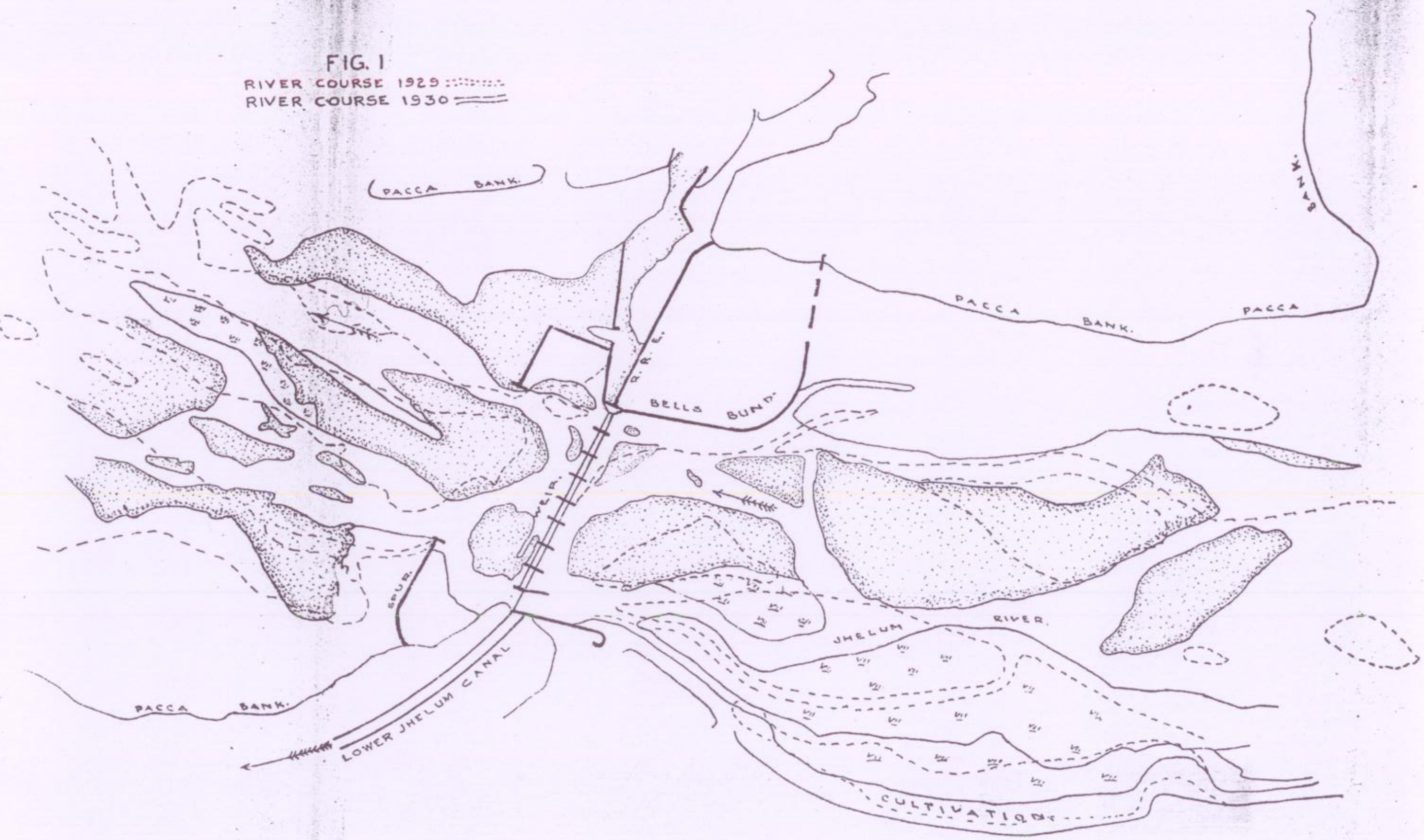
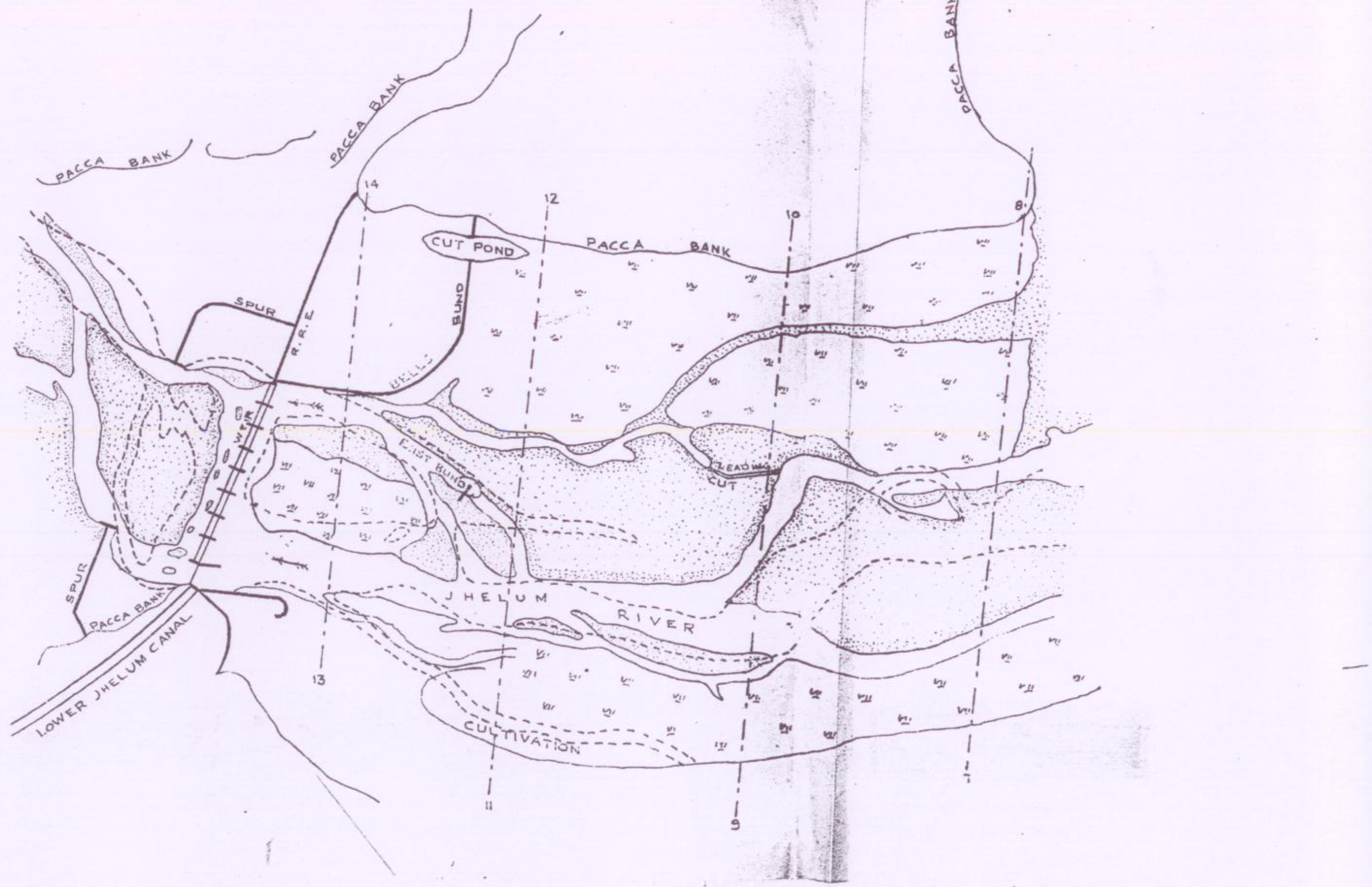

RIVER COURSE 1929
RIVER COURSE 1930
PACCA BANK.
PACCA BANK. PACCA
BANK.
R.R.E.
BELLS BUND.
WEIR
SPUR.
JHELUM RIVER.
PACCA BANK.
LOWER JHELUM CANAL
CULTIVATION.

FIG. 1

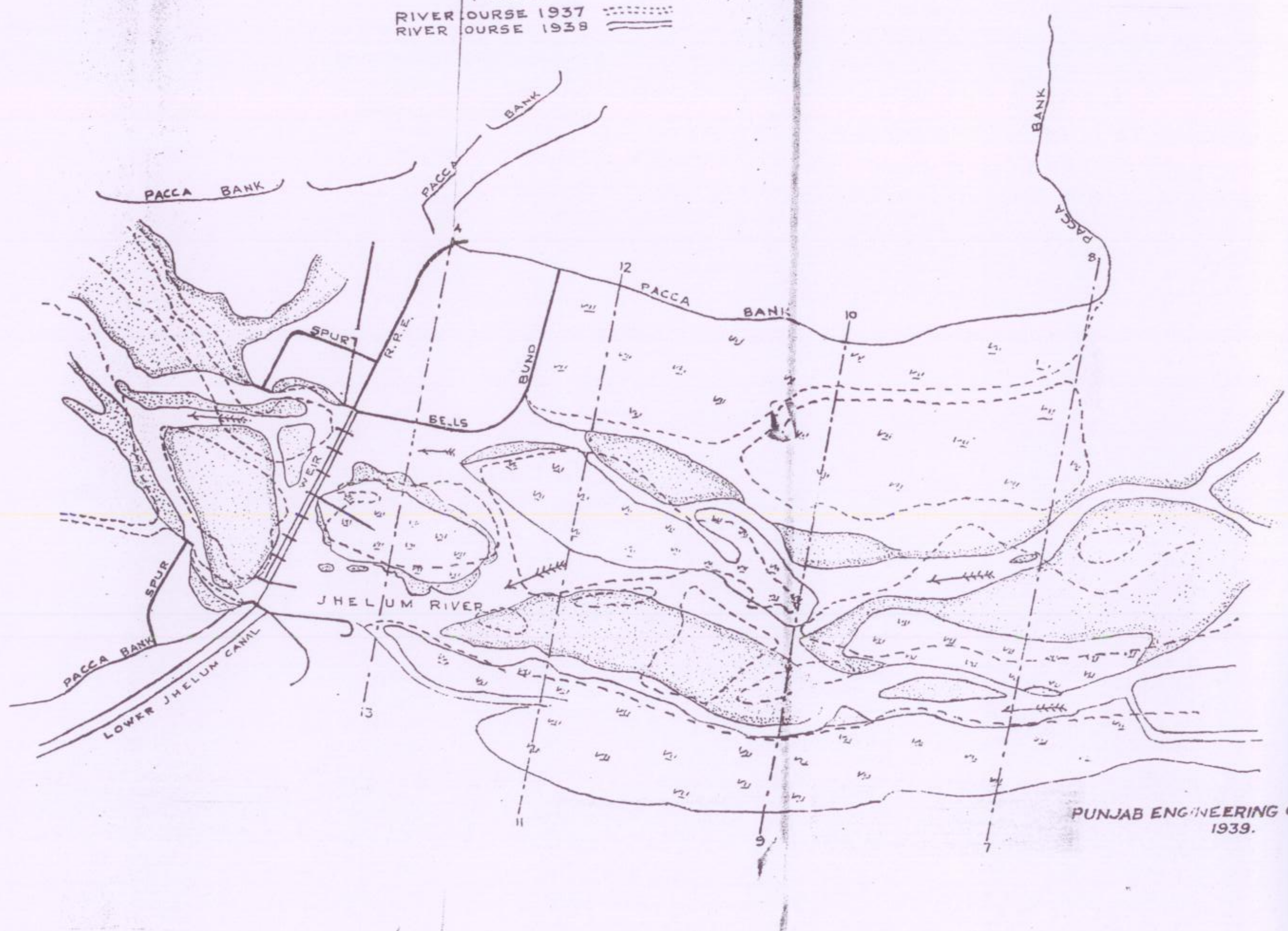
RIVER JHELUM
SURVEY P1
SCALE 2" = 1 M

FIG. 2
RIVER COURSE 1935
RIVER COURSE 1936



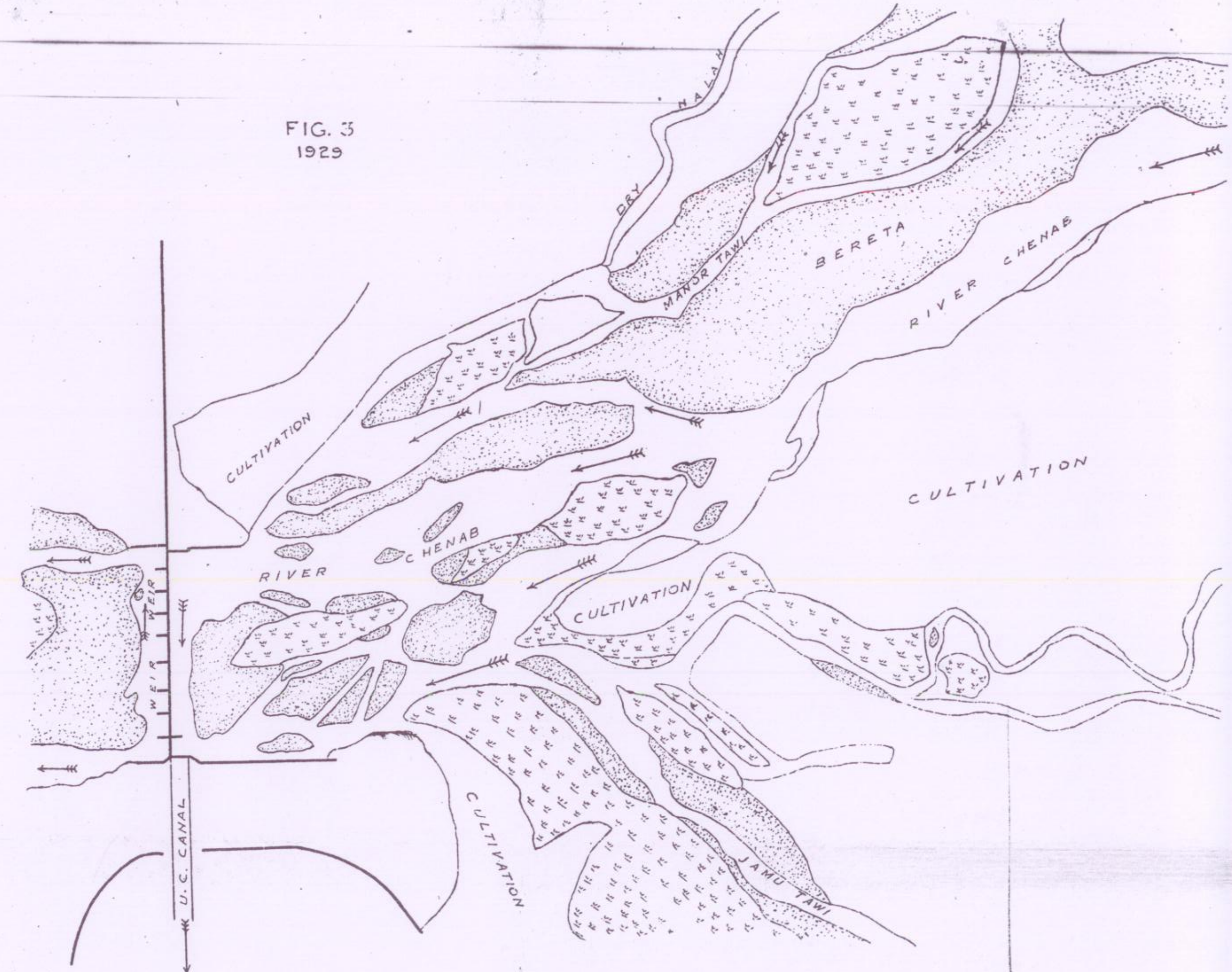
RIVER JHELUM AT RASUL
SURVEY PLANS
SCALE 2" = 1 MILE

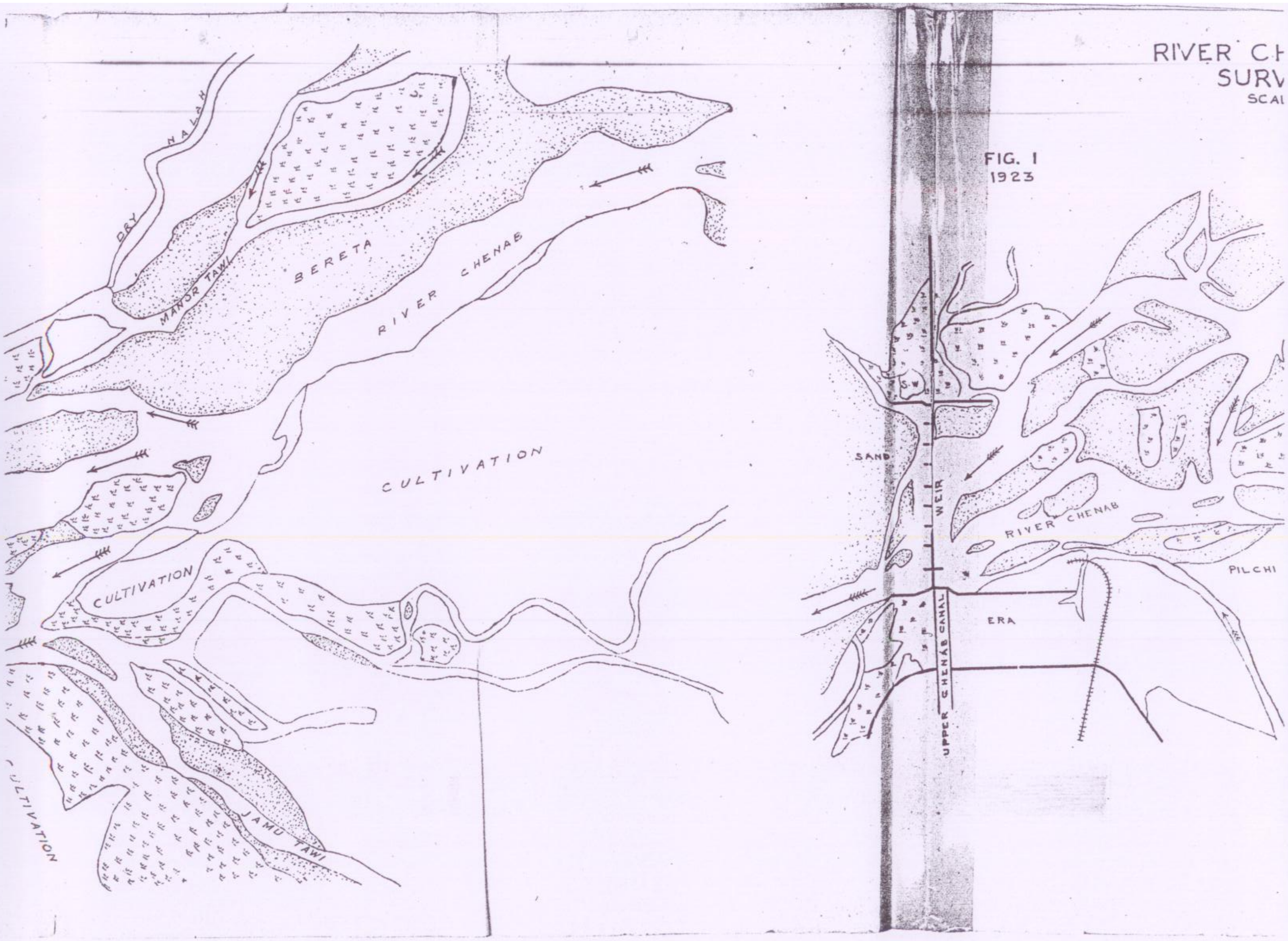
FIG. 3



PUNJAB ENGINEERING C
1939.

FIG. 3
1929


DRY NALAH
MANSR TAWI
BERETA
RIVER CHENAB
CULTIVATION
CULTIVATION
CHENAB
RIVER
CULTIVATION
WEIR
WEIR
U. C. CANAL
CULTIVATION
JAMU TAWI



RIVER CH
SURV
SCAL
FIG. I
1923
DRY NALAH
MANSR TAWI
BERETA
RIVER CHENAB
CULTIVATION
CULTIVATION
JAMU TAWI
CULTIVATION
SAND
S.W.
WEIR
RIVER CHENAB
PILCHI
ERA
UPPER CHENAB CANAL

PLATE IV
PAPER NO. 226

RIVER CHENAB AT MARALA
SURVEY PLANS
SCALE 2" = 1 MILE

FIG. 1
1923

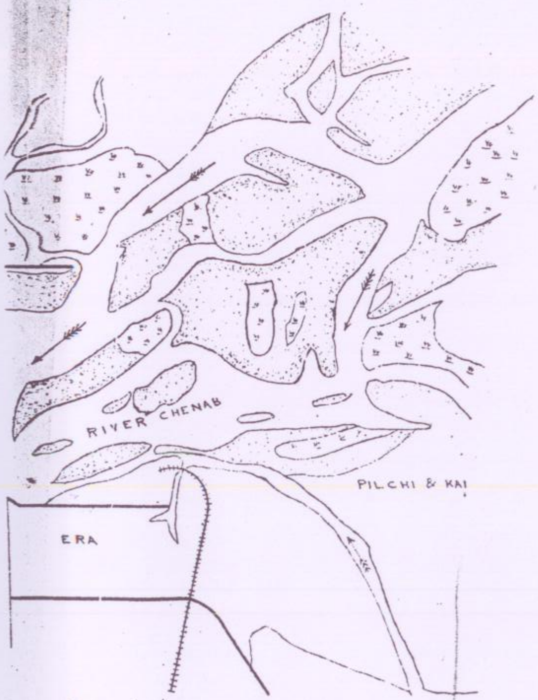
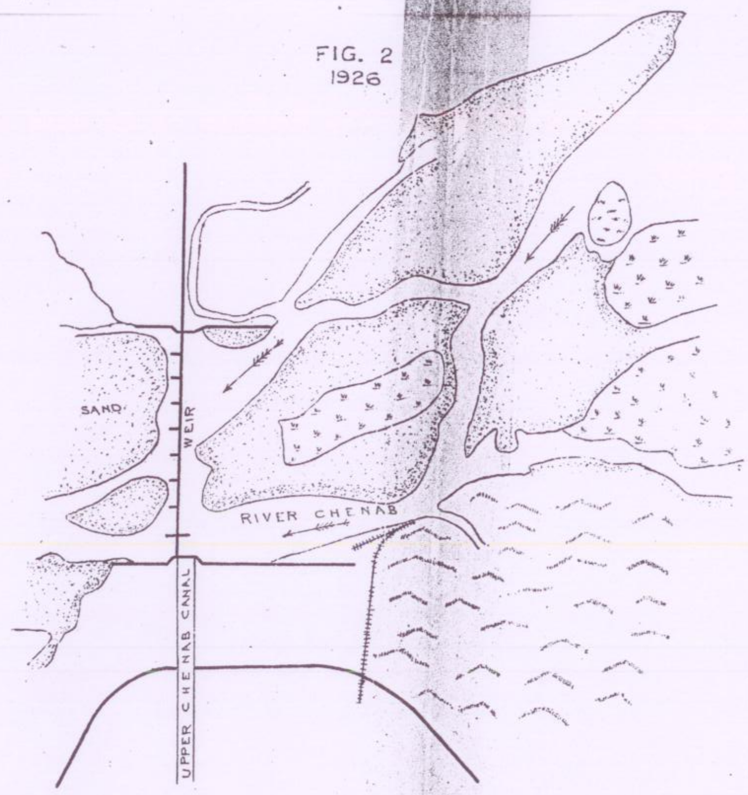


FIG. 2
1926



PUNJAB ENGINEERING CONGRESS.
1939.

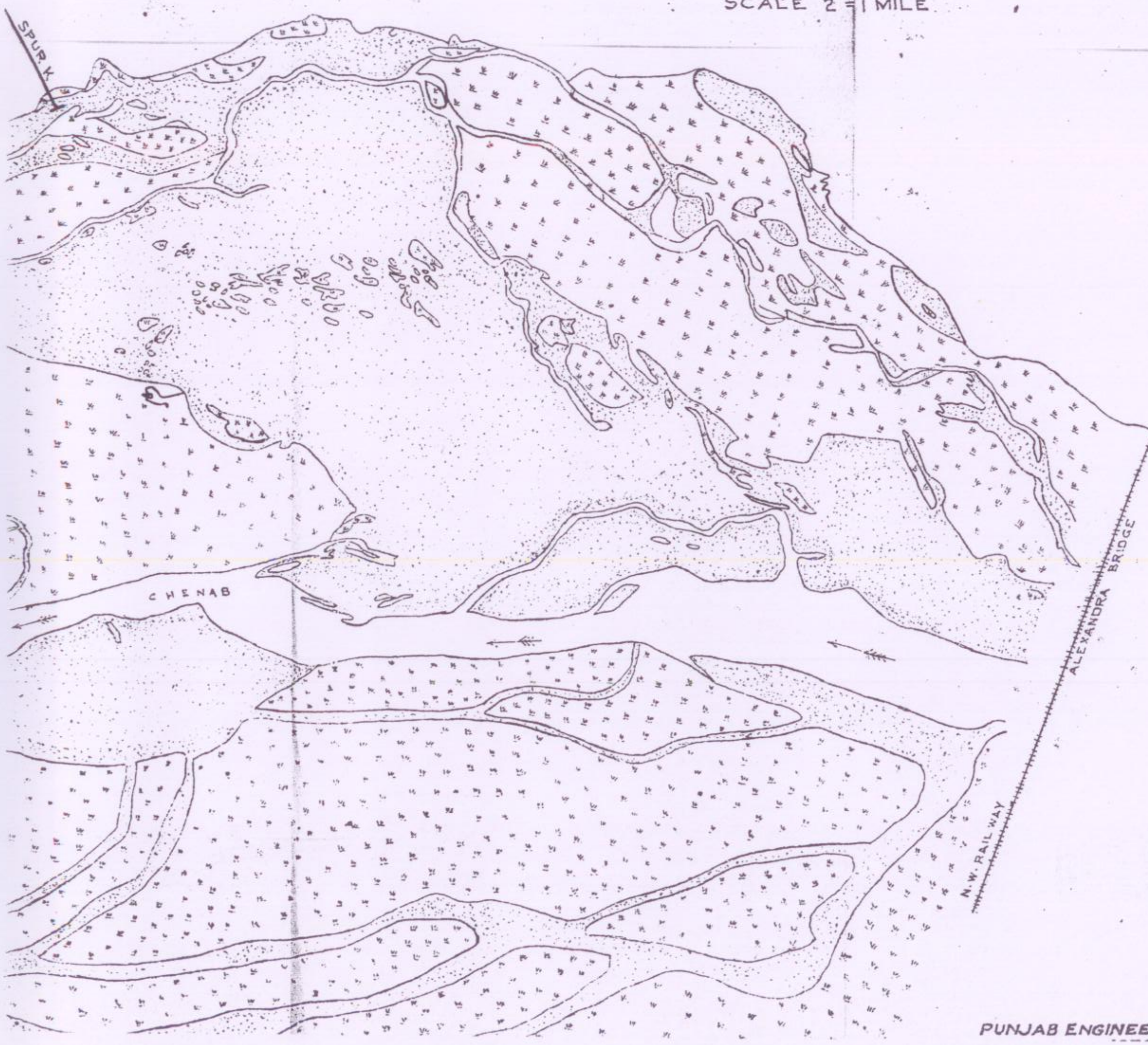

SPUR G.H.O
SPUR E
RETIRED BUND
BELLS BUND
SPUR A
KHANKI WEIR
LEFT PROTECTION BUND
LOWER CHENAB CANAL
SPUR W


RIVER CHENAB
SPUR K
SPUR J
SPUR I
SPUR G.H
SPUR E
SPUR A
BELLS BUND
RETIRED BUND

RIVER CHENAB AT KHANKI
SURVEY PLAN FOR THE YEAR 1903-04

SCALE 2" = 1 MILE.

PLATE V
PAPER NO. 228



PUNJAB ENGINEERING CONGRESS.

FIG. 1
1920-21

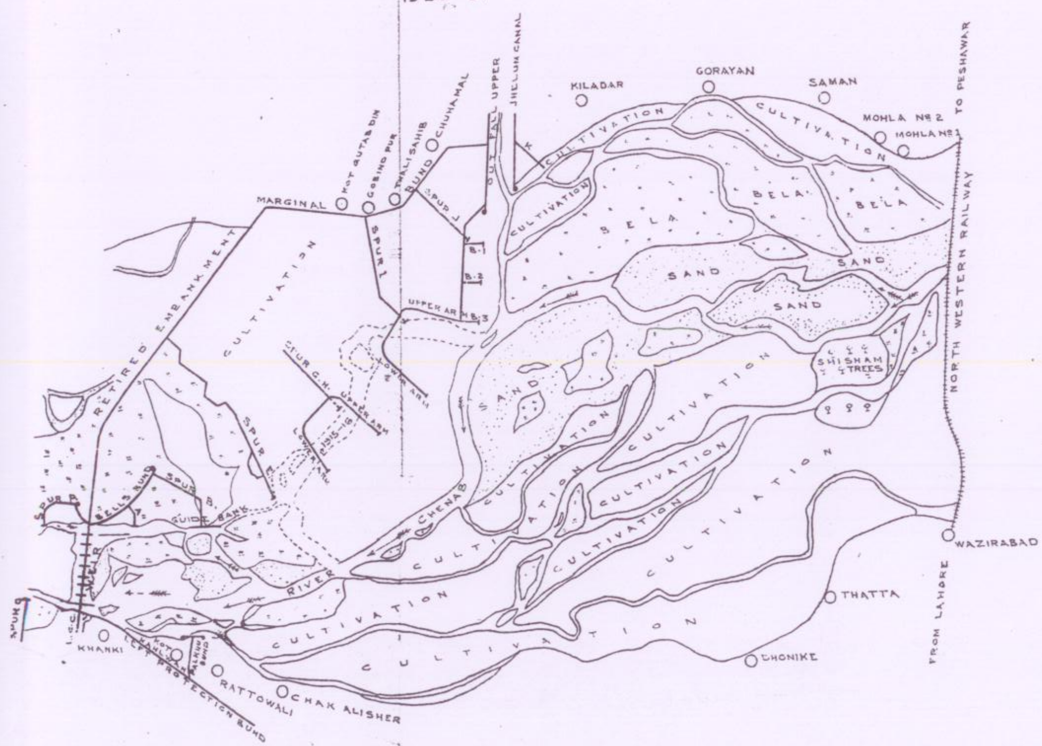


FIG. 2
1929-30

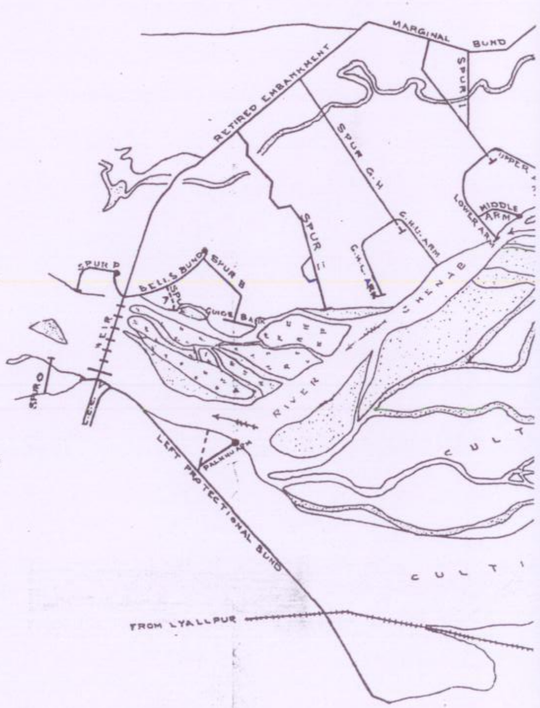
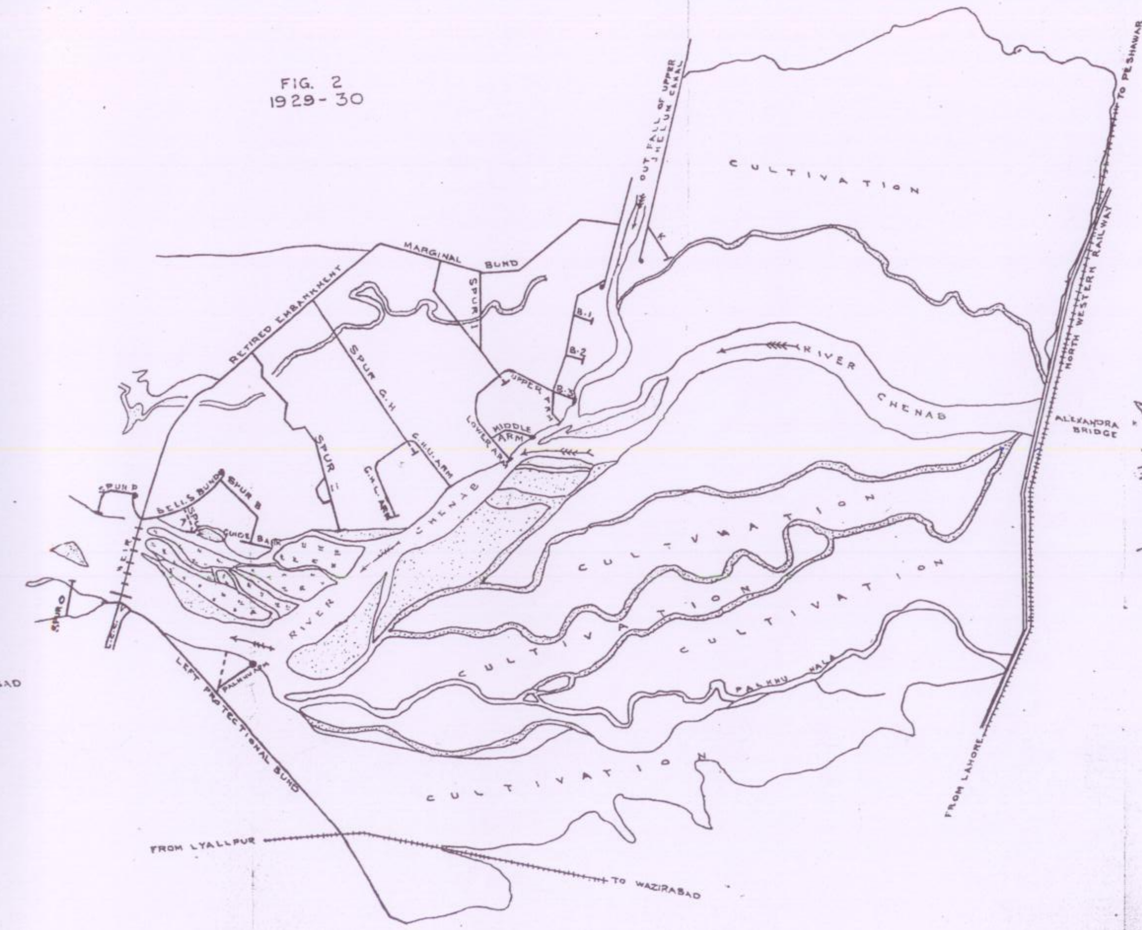


FIG. 2
1929-30



RIVER CHENAB AT KHA
SURVEY PLANS
SCALE 1" = 1 MILE

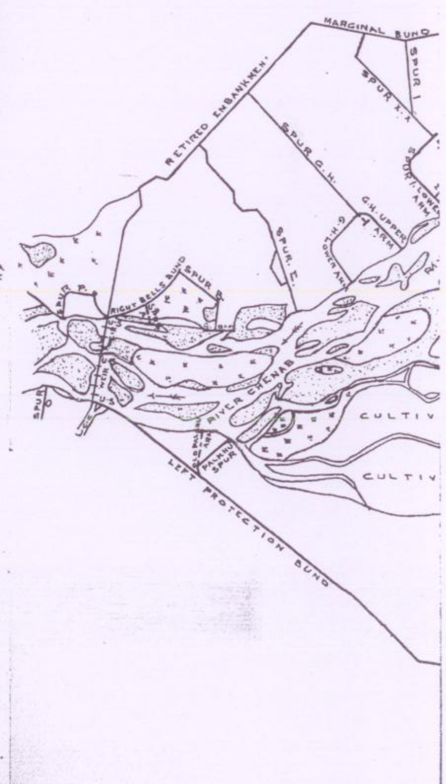
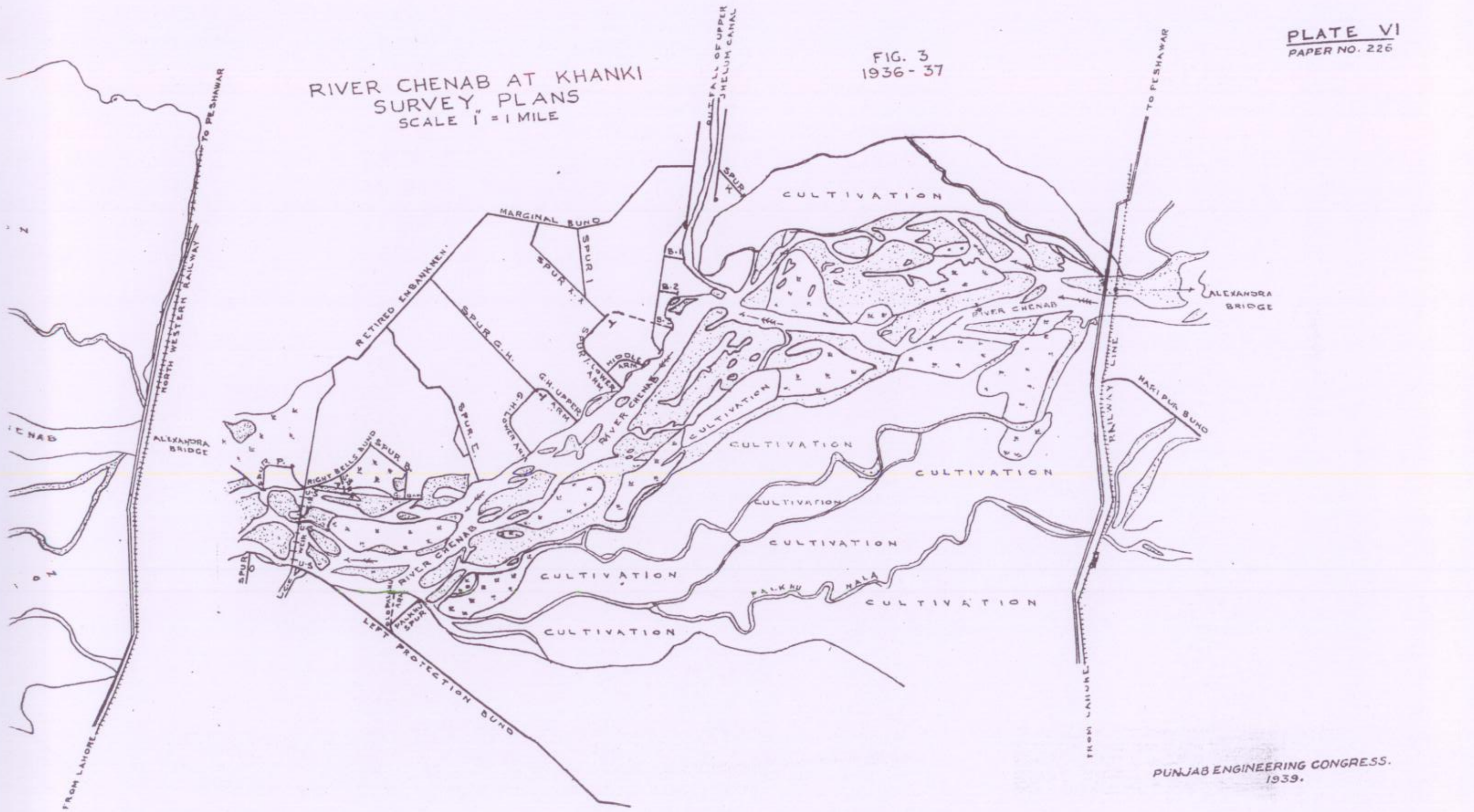


PLATE VI
PAPER NO. 226

RIVER CHENAB AT KHANKI
SURVEY PLANS
SCALE 1" = 1 MILE

FIG. 3
1936 - 37



PUNJAB ENGINEERING CONGRESS.
1939.

FIG. 1
901-1902

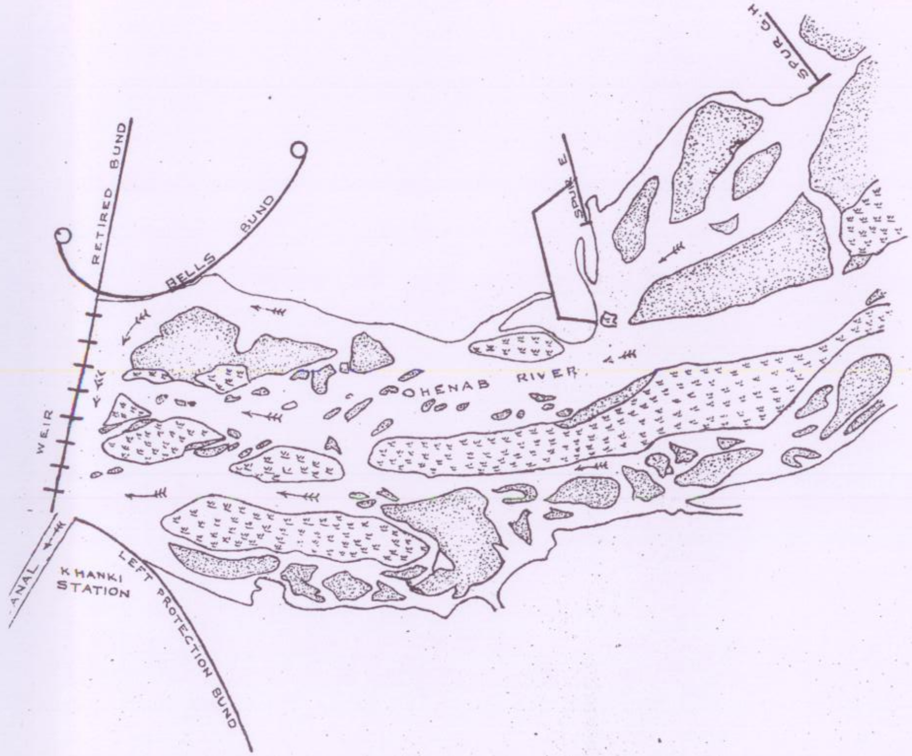
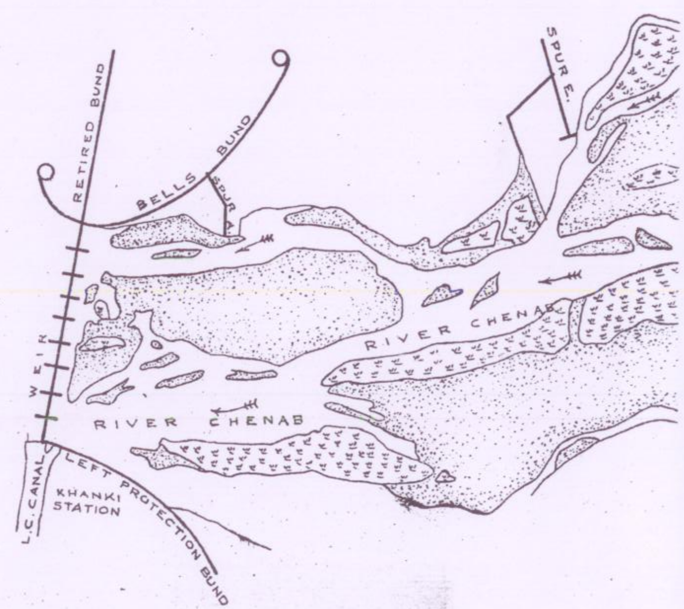


FIG. 2
1906-1907



RIVER CHENAB AT KHANKI
SURVEY PLANS
SCALE 2" = 1 MILE

FIG. 2
1906-1907

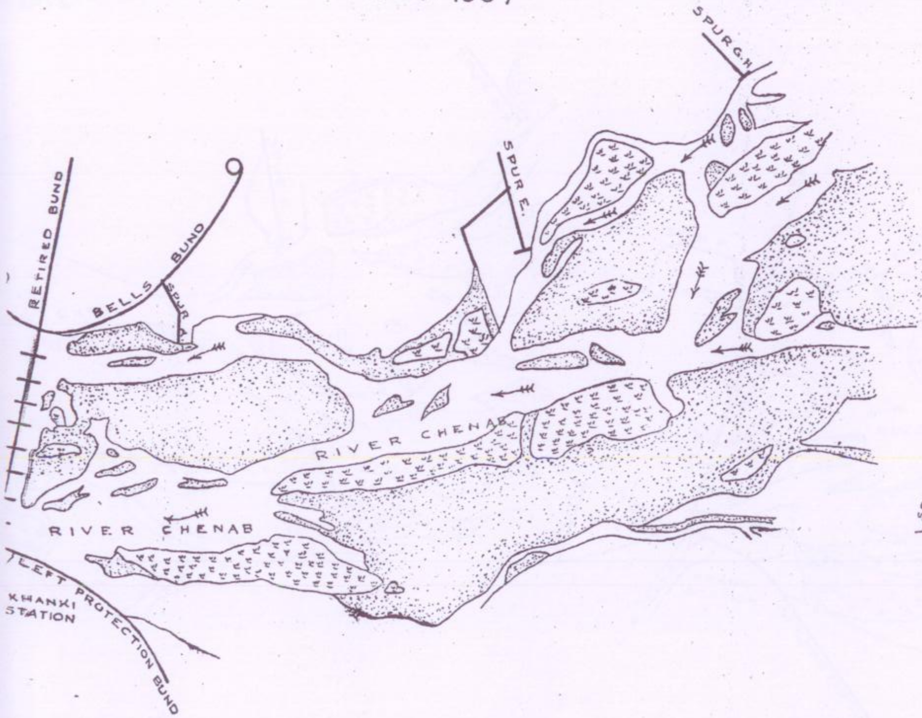


FIG. 3
1911 - 1912

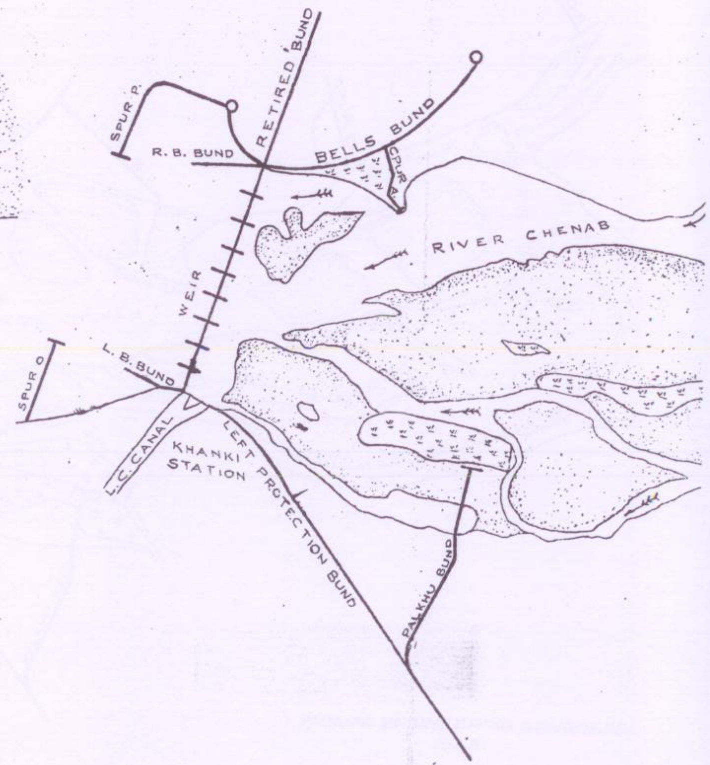


PLATE VII
PAPER NO. 226

.. 3
1912

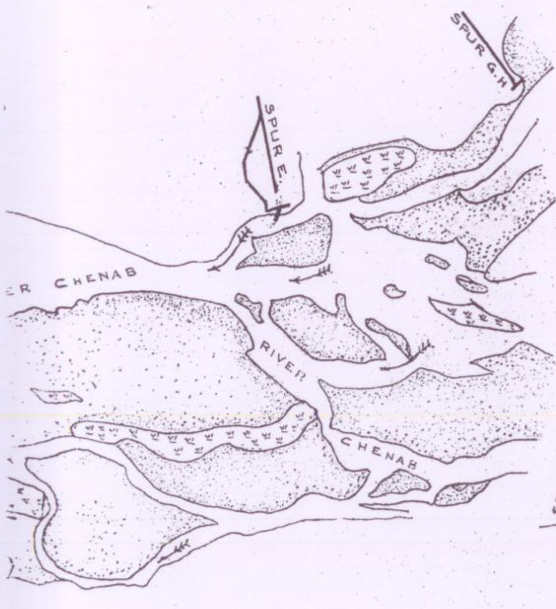
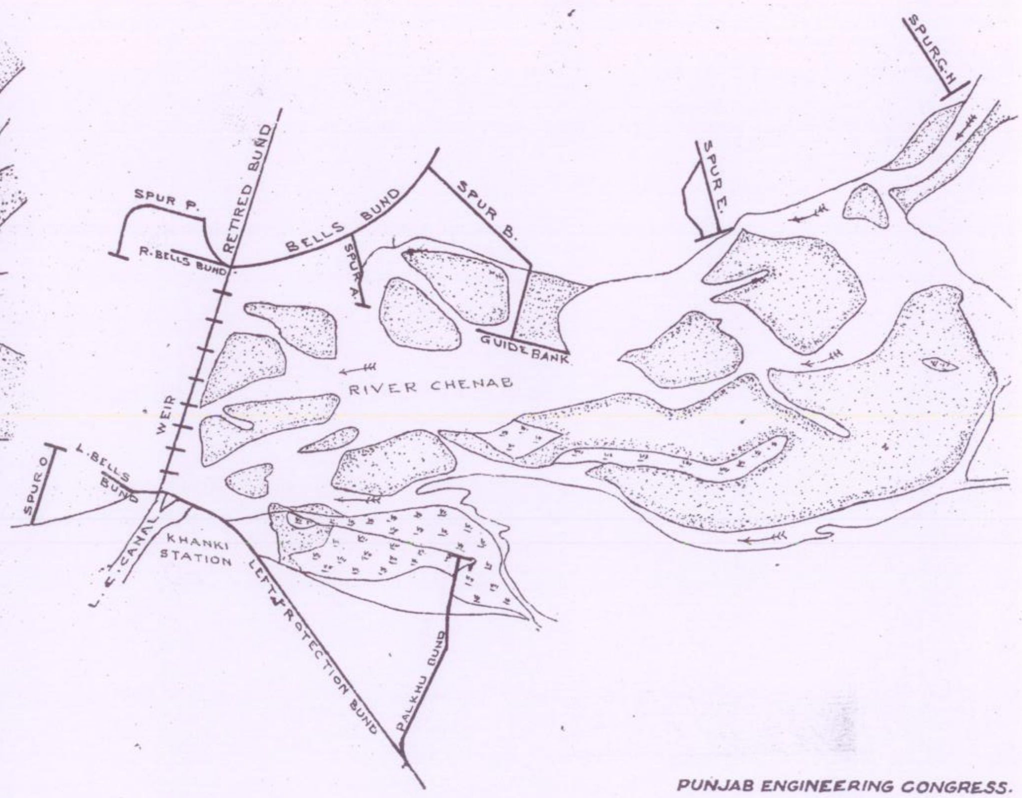


FIG. 4
1912-1913



PUNJAB ENGINEERING CONGRESS.
1939.

FIG. 1
1917-18

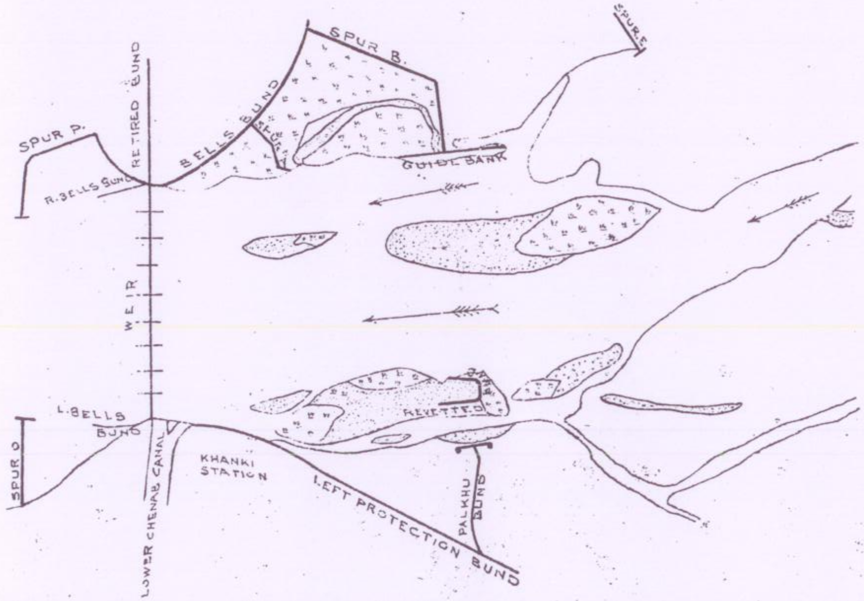
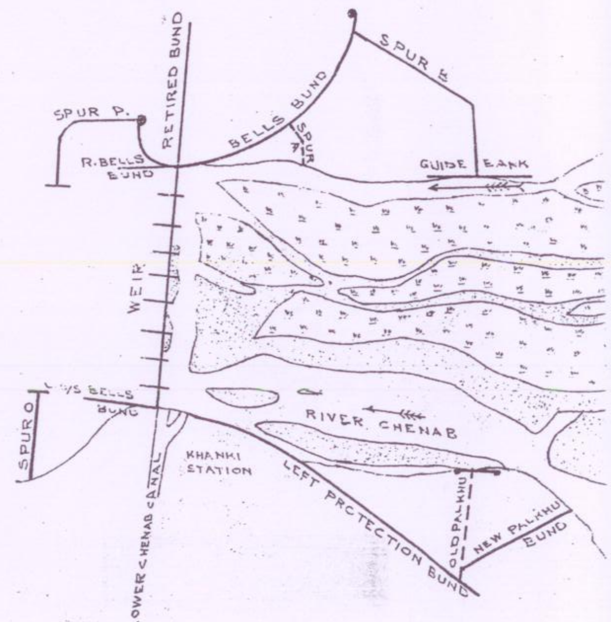


FIG. 2
1927-28



RIVER CHENAB AT KHANKI
SURVEY PLANS
SCALE 2"=1 MILE

FIG. 2
1927-28

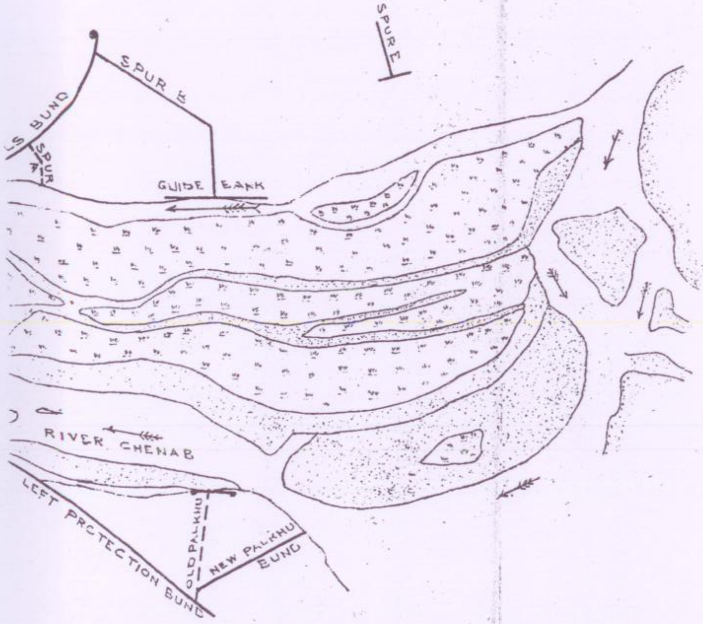
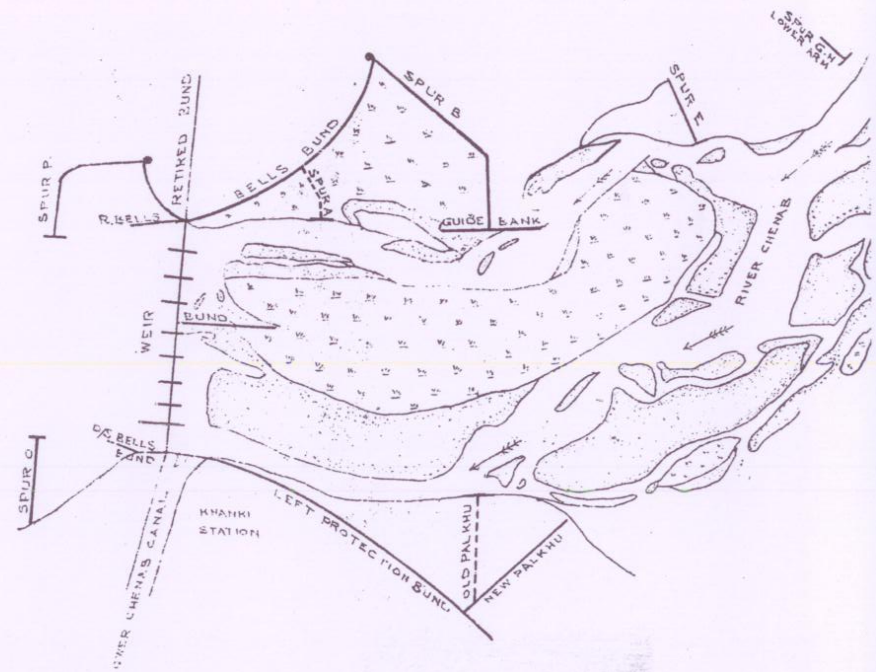


FIG. 3
1932-33



HAṄKI

PLATE VIII
PAPER NO. 226

FIG. 3
1932-33

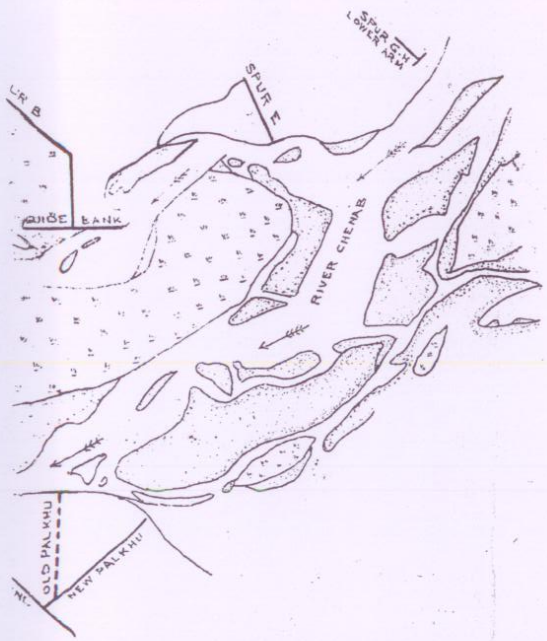
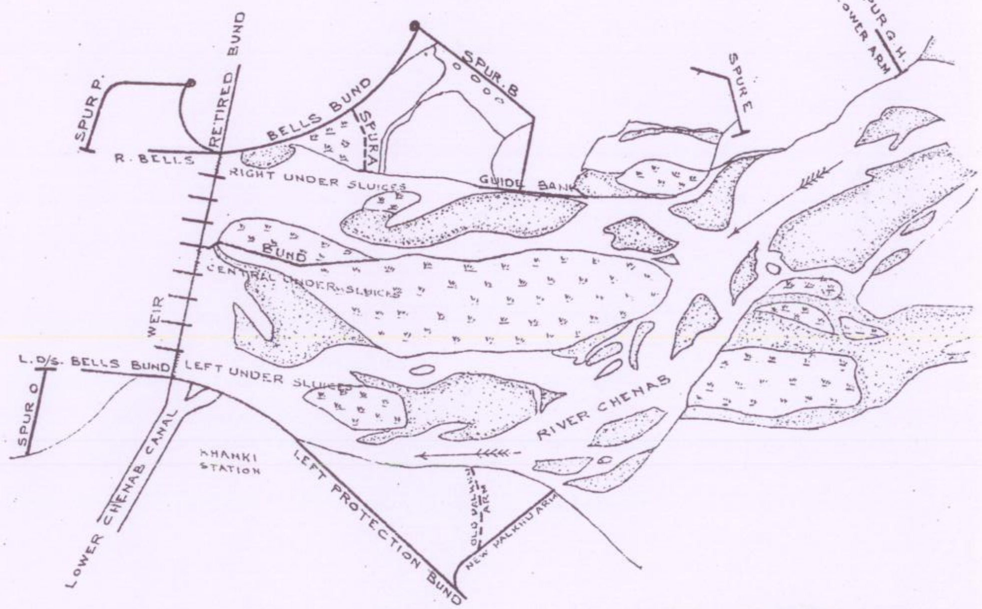


FIG. 4
1937-38



PUNJAB ENGINEERING CONGRESS.
1939.

ƎHOWING SILT INTENSITY
)ISCHARGE LEFT ARM

FIG. 3

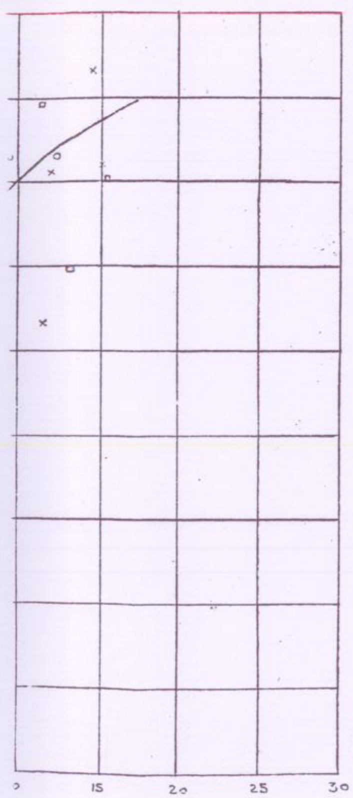
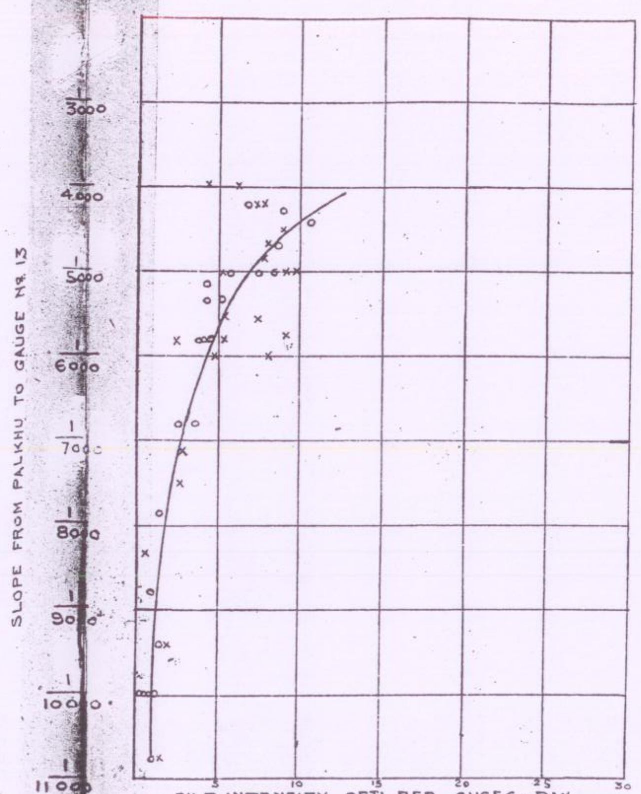


DIAGRAM SHOWING SILT INTENSITY
AND SLOPES FROM PULKHU TO GAUGE №13

PLATE IX
PAPER NO. 226

FIG. 4



PUNJAB ENGINEERING CONGRESS.
1939.

FIG. 2 SHOWING ACTION AT A SPUR HEAD

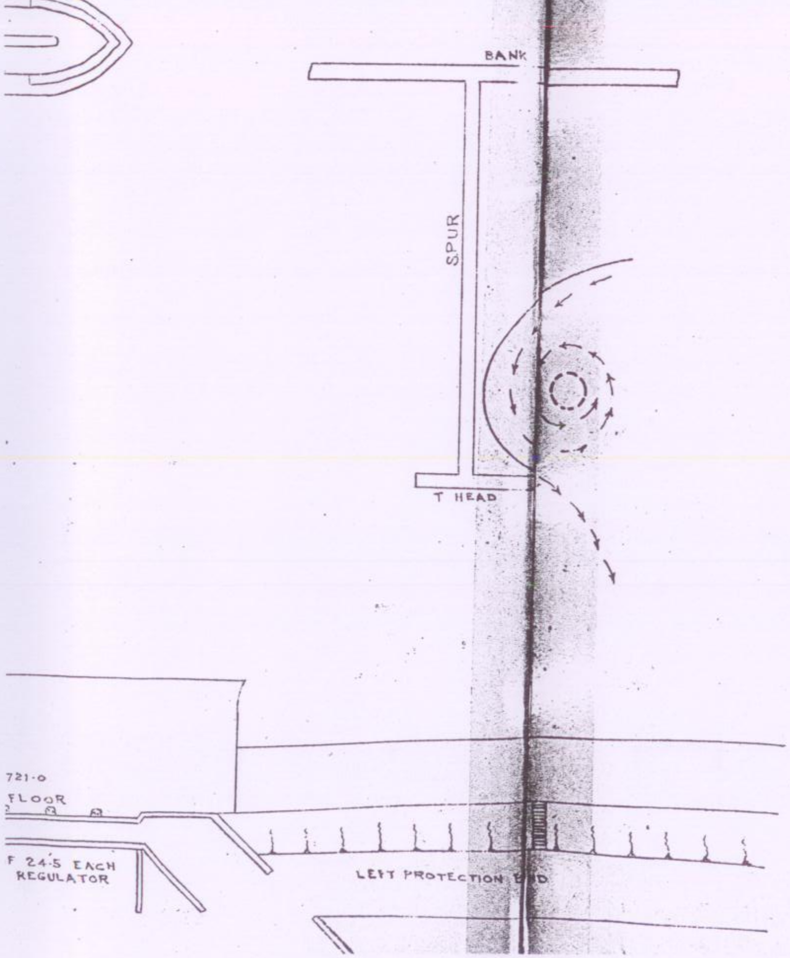


DIAGRAM SHOWING SILT INTENSITY
AND DISCHARGE LEFT ARM

FIG. 3

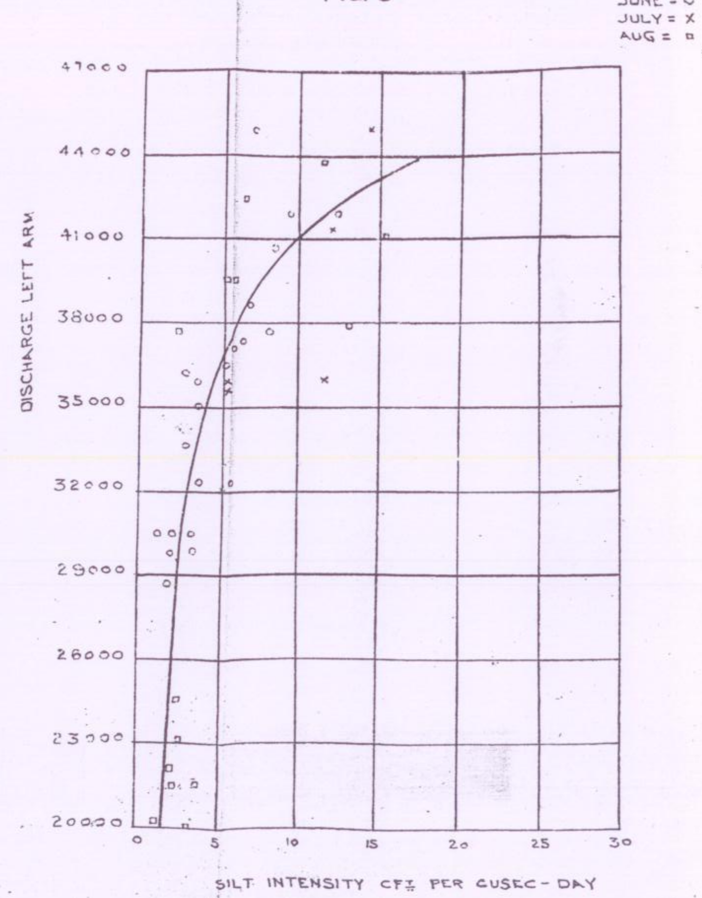


FIG. 1 PLAN SHOWIN LEFT UNDERSLUICES POCKET
AT KHANKI HEADWORKS
SCALE = 1/1000

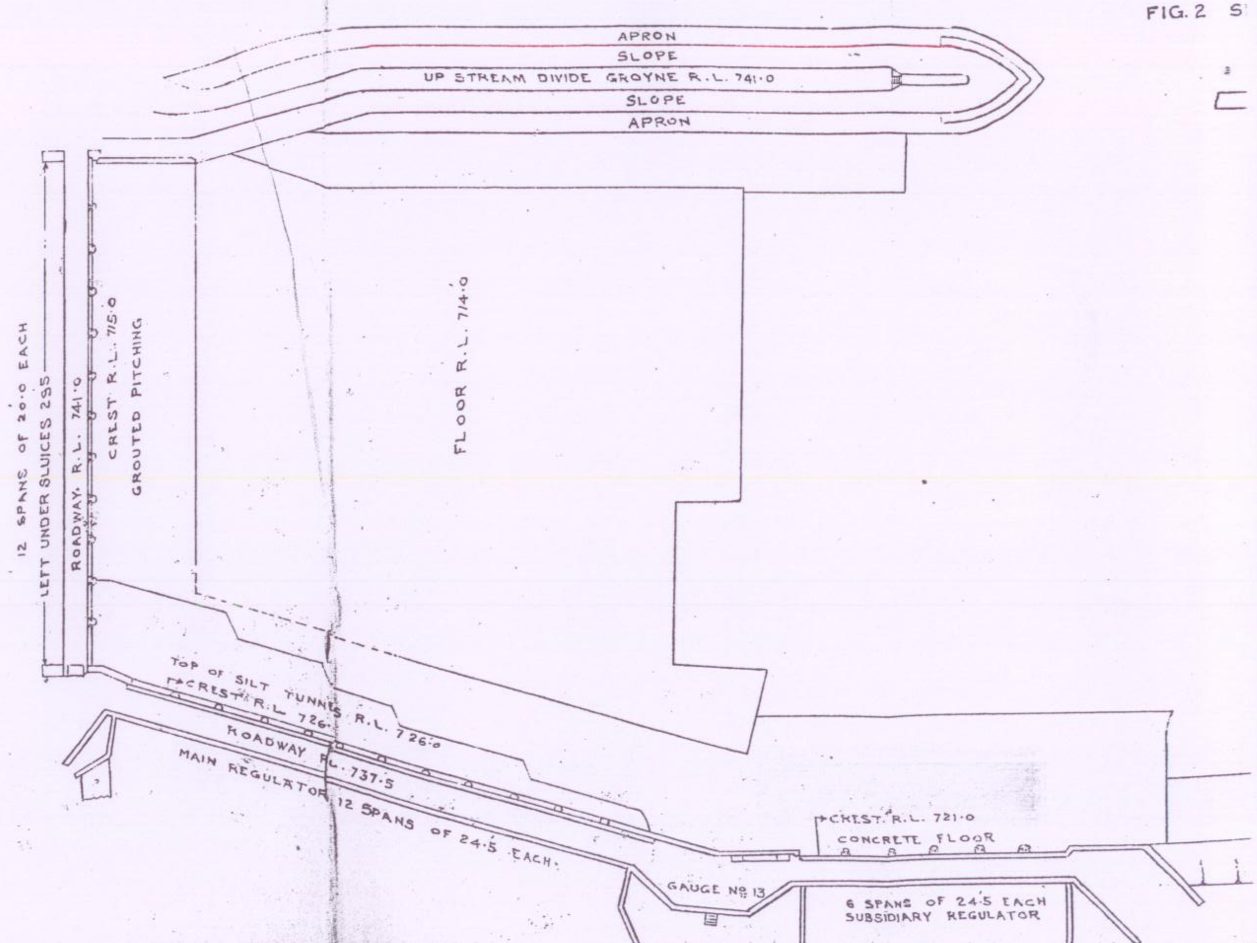


FIG. 2 S

DISCUSSION

The **Author**, introducing his paper, remarked that the silt trouble in Irrigation channels had been exercising the minds of irrigation Engineers ever since the advent of irrigation, but the Engineers were not yet quite clear as to the degree of silt exclusion required for keeping channels free of harmful silt nor about the methods of effective silt exclusion to be adopted at the different Headworks of the Punjab canals. All that was aimed at was to exclude as much of the heavier grades of silt as possible by all possible means, and in this manner generally success was achieved in keeping the Head reaches of the Canals clear of silt so that there might be no difficulty in feeding them and this was what really mattered.

This paper was an attempt at studying the methods adopted from time to time at the four shuttered weirs in the Punjab for silt exclusion from the canals.

The various methods were summarized on page 155 of the paper. Although the curvature of flow of the feeding channel at the point of offtake of a canal had considerable influence in the matter of silt entry into the canal, this point had not been specifically mentioned by the Author in the summary as it was included under the general heading of training works. The Author, therefore, tried to illustrate the influence of curvature by means of the appended diagrams.

At a bend the top water flowed towards the *concave* or outer bank and the bottom filaments towards the *convex* or inner bank. The effect of this phenomena was to cause the bed load to be drawn to the convex or inner side of the bend. A canal that took off on the concave side of a bend would, therefore, receive less silt load than one taking off on the other side.

The large difference in the silt load on the two sides was well illustrated by the observations made in the left undersluices pocket at Khanki. Plate X.

The direction of flow was shown by arrows. The silt intensity observed in different bays of the regulator varied and it was noticed that the silt entering the bays on the inside of the curve was sometimes as much as 8 times the quantity entering the bays on the outside of the curve.

This curvature effect also played an important part at other weirs as already stated in the paper.

At Marala the deep channel followed this course, and the bays on the right were fed as shown by arrows on Plate XI. Due to the position of the deep channel, the water in flowing towards the right side bays produced conditions of curvature which were very favourable for silt exclusion.

Mr. **Radha Krishna Khanna** congratulated the Author for producing an excellent paper, but differed from him in the matter of the observations regarding the necessity and method of silt control advocated by him. He said that the Engineer's ideas about harmful silt were not clear. At places shingle and coarse sand were considered as harmful silt and yet in other places canals got choked up with graphite-like fine silt. Nor did the Engineers have any satisfactory explanation about the paradoxical behaviour of silt at various places. The measures adopted for dealing with silting channels were in utter ignorance of the laws of nature. The speaker added that the still pond system of regulation was said to have proved very satisfactory for keeping the head reaches of channels clear of silt but it required frequent closures of the canal and was therefore detrimental to the interest of irrigation. But here again the Engineers should know the essential elements in this system which prevented silt entry into the canal. Frequent closures for clearing the pocket of silt were not necessary, as scientific investigation might prove that the entry of any quantity of silt in the canal was not harmful so long as it did not interfere with the feeding of the canal. The speaker further added that he was inclined to the view that silt was intended by nature for the preservation of regime of channels and that it was neither possible to effectively control the entry of silt into artificial channels nor was there any scientific basis for the supposition that exclusion of silt was a remedy for silt trouble. Exclusion of heavy silt might, under certain circumstances, wash out the bed lining of silt to some extent from the head reach of the channel but in most cases such scour had no utility. The speaker's conviction was that silt trouble occurred only where working head was insufficient and feeding arrangements for the channel were unsatisfactory. According to the speaker there was not a single instance in which any mitigation of the silting trouble had been achieved by steepening the gradient of flow.

Mr. **T. A. W. Foy** remarked that Mr. B. K. Kapur's careful paper discussed the effects of river training works at Rupar, Marala, Rasul and Khanki in their dual purposes of—

(*a*) Silt Exclusion from the canals.
(*b*) Training the river approaches to give maximum safety to the weirs during high floods.

Regarding the first aspect the paper showed clearly their complete failure. The successful silt exclusion at Rupar was entirely due to the still pond method of regulation and as shown in the paper at P. 132 when this method of regulation was departed from in 1931 silt entered the canal despite the upstream training works.

At Marala there were no training works other than the guide banks and successful silt exclusion was attained purely by regulation and its success was dependent on the relatively better command over the river afforded by the weir than was the parallel case at Rasul.

stages was just sufficient to suit the design adopted in 1929 when the solid crest was removed in two bays 3 and 4 and 6 foot shutters substituted. This was clearly shown by levels attaining during the winter freshets. The big winter flood at the beginning of April, 1930, which amounted to 2,90,000 cusecs completely altered the conditions and raised the levels downstream of the weir by 3 feet at low discharges and by 2 feet at discharges of about 30,000. When in the winter of 1930-31 the design was reconsidered afresh it was thought that this silting up might well be cleared out in the early stages of a big flood, so that the paramount consideration was to provide more waterway for high floods and in consequence bays 5 and 6 were also shuttered. In the light of subsequent history and the further silting of the river bed downstream of the weir this decision appeared to have been mistaken.

The speaker added that regarding the question of constriction of weirs the ruling factor was the maximum flood discharge and the maximum discharge per foot run which could safely be passed. This fixed W. the clear width of the weir. In passing the speaker remarked that in building a weir no trouble or expenditure should be spared to get the downstream protection as low as possible to enable the permissible discharge per foot run to be as high as possible This permissible discharge q. should be worked out for each foot of the downstream gauge and kept up to date as that gauge altered from year to year.

The speaker added that a river tended to have one main channel It might have a subsidiary channel but in times of high flood the main channel being more efficient hydraulically carried a higher percentage of the discharge. Now the fundamental difficulty with the Punjab rivers was that they normally carried a discharge of 1 lac (it varied for different rivers and from year to year but was in this neighbourhood) and with this discharge they had to keep clear a water-way to take a flood discharge which varies from about 3 lacs at Rupar to 9 lacs at Rasul. In proportion as the ratio of the mean summer discharge to the flood discharge approached unity the rivers were stable, other factors being equal. A most important guide had been given by Mr. G. Lacey's Formula $P=2{\cdot}67\sqrt{Q}$. If P was taken approximately equal to width (W), the width (W) required for a discharge of 1 lac was 850 feet and this was of the order of the actual effective widths of the Punjab river channels.

The ratio W/w is the measure of the difficulty at each weir site of expanding the channel to fit the necessarily wider weir.

By regulation at weirs the Engineers attempted to train two or more channels so as to facilitate dispersion, but in the speaker's opinion two mistakes were made :—

(*a*) The distance back from the weir under which such control was exercised was underestimated. The control did not under any ordinary conditions extend to a greater length than half the width of the weir.

(*b*) A system of lowering shutters or working gates was adopted over a whole working season. If the system was successful in its initial aim say of shifting a bela on the right, a corresponding bela grew up on the left. The speaker suggested that if shutters were worked in the order 4, 3, 2, 1, to do so the working should be limited to 10 days and then reversed so as to shift the newly deposited bela before it became firm.

(*c*) The Engineers did not work the weirs to the maximum which they could stand. For instance if attempt was made to shift a bela on the right, the gates should be worked to pass the maximum permissible discharge for any downstream level entirely from the right, keeping sufficient of the left hand gates shut fully to utilize all the available discharge on the right.

Mr. **G. R. Sawhny** remarked that the Author had read a paper which gave a detailed history of the Canal Engineer's failures at the four Headworks from the early days of their construction to date. It was a pity that the result of the various efforts had been more or less the same at each of these Headworks.

What Col. Ottley realized to be the main cause of the troubles in 1893 still remained the primary and unsolved problem and the tale of universal trouble on all headworks was not surprising. The speaker considered it a pity that the author had made no constructive suggestions as to what should be done. The author should also have brought out in his paper what good came out of the various methods tried at different times at the various Headworks. As it was the paper did not help much.

The speaker added that as clever Engineers had been in charge of the Headworks in the past and yet their efforts for solving the problem had not succeeded, the failure was due to the data accepted by the Engineers not having been recorded by the subordinate staff with the required accuracy and care.

Mr. **Nand Gopal** stated that the author had taken great pains in collecting useful information about four headworks from the printed histories and old files.

The speaker pointed out that the subject of River Control at Headworks had been sadly neglected by Engineers and no contribution had been made on this subject since Spring wrote his book some forty years back, and hence the author's work was the more valuable. But the speaker thought that the author was hazy in his conclusions and contradicted himself at places.

The author considered the Merala Method as the best for silt control. The speaker referred to Plate XIV showing coarse silt in gramms per litre for flood season 1938 in monthly averages for the days each canal was in flow at the three Headworks Merala, Khanki and Rasul. It was seen that the Canal at Rasul drew the least amount of coarse silt, Merala and Khanki were much the same with a little preference in favour of Khanki. When it was mentioned that Rasul had the least man control on the river, which was partial even at a discharge of 20,000 cusecs passing below weir, and lasted only up to 1,50,000 cusecs, Merala had control up to about 2,00,000 cusecs and Khanki up to 3,00,000 cusecs, the superioirty of Rasul Method which followed the Rupar Method, was apparent. It might be argued that perhaps the River at Rasul had less silt. Unfortunately analysis of River water samples had not been practised at Khanki or Merala and no comparison was possible. But from the mere fact of lie of these Headworks with reference to their distances from hills, it might be concluded that while at Merala the River might have more silt intensity of coarse variety. Khankiwould have less than Rasul. If the reason for less silt in the canal at Rasul was looked for it would be found that while silt was definitely affected to some extent by the Discharge of the River, Slope, Pond Level, Cill Level, Divide Groyne, etc., as the author and others had thought but these came into action in a subsidiary measure only after the set of the approaching stream towards the weir and undersluices pocket had taken place. Therefore the current direction was the most important factor. It was the last named factor that was ignored at Khanki but was attained almost to perfection at Rupar and to a considerable extent at Rasul which accounted for the Rupar Method being successful. On page 131 of the paper it was stated that all the devices adopted at Rupar in 1894 did not bear fruit because the method was not applied properly. It was also stated that spurs were chiefly meant for protecting the left bank against erosion and only as a possible aid in silt trouble! The spurs actually did both. Other devices were in operation for 7 years but success was obtained in 1901 when spurs had been in existence since 1897 and had produced the desired effect on curvature of flow in 3 years. Surely it would be more correct to say that spurs cured the silt trouble.

The conditions for silt control had been beautifully laid down by the late Mr. Nicholson as quoted by the author on page 150 of his paper as follows:—

"The main stream in the left arm from which the canal took off should approach the weir in a right hand curve so that the heavy silt laden water passes on to weir and comparatively silt free water goes to the pocket where in the Still Pond more deposit takes place, which is periodically scoured out by closing the Canal and opening the under sluices and thus the canal gets very little silt from the River,."

This was secured at Rupar by spurs. At Rasul it was done by the Left Guide Bund which was inclined to the line of the weir at 75°. If similar conditions could be brought about at Khanki silt trouble there would end. Mr. Nichloson thought of many things but unfortunately he omitted two points (1) that Bifurcation of 'Divide' was too far which had been noticed by the author also (2) that left guide bund at Khanki was curved away from the weir. If these omissions were made good (1) by a cut in the Bela about a mile up from the weir (2) by a spur suitably placed or perhaps without it by using gated Bay 4 at risk of temporarily excessive silt going into the canal for a fortnight or perhaps a month, the speaker assured the author that his silt trouble would be solved thereafter.

While the speaker admitted that the Merala method was admirably suited for conditions at Merala, he was not quite sure if the Rupar method had had a proper trial there, just as it had not had at Khanki. At Merala there was the important point of difference " Jamu Tawi" on the left flank which possibly equalled up the discharge distribution in a flood and even so, this method was successful since 1929 only (after which no really big flood had passed) and that only in the matter of silt control; it remained to be seen if in such a flood the weir would not be damaged due to aslant approach and unequal distribution of discharge. At Rasul or Khanki there was nothing corresponding to " Jamu Tawi" on left side and if the Merala method was tried there, it was almost certain that the left channels getting choked up in years of low discharge, distribution would be uneven and the right side Bays would be unduly strained and damaged. The speaker suggested to the author to give the Rupar method, or the Rasul method as it might be so called, a fairer trial in the ensuing flood season and the speaker was sure a pleasant surprise awaited the author in the results that would follow. At Rasul also, previous trials had failed but since 1932 success had been achieved; so might be the case at Khanki, and more easily on account of the three times better man control there, as compared to Rasul. It must not be forgotten that River channels could be developed only in early or falling stages of floods when control by shutters and gates was good and effective. Not much could be done when surplus was very small or nothing at all when control almost ceased. In fact the word 'control' did not express the real meaning of operations at such weirs. The river could merely be *guided* at certain opportune times and for this to be fruitful a careful watch had to be kept of the beaviour, before and after any action taken in the matter of observing soundings and sections. Though the streams which had to be dealt with were mighty, they were known to have been diverted in their course by even a straw judiciously placed at the right time and place. Man and the Engineer in man was mightier and could control nature to his benefit but he must bide his time and strike at the correct moment.

Mr. **M. D. Mithal** drew attention of the Congress to the fact that as at Merala if the river was kept on to the right and the flood discharge struck the weir at a skew, then there always was damage in the right bays.

The speaker did not consider any justification existed for the author's view that the still pond system was the best. At Merala itself up to 1930 partial flow system had been eminently successful and it was only when the regulation rules were ignored that silt deposited within a few days. But for that occurrence the still pond system would not have been even tried at Merala. The speaker advocated going back to partial still pond system, which was in force prior to 1930 to avoid wastage of time and dislocation of running of channels caused by sluicing closures which were necessary accompaniments of the complete still pond system.

The speaker drew attention of the Congress to his criticism of the silt excluding arrangement at Khanki, during the discussions on Mr. Khosla's paper on "Reconditioning Khanki Weir". He claimed that the existence of silt trouble in the Lower Chenab Canal even after the construction of the silt excluder, showed that his criticism, that the design of the silt excluder needed improvement, was justified. He regretted that Mr. Khosla had not been able to write a paper on the design of the excluder at Khanki which he promised during that discussion.

Mr. **G.H. Dundon** remarked that the Author must be congratulated on his very interesting paper, which bore evidence of a very careful study of the history of four of the Punjab Major Headworks. This Paper formed a most useful reference for those who required to study problems of River control and silt exclusion.

The Author's purpose was to find out the best methods of River regulation to be adopted in future. It must be admitted from a perusal of this Paper that no great success attended the efforts of the Canal Engineers in the past for many years at some of the Headworks, nor could it be maintained that complete success had been yet achieved at some of them. The speaker's own view was that control of a River must be effective before adequate control over silt drawn into the Canal could be achieved. Comparing the four Headworks, the River at Rupar and Khanki was under control by a system of training works, whereas at Merala and Rasul there were no such works other than local protection works near the Weir Line. Those with experience of these Headworks would readily agree that conditions at the former were satisfactory and reasonably stable, whereas there was no permanent regime of the River, and a definite possibility of unsatisfactory conditions developing at the latter (Merala and Rasul) Headworks. The advantage of training a River to a definite course was undeniable, even though as at Khanki the training works were designed with a view to protecting the marginal embankment than leading the River on to the Weir Line.

He added that in regard to the problem of silt exclusion, it was true that knowledge of matters connected with Headworks has advanced greatly in recent years as the result of model experiments.

The pioneer work must be credited to Kennedy, the author of the still pond system, vide his exposition of this system in a technical Paper read before the Irrigation Conference, Simla, 1904, in particular, the definition of his theory at page 169 of the Proceedings, and his remarks at page 49, Volume 2 of the Proceedings. Those studying the subject would also do well to read Bombay Technical Paper No. 45, in which the results of model experiments were clearly set forth. The conclusions in this paper were clear and definite, namely that "*the dominant factor in silt exclusion was curvature of flow in the approach channel, and the effect of the curvature could often be intensified by still pond regulation*". It followed, therefore, that the main aim of the Engineer should be to train the River Upstream so that the Canal took off from the outside of a bend.

The conclusions, which the Author gave at the end of his paper did not appear to be sufficiently definite, nor did they show that the Author had arrived at a convinced conclusion from his study. The ideal method was said to be to distribute the River into two Branches, but a division in two Branches was said to be unstable. The suggested alternative was to follow the Merala method. As the speaker was at Merala during the period, when the present system of regulation was evolved, he could claim some authority in defining the Merala method as a fortuitous adaptation of regulation methods to existing River conditions. The River at Merala was in unstable regime, and with a marked change in the River, the so-called Merala method would come to an end. On the basis of the Author's study, and to an extent on personal experience of three out of four Headworks, the speaker would suggest the following as conclusions with a general application to all rivers :—

(1) A river should be trained upstream in order to achieve stability in its direction of approach to the Weir.

(2) Curvature of flow above or in the approach channel to the Canal Head was essential to silt exclusion.

(3) It was also essential to ensure adequate depth of flow in the approach channel.

These conclusions were fully supported by the History of Rupar Headworks, which must be looked upon as the one completely successful Headworks in the province. The Weir had escaped damage for many years, and silt trouble was relatively less; this in spite of the fact that the Canal took off from a shingle reach of the River, and had the flattest slope, 1/8000, of any of the old Punjab Canals. The curvature above the approach channel was undoubtedly the main factor contributing to this success, and still pond regulation was only a subsidiary factor. Where such curvature of flow above the approach channel was absent, curvature could be induced as in the Bombay Technical Papers, to which the Author had referred. Officers in charge of Headworks would do well to study these papers carefully ; for one reason, they explained methods of scouring the approach channel, which had not yet been put into practice at the Punjab Headworks, and which, if properly applied, might go a long way towards removing the serious objection to still pond regulation, namely the frequent closures, which were necessary at certain seasons to scour the approach channel.

Mr. **Ajit Singh Kalha** remarked that the conclusion of the Author was that the advantage of still pond system lay in the flat slope that it created at the entrance to the pocket. This appears to be far-fetched. Taking his own example the discharge of Lower Chenab Canal at head was about 10,000. Supposing another 1000 cusecs were taken in the pocket and escaped through the under-sluices, this 1,000 cusecs could not increase, by any appreciable means, the slope in the approach channel, but it would be enough to create such a heavy disturbance at the point where the canal takes off that all the bottom silt would be thrown into the canal. It appeared to the speaker that the main advantage of the still pond system was that it transferred the off-take of the canal from its pacca head to a line at right angles to the divide groyne nose. The pocket became a part of the canal and at the point of separation of the canal water from the river stream, there was no change of direction of flow. Due to the silting of the pocket the off-take was also from the top water. Canal water was thus taken off smoothly without any disturbance and it would naturally contain the minimum silt. If a canal head could be designed, which could enable the water to be taken off from the river stream without any disturbance or change in direction of flow at the point of separation of the water to be taken into the canal from the water in the river stream, all the advantages of the still pond system would be obtained.

Mr. **Kanwar Sain** remarked that during the design of the Headworks of the Haveli Canals special attention was paid to the exclusion of objectionable silt from entering the canal. A double set of Under-sluices had been provided as shown in Plate No. XII. The object of providing these double sluices was to control the curvature of flow in the pocket as well as to provide a full slab silt excluder in the river pocket. By this arrangement it was claimed that a very high efficiency of silt exclusion would be obtained. The design was a development of Mr. Elsden's idea and was claimed to be an improvement on that idea. Double gates had been provided. The water on top of the silt excluder slab would all go to the canal, while a suitable flow would be maintained under the slab to lead away the bottom water down the river. This design was first worked out by the speaker during the preparation of the 1936 Thal Project, and was claimed to be original as regards the arrangement of sluices was concerned. In fact, in Thal, 3 sets of undersluices were suggested as shown in Plate XIII. When the Haveli Main Canals started working, observations on this type of silt excluder would give very valuable information and should be made available by some officer who was in charge of the Trimmu Division for general discussion in the Punjab Engineering Congress.

The **Author** in replying to the criticism stated that Mr. Khanna had referred to matters which were not quite within the scope of the paper. The words " Harmful Silt" as used in the paper stood for all silt that settled down in the Head reach of a canal.

The quality of silt entering a canal must greatly depend on the quality of silt entering at its head and could not be guided by its regime as stated by Mr. Khanna.

Mr. Foy's assertion that successful silt exclusion at Rupar was entirely due to the still pond system of regulation and that the training works upstream did not in any way help to exclude silt from the canal, was not borne out by facts already quoted in detail in the paper.

The efficiency of the still pond system of regulation was mostly due to the favourable curvature of flow that it created and the training works upstream of Rupar played a very important part in creating this favourable curvature of flow and in directing the main stream of the River towards the middle of the weir, which resulted in a uniform distribution of discharge across the weir.

A reference to the Survey Plan of the River Jhelum at Mangla would show that silt exclusion was achieved on the Upper Jhelum Canal without the still pond system of regulation, simply by the favourable curvature of flow provided by nature.

The main advantage of training a river to a definite course upstream of Headworks was the creation of stable conditions of flow. Without any training works, the River course was liable to change during floods and stability would not be attained.

The failure of the training works at Khanki in controlling silt and in distributing the river discharge uniformly across the weir was due mainly to their being situated along the outside of a curve.

In order that such training works could efficiently perform the double function of silt control and uniform distribution, they should be aligned along the inside of a curve as at Rupar.

The silting of the River Downstream of the Rasul Weir, mentioned by Mr. Foy, appeared to have been caused by the passage of floods at low levels upstream which results in steeper slopes. It was essential that at every Headworks there should be sufficient control to pass floods at the desired level, in such a manner that the fall at the weir was not converted into a slope.

As regards Mr. Foy's remarks on regulation, it had already been stated on page 162 of the paper that the manipulation of ...

very limited control as the effect of such manipulation did not extend beyond a few hundred feet.

He agreed with Mr. Foy that the system of working the shutters and gates should be frequently altered, so as to keep a clear channel immediately above the weir.

The author referred Mr. Sawhney to the last lines of his paper, wherein it had been stated that the Main River Channel should be trained towards the middle of the weir and the canal fed from it by means of a subsidiary channel.

In reply to Mr. Nand Gopal, the author summed up the conclusion arrived at in the paper as follows :—

1. The artificial distribution of a River into two separate channel, as done at Khanki and Rasul was not recommended as it was not stables although it might be quite useful as a temporary measure.

2. Training works were necessary to achieve stability of the River Course upstream of a weir.

3. Curvature of flow was essential for silt exclusion and this could be best obtained by having the Main River Channel running towards the middle of the weir, so that there might be uniformity of distribution across it.

Mr. Nand Gopal's arguments for the superiority of what he called the Rasul Method were based on the wrong assumption that the River silt at Rasul was coarser than at Khanki, because of the latter's nearness to the Hills. Silt analysis of the bed samples taken upstream of the three weirs showed that the mean diameter of River bed silt was about 0·5mm. at Marala, 0·4 mm· at Khanki and only 0·3 mm· at Rasul and this explained the supposed efficiency of the so called " Rasul Method".

The author agreed with Messrs. T.W.M. Foy and M.D. Mithal that if the main river channel were trained on the extreme right, the weir was likely to be damaged by cross flow during big floods. He had therefore recommended the training of the Main River Channel towards the middle of the weir, which would result in better distribution and reduced cross flow.

The superiority of the Still Pond System had been established both experimentally and by actual adoption at most of the Headworks and did not need further proof.

Replying to the remarks by Sardar Ajit Singh Kahla the author stated that an increase in the discharge in the pocket did increase the surincrease. If the discharge was increased by 10 per cent, the increase in slope would be small, but if it was increased by 100 per cent the increase might be very much appreciable.

The main advantage of the Still Pond System was the favourable curvature of flow which it created and which was lost if the undersluices were opened.

Mr. Kanwar Sain made mention of the design of the Headworks of the Haveli Canals and the special attention paid to exclude objectionable silt, and claimed originality for the arrangement of sluices.

He was referred to the author's remarks in the discussion on paper No. 195, wherein the author suggested the construction of a divide wall for dividing the pocket into 2 parts.

The Author agreed with Mr. Dundon that the dominant factor in silt exclusion was the curvature of flow and that the Engineer's main aim should be to train the River upstream so that the canal took off from the outside of a bend.

The Marala Method, as the author understood it, was described on page 165 of the paper, according to which the main supply of the River in excess of the canal requirements was passed over Bays Nos. 4, 5, 6, 7, and 8.

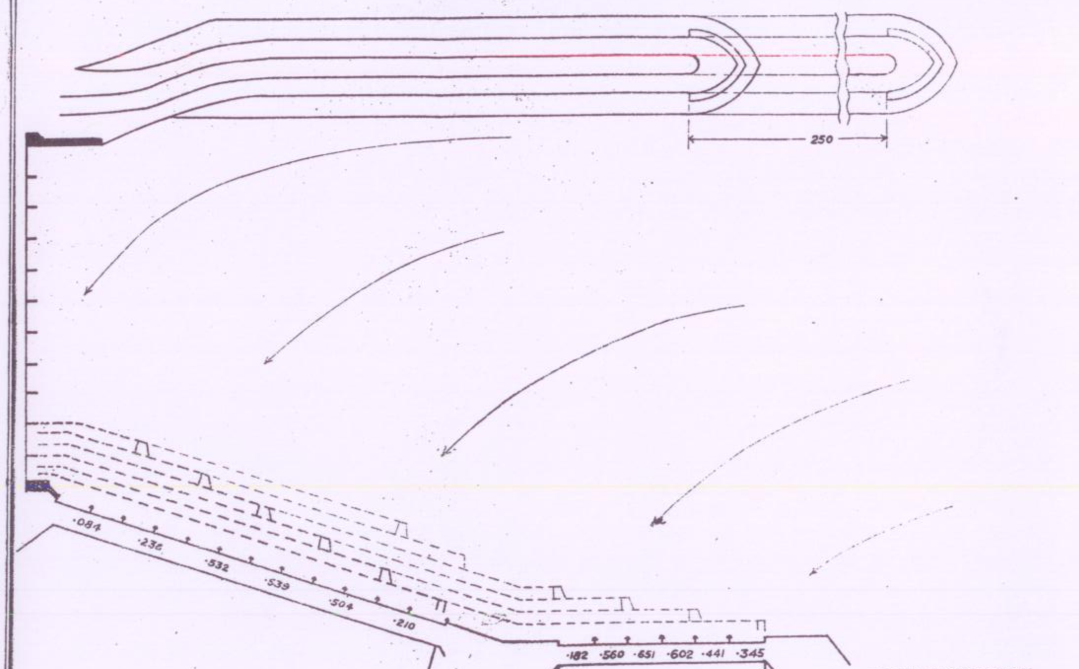
If the Main River Channel was trained to Bay 4, the escaping of the surplus supply through Bays 8, 7, 6 and 5 in the order given, would result in the desired curvature of flow, so that the canal supply would take off from the outside of a curve.

The method followed at Marala had to be slightly modified to suit the conditions at Khanki, because of the absence of a source of supply like the Jammu Tawi, at the latter Headworks.

The River at Marala might be unstable, but the River at Khanki above the nose of the central Bela was fairly stable and it was possible to modify the Marala Method as described above, to suit the conditions at Khanki.

PLATE X
PAPER NO. 226

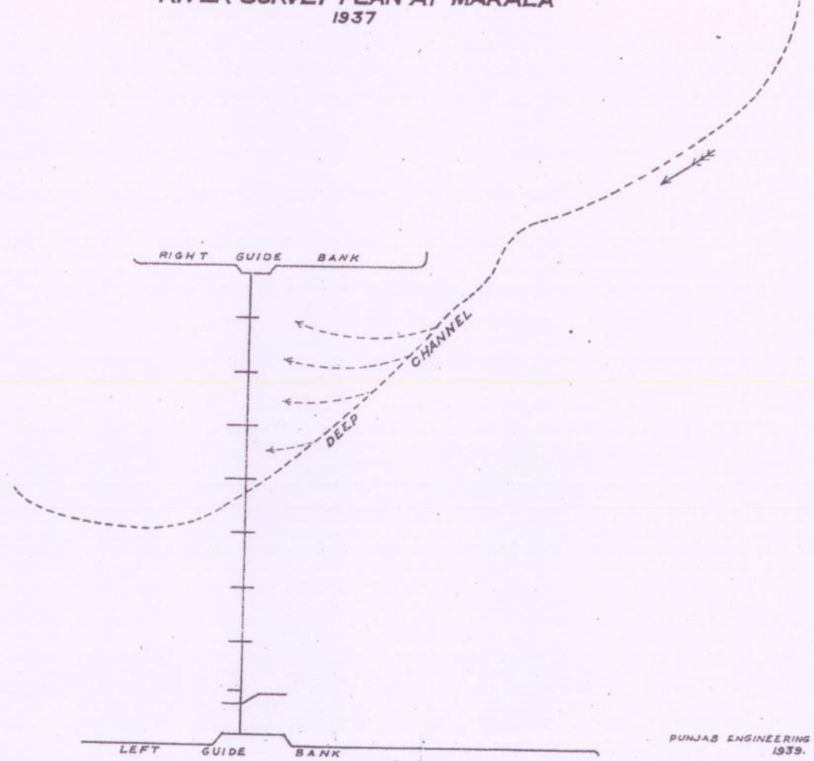
KHANKI HEADWORKS
LEFT UNDERSLUICES POCKET



PUNJAB ENGINEERING CONGRESS
1939.

RIVER SURVEY PLAN AT MARALA
1937

PLATE XI
PAPER NO. 226



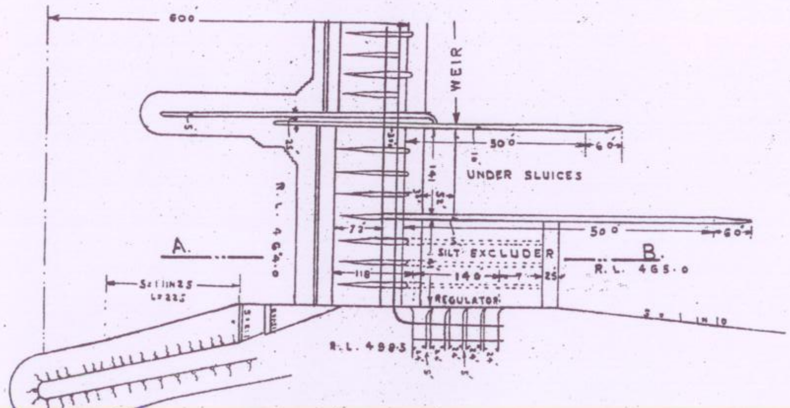
PUNJAB ENGINEERING CONGRESS.
1939.

PLATE XII
PAPER NO. 226

EMERSON BARRAGE

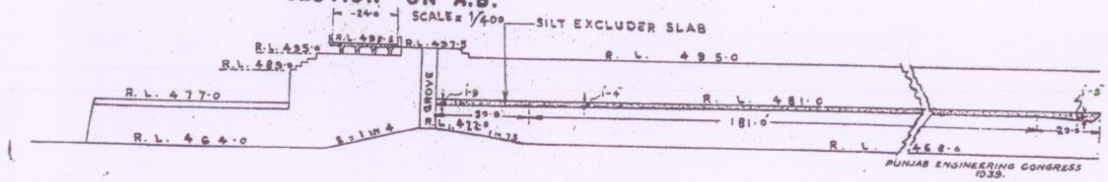
PLAN SHOWING ARRANGEMENT OF LEFT UNDER SLUICES AND SILT EXCLUDER

SCALE = 1/2000



SECTION ON A.B.

SCALE = 1/400



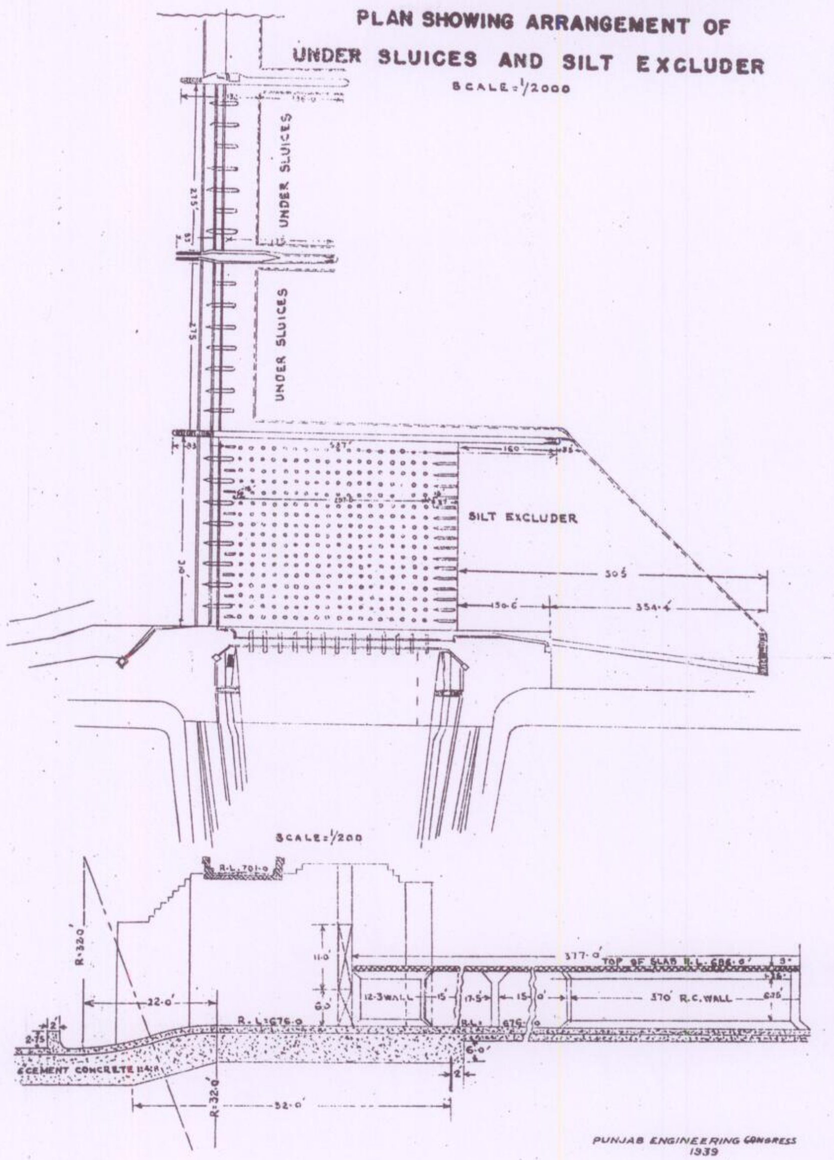
PUNJAB ENGINEERING CONGRESS 1939.

PLATE XIII
PAPER NO. 226

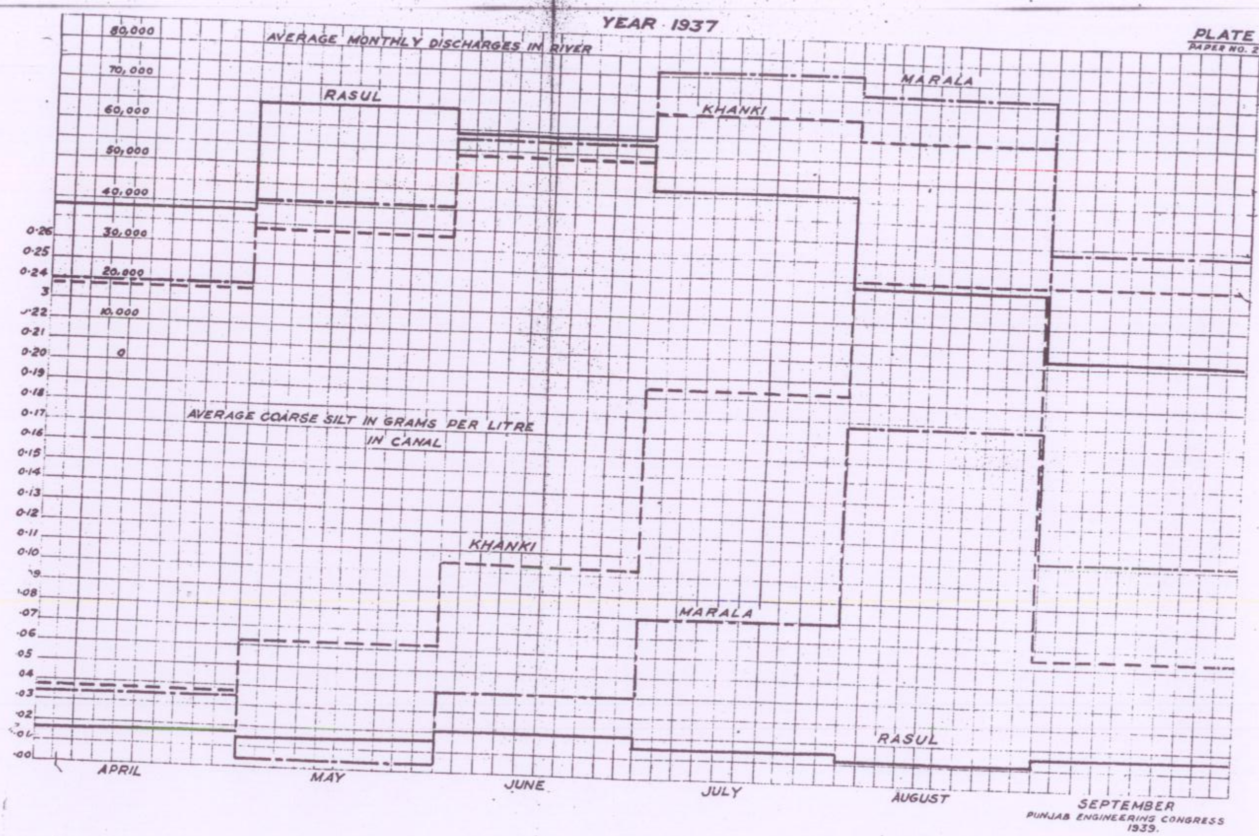
KALA BAGH HEAD WORKS (1936)

PLAN SHOWING ARRANGEMENT OF UNDER SLUICES AND SILT EXCLUDER

SCALE: 1/2000



PUNJAB ENGINEERING CONGRESS
1939



YEAR 1937
PLATE XIV
PAPER NO. 226
AVERAGE MONTHLY DISCHARGES IN RIVER
RASUL
KHANKI
MARALA
AVERAGE COARSE SILT IN GRAMS PER LITRE IN CANAL
KHANKI
MARALA
RASUL
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0·26
0·25
0·24
0·20
0·19
0·18
0·17
0·16
0·15
0·14
0·13
0·12
0·11
0·10
·07
·06
·05
·04
·03
·02
·00
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
PUNJAB ENGINEERING CONGRESS
1939.

ERRATA.

Corrections :—Page 174 Line 8th.

(1) The regulation programme followed after the reconditioning of the weir was to pass two-thirds of the discharge (a greater proportion) down the right channel and (one-third) lesser proportion in the left channel. The ratio of $\frac{2}{3}$ and $\frac{1}{3}$ applied to 1938 only because the discharge in 1938 was high. The highest proportion of discharges passed in the right and left channels respectively during 1937, a low year, was 1·6 : 1.

(2) Page 188.

(*iv*) The most suitable discharge in the left arm for optimum silt entry in the canal is less than 40,000 cusecs.

(*v*) The most suitable water surface slope between Palkhu spur and gauge No. 13 for optimum silt entry in the canal is flatter than 1/4000.