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"The Punjab Triple Canal System."

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THE name "Punjab" (or "Panjab") is derived from two native words (*panj*, meaning five, and *ab*, water), and, though now applied to the whole of the British Province of that name in the North-West of India, was originally restricted to Ranjit Singh's Sikh kingdom, which was truly the "Land of the five rivers," as it was traversed by the Sutlej, Beas, Ravi, Chenab, and Jhelum, all perennial rivers, all rising in the Himalayas, and all tailing eventually into the mighty Indus, which is known by natives under the name of the Sind river (Fig. 1, Plate 1).

The tracts between these rivers are known locally as "Doabs" (from *do*, meaning two, and *ab*, water), and are distinguished from each other by the initial letters of the rivers bounding them; thus the Bari Doab indicates the tract between the Beas and the Ravi, the Rechna Doab that between the Ravi and the Chenab, and the Jech, or Chaj Doab, that between the Chenab and the Jhelum rivers.

The soil is usually rich alluvium, often of great depth, and the ground-level contours of the country are generally parallel to the Himalayas, the lines of steepest slope (i.e., at right angles to the contours) being for the most part nearly parallel to the rivers.

The configuration therefore is such as to lend itself admirably to the construction of irrigation-works, and it is consequently not surprising that great advances should have been made in this direction since the annexation of the Punjab about the middle of the last century.

Indeed, when the project which is the subject of this Paper first came up for consideration, immense strides had been made the annual irrigated area in the Punjab had increased within the preceding 30 years from $2\frac{1}{2}$ to $7\frac{1}{2}$ million acres, the net revenue returns on the capital expenditure had risen from nothing to over 15 per cent., and, amongst other works, the Sutlej, the Upper Bari Doab, the Lower Chenab, and the Lower Jhelum canals had been completed and were at work.

The position was that on the east of the Central Punjab there was a great tract of more than $1\frac{1}{2}$ million acres of splendid land lying waste for want of water that could not be supplied from any source near at hand, because the perennial supplies from the Sutlej, Ravi, and Chenab had already been fully utilized, whilst the water of the Beas, an affluent of the Sutlej, had been reserved for a vast arid tract on the east of the latter river.

On the other hand, it had only been possible to utilize about a quarter of the perennial supply carried by the Jhelum river, and accordingly the suggestion was made that this surplus supply should be diverted to the east for the irrigation of the Lower Bari Doab. It was clear that, unless this were done, the surplus water of the Jhelum must be allowed to run to waste for ever in the ocean, whilst the arid tract of the Lower Bari Doab must be deprived of irrigation for all time.

It was obvious, however, that the conveyance of this surplus perennial water-supply from the west to the east of the province would be by no means a simple problem, as it involved the crossing not only of the Chenab and Ravi rivers, but also that of numerous and formidable hill torrents; and it was clear from the first that the project would necessarily be more than usually costly, and one, indeed, that could not have been undertaken at an earlier stage of the Canal Administration of the Punjab.

The project, then, with which this Paper deals relates to the design and construction of three large separate and inter-connected canals, now known as the Upper Jhelum, the Upper Chenab, and the Lower Bari Doab; these canals have been designed to irrigate the Upper Jech Doab, Upper Rechna Doab, and Lower Bari Doab, respectively. The former two canals have been developed into remunerative projects which will irrigate as much as the last work, while together yielding half of the aggregate net revenue of the whole scheme.

The transfer of water from west to east is only required in the Punjab for the cold-weather low perennial supply, the conditions being as follows:—In the Punjab there are two distinct agricultural seasons and two annual crops. The first of these seasons comprises six hot months, April to September, when the melting Himalayan snows—in conjunction with the rainfall from July to September—afford abundant supplies in the rivers for the summer crop, which is known as the *kharif*. The second season comprises the six cold months, October to March, during which only about 10 per cent. of the annual rainfall is received; most of the rivers then carry low supplies, and transfer from west to east is required for the cold-weather crop, which is known as the *rabi*. Two crops are better than one, and are essential for financial success; all the most successful canals in the north of India are perennial and furnish adequate supplies of water for both *kharif* and *rabi*.

Locations of Main and Branch Canals.

The location of the Upper Jhelum canal system is shown in Figs. 1 and 2, Plate 1. The existing Lower Chenab canal fully utilizes all the perennial supply of the Chenab river; it is therefore necessary to tail the Upper Jhelum canal into the Chenab river above the offtake of the Lower Chenab canal, and to supply as much water as the Upper Chenab canal will withdraw, 34 miles farther up-stream. The available supply in the Jhelum river fully meets this requirement. This was the principal condition in fixing the high level chosen for the Upper Jhelum canal. The surveys showed that it would be advantageous to project the canal at a still higher level in order to secure an offtake from the Jhelum where no weir over the river will be required, and also to procure suitable crossings of the numerous hill torrents which have to be crossed. The canal is aligned on an inclined contour until it falls into the Bhimbar torrent diversion to the river. The Upper Jhelum canal also supplies the Gujrat branch and a system of distributaries with water.

The location of the Upper Chenab canal is shown in Figs. 1 and 3, Plate 1. The chief object of this canal is to convey the requisite perennial supply to the Lower Bari Doab canal; but in order to add to the financial stability of the scheme it will also supply water to the Nokar and Raya branch canals, and to a system of distributaries in its own length. The alignment reaches the crest of the country in the 27th mile.[1] The formidable Deg torrent—carrying a maximum flood-discharge of 34,000 cubic feet per second—was encountered in the lower part of the canal, and was diverted to the Ravi river.

[1] In the works described in this Paper 5,000 feet is reckoned as equal to 1 mile.—J. B.

The location of the Lower Bari Doab canal, the last part of the triple project, is shown in Figs. 1 and 4, Plate 1. This canal takes off the Ravi river directly opposite the tail of the Upper Chenab canal, control of the river being secured by a barrage over the channel. The canal attains the crest of the country in the 34th mile, and it supplies an extensive system of distributaries designed to serve the whole commanded area.

Typical longitudinal sections of portions of the three canals are shown in Figs. 5–9, Plate 2.

Need for Irrigation and Irrigable Areas.

The average rainfall on the Upper Jhelum, Upper Chenab, and Lower Bari Doab canal-tracts is 25, 15, and 10 inches respectively, and there is need for irrigation in all these areas, more especially in dry years, when the precipitation is little more than half of these amounts.

In the Punjab the rich deep alluvial soil rests everywhere on a formation of fine pure sand of great but unknown depth. This sand is charged with water to various heights, and irrigation from cylindrical brick wells, by the use of bullock-power, is practised in most parts to some extent, where the lift is not too great to make it financially impracticable. The lift is 20 to 80 feet on the Upper Jhelum, 30 to 60 feet on the Upper Chenab, and 45 to 67 feet on the Lower Bari Doab tract; where the lift exceeds 35 to 40 feet the extent of irrigation from wells is negligible. Whatever the height of lift may be, experience shows that the advent of canal irrigation is followed by efforts on the part of the cultivators to procure a canal supply laid on by gravitation, and when this is secured irrigation from wells is abandoned. It is contrary to the policy of Government to have the extent of well-irrigation lessened, and, as far as feasible, canal-water is allotted in a manner which will prevent this. On the most successful Punjab canals about 75 per cent. of the culturable commanded area is irrigated from canals and wells together, and this percentage was adopted in the case of all the projects now under consideration, except the riverain part of the Lower Bari Doab, for which 50 per cent. was used.

When the project was prepared the percentage of the gross area which would be culturable was not known, and it was assumed to be 95 per cent. in the case of the Upper Jhelum and Upper Chenab, and 85 per cent. in the case of the Lower Bari Doab.

Deducting 183,430 acres and 497,773 acres for irrigation from wells on the Upper Jhelum and Upper Chenab canals respectively, and applying these percentages, the extent of annual irrigation on the triple project was found to be 1,875,855 acres, out of a gross area of 3,997,434 acres; since the former area is a conservative estimate, it may be said that the triple canal system will irrigate annually 2,000,000 acres out of a gross commanded area of 4,000,000 acres.

The next question which called for consideration was the distribution of the aggregate annual area of 1,875,855 acres between *kharif*, perennial *rabi*, and *rabi* first waterings, the latter being all that is allowed where the sub-surface water-table is high, and water-logging an evil to be guarded against. Preliminary examination of the perennial cold-weather supply in the Jhelum river—available for the *rabi* crop—showed that it would only suffice for about half of the annual irrigation; since equal proportions of *kharif* and *rabi* obtained on some existing canal systems, this subdivision was adopted for the triple system. A higher ratio of *rabi* to *kharif*, such as 1·5 to 1, or 2 to 1, would have served to reduce the canal-capacities; but the data then available offered no promise of this being possible, while shortage of carrying-capacity was—in the light of past experience—an evil to be guarded against. As already explained, the river water-supply is always abundant in the *kharif* crop. The Table shows full details of the distribution of

Canal.	Annual Irrigation.	Kharif.	Rabi.	
			First Waterings.	Perennial.
	Acres.	Acres.	Acres.	Acres.
Upper Jhelum . .	344,960	172,480	20,000	152,480
Upper Chenab . .	648,367	324,184	67,333	256,851
Lower Bari Doab .	882,528	441,264	16,000	425,264
Total Triple System	1,875,855	937,928	103,333	834,595
			937,928 (103,333 + 834,595)	
Add Lower Jhelum.	766,182	383,091	53,091	330,000
Grand Total .	2,642,037	1,321,019	156,424	1,164,595
			1,321,019 (156,424 + 1,164,595)	

the annual irrigation. The Author has added the figures for the existing Lower Jhelum canal, which also derives its supply from the same river, since the adequacy of the supply to meet all requirements has to be considered later on.

Duties, Losses, and Maximum Capacities.

The use of the word "cusec" to denote a water-supply of 1 cubic foot per second has been general in India for many years, and is convenient. "Duty" of water to a given "base" may be defined as the number of acres irrigated per cusec of average supply obtaining for the number of days comprised in that base; for example, if an average supply of 1 cubic foot per second matures 200 acres of irrigation during a period of 182 days, the duty will be 200 acres per cusec, and the base 182 days. The base is the number of days during which the canal is open at the head of the system.

Each of the three canal-systems comprises a main canal, branch canals carrying over 250 cusecs, and distributaries carrying up to 250 cusecs. In the Punjab it is found that the losses by absorption and evaporation in main and branch canals amount to 8 cusecs per million square feet of wetted area. With regard to distributaries, the records of existing Punjab irrigation-works show that the duties on the average supplies entering the heads are: *kharif* 100 acres, and *rabi* 200 acres, per cusec. Since the *kharif* and *rabi* areas are equal, while the duty for the former is only half that for the latter, the maximum capacity is required for the *kharif* crop. The maximum supplies have been assumed to be 1·25 times the average supplies. The maximum capacity required at any point in a main or branch canal is the total of absorption and evaporation losses between that point and the tail plus 1·25 times the aggregate of all the supplies of distributary offtakes below the point. The maximum head capacities given to the heads of the three main canals are 8,500, 11,741, and 6,750 cusecs for the Upper Jhelum, Upper Chenab, and Lower Bari Doab canals respectively.

Maximum "Kharif" Capacities.

Canal.	Losses in Channels.	Maximum Supplies at Heads of Distributaries.	Total.	Executed Capacity.
Upper Jhelum . . .	536	2,156	2,692	8,500
Upper Chenab . . .	1,116	4,052	5,168	
Lower Bari Doab . .	780	5,516	6,296	6,750
Total Upper Chenab	1,896	9,568	11,464	11,741
Lower Jhelum . . .	624	4,789	5,413	4,563
Grand Total . .	3,056	16,513	19,569	24,804

The loss in the Upper Jhelum canal is 815 cusecs, but 279 cusecs will return to the river in the first 50 miles, and the difference between these quantities is the 536 given in the second column of the Table. The entries in the third column are $1\cdot25 \times$ *kharif* areas $\div$ 100. The 8,500 cusecs capacity for the Upper Jhelum canal is for the *rabi* supply for the other two canals. The excess of 6,750 over 6,296 will be utilized for linking up the Sidhnai canal. The 4,563 cusecs capacity of the Lower Jhelum canal was given before the triple project was thought of, and is to be increased.

Required and available Supplies for the "Rabi" Crop.

The estimated irrigation for all four canals has been shown to be 1,321,019 acres in the *rabi*, and with a duty of 200 acres this would require an average supply of 6,605 cusecs at the heads of distributaries, which will be shown below to correspond to 9,352 at the head of the Upper Jhelum canal.

It is customary in India to operate canals rotationally in the *rabi*, in order to reduce absorption-losses. In the case of the canals now under consideration the proposals are that in a 30-day month the entire river-supply may be used on the Upper Chenab and Lower Bari Doab for 19·5 days with 2,432 cusecs losses; on the Upper Jhelum and Lower Jhelum for 10·5 days with 1,160 cusecs losses. The weighted average losses for the 30-day month will then be 1,987 cusecs, or 65 per cent. of the 3,056 cusecs losses when all the channels are simultaneously in flow. This will only be possible when the Upper Jhelum canal, with 8,500 cusecs capacity, can carry the whole of the river-supply, and is the reason for giving this canal such a large capacity. From discharge observations extending over the 15 years ending with 1909–10, diagrams were prepared, and the monthly supplies were ascertained. The net results are that the

"Rabi" Supplies and Irrigation.

Particulars.	Average Supply.			Irrigable Area with 200 Duty.
	Canal Head.	Losses.	Distributary Heads.	
	Cusecs.	Cusecs.	Cusecs.	Acres.
Required	9,352	2,747	6,605	1,321,019
Available—				
Minimum supply, 2 years in 15 .	8,071	2,399	5,672	1,134,400
Average of 15 years . . .	10,295	2,747	7,548	1,509,666
Maximum . .	12,453	3,056	9,397	1,879,400

average *rabi* supply of the Jhelum river is 10,295 cusecs, corresponding with 7,548 cusecs at the heads of distributaries, and this, with a duty of 200, will suffice for the irrigation of 1,509,666 acres, as compared with the required 1,321,019 acres.

The average *rabi* irrigation which will be possible is therefore about 188,000 acres more than was considered feasible from the available data in 1904; later on, when designing the distributaries, advantage was taken of this result to increase the area of *rabi* and to decrease that of the *kharif* on the Lower Bari Doab canal.

Headworks of Canals.

The location and the design of the headworks, Upper Jhelum canal, are shown in Figs. 10, 11, and 11A, Plate 3. The configuration of the sandstone rocks is such as to make any change of course of the river impossible, and it must continue to hug the site selected for the canal offtake, where the deepest bed is about 20 feet below the regulator-crest. The maximum floods attain a height of 60 feet over the regulator-crest, and the range of the water-level is 40 feet. The maximum discharge of the river is about 700,000 cusecs, and in high floods there is a maelstrom with very high velocity. Boulders and shingle are swept along the bed of the deep stream, and drift timber of large sizes along the surface, and all have to be excluded from the canal. On leaving the bend of its course opposite the canal offtake the river widens, and the depth decreases to a point 4,500 feet from the regulator-site where there is a great flat boulder bar, which has not changed within the memory of man, and which cannot change materially in future. The full-supply level in the canal is 5 feet below the crest of this bar. It has been considered unnecessary to construct a weir over the river, since supply will be assured without any such work, while no trouble, from either shingle or silt, can ever arise to call for face scouring.

The regulator has been placed a short distance back from the river, which carries very little silt, and it is founded on sandstone with great spread, the line of resistance coming well within the middle third. The design consists of twenty bays of 12 feet span, in each of which are three Stoney gates, 6 feet 6 inches, 6 feet 9 inches, and 8 feet high, operated by overhead winches. Each group of four bays has one winch, to which one, two, or three gates in each bay can be attached. The middle gate can be raised independently of the lower one. The canal supply can be passed in over the masonry crest, the top of the lower gate, or the top of the middle one. Two to four men will suffice for working the gates, and complete closure in 15 minutes would be possible, although inadvisable for the stability of the banks of the canal farther down its course.

The headworks of the Upper Chenab canal were constructed by Mr. H. W. M. Ives, M. Inst. C.E., who, it is hoped, will hereafter submit a Paper on these works.

The main object of the headworks of the Lower Bari Doab canal is to pass the tail supply of the Upper Chenab canal across the Ravi river to feed the former canal. After supplying the Upper Bari Doab canal, the supply of the Ravi is reduced to a few hundred cusecs of seepage at this crossing; however, in the flood-season the maximum discharge of the Ravi is about 200,000 cusecs. The subsoil is sand to an unknown depth. At first sight a siphon appeared to be the most suitable work, but its cost having been found to be considerably in excess of what could be afforded, it was eventually decided, in the interest of economy, to adopt a level crossing, in spite of its many obvious disadvantages. The executed work, as shown in Figs. 12–14, Plate 3, comprises a tail inlet of fifteen bays of 10 feet for the Upper Chenab canal on the right bank; a barrage of thirty-five bays of 40 feet, with counterbalanced 12-foot 6-inch gates worked by overhead gearing; a regulator for the Lower Bari Doab canal of fifteen bays of 20 feet span, with top and bottom steel gates operated by overhead gearing; and a system of river-training works extending 4½ miles up-stream. The heavy floors are required to prevent blowing, and the up-stream one is to be extended by 75 feet to 100 feet. The head regulator is designed to take in only top water. The training-works enforce a direct approach. The work was built in the dry, in a loop of the river, only three 150-foot leading cuts being dug along the 1¼-mile chord. The old channel was left open, and the advent of the great floods was awaited. The river took to the new course, widening the 450 feet of leading cuts to 1,682 feet in one season, while largely silting up the old channel, and driving a straight course through the down-stream winding channel which threatened to cut the canal. These arrangements for "directing the great sources of power in Nature for the use and convenience of man" met with gratifying success.

Design of Main and Branch Canals.

Transverse and longitudinal sections of the river, and contoured maps of the tracts having been prepared, a head bed-level was selected, which, in the light of past experience of executed works, promised to suit the headworks. From the river offtake down to the point where the crest of the country was reached, an alignment was chosen on the contoured map which appeared to meet the requirements of an assumed suitable slope, and those of due economy. Longitudinal sections were prepared from the levels on the map, and such modifications as suggested themselves were made. A trial line on the ground, on being levelled and plotted, provided a basis for making further improvements. From the point where the crest of the country was reached the trial lines were run down the main ridge for the main canal, and on subsidiary ridges for branch canals. In grading, assumed slopes likely to answer were used, and canal falls were introduced as required. The first approximation to supplies, bed-widths, and depths could be made on the bases of the known areas and supplies for the roughly-schemed distributary channels projected on the subsidiary ridges. This afforded data for calculation of the absorption areas and losses. The next approximation took into account both irrigation supplies and losses. The discharge-formula used was that of Kutter with $N = 0 \cdot 02$ for the Upper Jhelum, which does not carry much silt, and $N = 0 \cdot 0225$ for the Upper Chenab and Lower Bari Doab canals where freedom from silt-troubles is less assured. Channels carrying much silt are liable to have rougher beds than those which carry very little of it. It is possible that $N = 0 \cdot 02$ may be found to answer for all three canals when no erosion takes place in the river above the offtake, and when the headworks are fairly free from sand shoaling. It was considered advisable to adopt values of N which would never lead to encroachment on the freeboard of the channel-banks.

The hydraulic diagrams of Mr. R. G. Kennedy,[1] C.I.E., were used; these give, by inspection, grading, bed-widths, and depths which will not result in silting. If D is the depth, and V_o the critical velocity below which silting will be liable to occur with sand of the grade found in the Punjab, then $V_o = 0 \cdot 84 \ D^{0 \cdot 64}$. It is found that V_o may gradually decrease to $0 \cdot 8 \ V_o$ at the tail of the canals. For the fine sand of Sind $0 \cdot 84$ becomes $0 \cdot 63$, and for the very coarse sand of the Cauvery and Kistna rivers $1 \cdot 01$. Mr. Kennedy's non-silting channels have saved the Government of India vast sums of money.

The particulars given in the Table on p. 34 will afford a general idea of the channels executed under the triple canal scheme.

In the case of the Upper Jhelum canal the above particulars for the head and tail relate to what obtain at 5·6 and 83·7 miles. The aggregate head capacity of the canals is about

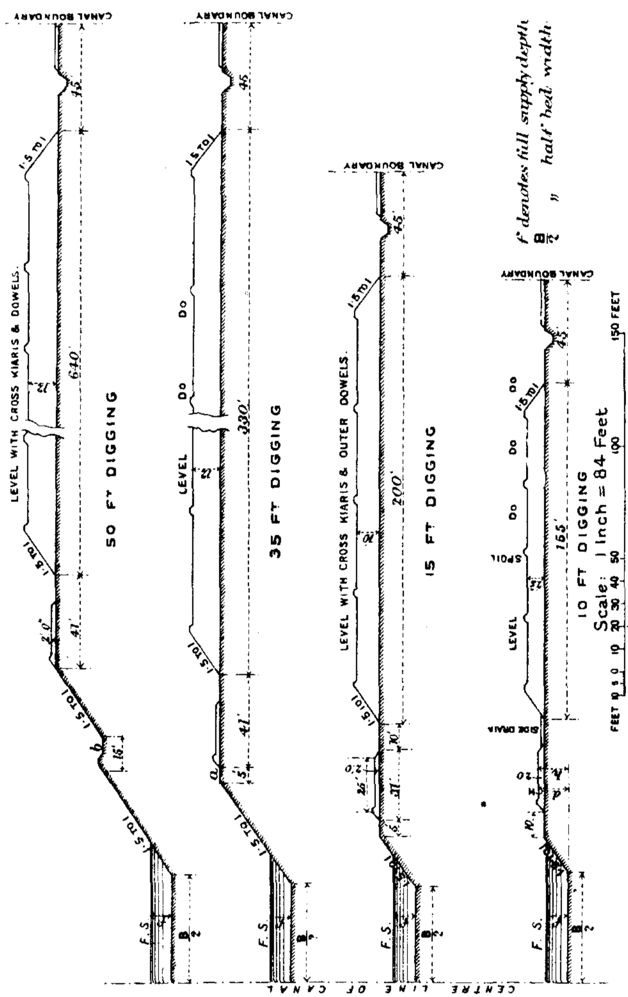
[1] "The Prevention of Silting in Irrigation Canals." Minutes of Proceedings, Inst. C.E., vol. cxix, p. 281.

Particulars.		Upper Jhelum.	Upper Chenab.	Lower Bari Doab.	Total as Executed.
Head capacity	Cusecs	8,500	11,744	6,750	26,994
Tail ,,	,,	7,812	6,750	1,188	
Bed slope, Main canal at head		1/6666	1/6666	1/6666	
Head bed-width, Main canal	Feet	220	240	195	
Tail ,, ,,	,,	205	185	67	
Head depth	,,	9·6	11·83	9·6	
Tail ,,	,,	9·5	10·1	6·4	
Freeboard	,,	3·0	2·5	2·5	
Length, Main canal	Miles	88	188	133	339
,, Branch canals	,,	48	95	41	184
,, Distributaries	,,	585	977	1,071	2,633
,, Watercourses	,,	4,113	6,460	8,916	19,489

27,000 cusecs, and the aggregate length of channels is 22,645 miles. *Figs. 15–17* (pp. 35–37) show typical cross sections of banks. The side slopes in digging were made 1-to-1 for good soil, and 1½-to-1 for sandy soil; the spoil-banks were usually given 1½-to-1 slopes, and 2-to-1 in sandy soil. In the case of very high banks 5-to-1 outer slopes were given, while the banks were made wide enough to give 3 to 5 feet of dry earth over a 5-to-1 hydraulic gradient drawn from the point where full supply meets the inner slope. The profiles show inside berms, and in some cases extensive setting-back of the banks, the underlying principle being that the silt-laden canal-water will eventually silt up to a ½-to-1 slope and to full-supply level. The discharges have been given for ½-to-1 slopes. In some parts of the Upper Jhelum canal the bed is above natural surface, and in the light of experience reliance is placed on the canal silting up these depressions. On the Lower Bari Doab canal, where low ground is crossed, the banks are set back in order to furnish more spoil; spurs of earthwork are formed at 250-foot intervals to induce silting. The digging of outside borrow-pits was avoided, since it leads to pools of stagnant water, the breeding of mosquitoes, and increase of malaria. The crest-widths of the patrol-road and opposite bank were made 25 feet and 15 feet respectively; when inside silting-up is complete the banks will have about twice the constructed width at full-supply level. Drainage of banks and slopes was carefully attended to.

In the alignment, curves of more than 5,000 feet were used wherever possible, and where sharper curves were unavoidable the slope on the concave bank was protected with stone or shingle facing; similar protection was given where the external spring-level was above the canal-bed, a 3-inch coat of fine gravel being given under the facing.

Figs. 15.

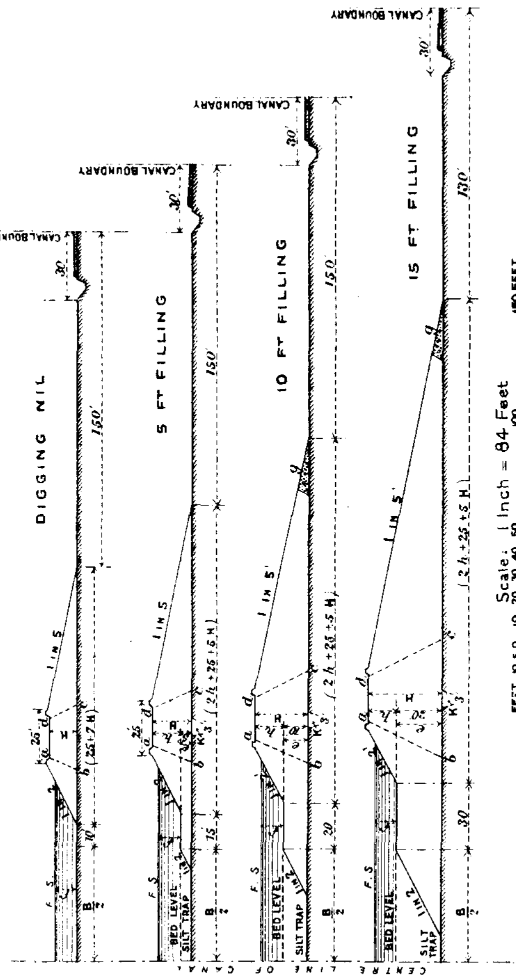


UPPER JHELUM CANAL: TYPICAL CROSS SECTIONS OF CANAL BANKS.

DESIGN OF DRAINAGE-CROSSINGS.

Throughout its entire length of 90 miles the Upper Jhelum canal crosses formidable torrents from the Himalayas, and from their offshoot the Pabbi range of hills. The rain-bearing clouds are pocketed, and the precipitation is abnormally great. Most of the drainages are 2 to 8 miles in length, the longest north of the Pabbi range being 24 miles, and south of it 32 miles. The

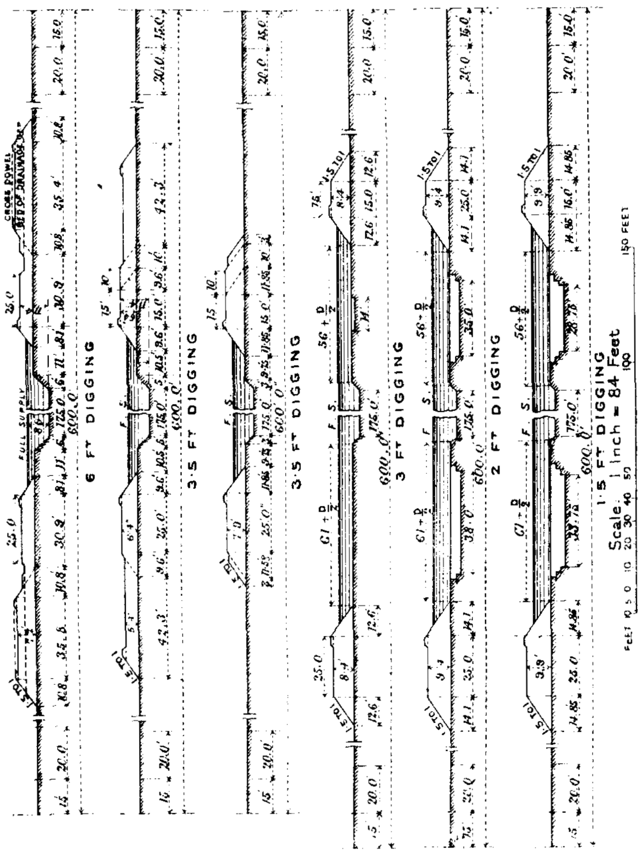
Figs. 16.



UPPER JHELUM CANAL: TYPICAL CROSS SECTIONS OF CANAL BANKS.

soil is clay and sand. The declivity of the torrent-beds ranges from 1 in 57 in the upper parts to 1 in 500 at the canal-crossings; the discharge is very rapid and very turbid. Observations were carried out for 5 years before deciding on the waterway required and on the designs. Ten rain-gauges were established, flood-gauges were erected in all the channels, numerous discharge-observations were made, flood-markings were carefully surveyed, and longitudinal sections were prepared. Careful tables were prepared for each torrent, showing rainfall for the year, days, hours, and shorter periods

Figs. 17.



Lower Bari Doab Canal: Typical Cross Sections of Main Canal and Banks.

measured in minutes; observed and calculated discharges, Kutter's N, and the discharge per square mile; catchment-area, extent of cultivation and of terracing, character of soil, and length of torrent. With all this information in view it was possible to arrive at consistent intensities of discharge, and at safe maximum flood-discharges which promised not to be exceeded. The following maximum intensities of rainfall in short periods were observed in 1908—a year of maximum precipitation:—

Period of fall in minutes	130	5	20	5	5·7
Rate per hour in inches	5·7	5·4	4·8	4·2	3·3

The first of these results obtained at only one station, while the second lasted for only 5 minutes. The average maximum intensities per hour for drainage-basins throughout their length were 4·5 inches for 10 minutes, and 4 inches for 20 minutes. If the discharge were 75 per cent., 5 inches per hour would give 2,420 cusecs per square mile, and 4 inches would give 1,936 cusecs.

Altogether there are on the 90-mile length of the Upper Jhelum canal sixty-four drainages, sixty-two works, 15 miles of diversion-channels, and about 604,000 cusecs of flood-discharge, which last is disposed of as follows:—

2 per cent. is passed into the canal, and out again on the opposite side through a regulator near at hand. Discharge 1,600 to 2,000 cusecs per square mile.

42 per cent. is passed over the canal by level crossings, the works being Suketur torrents Nos. 1 and 2 and Jabah torrent. Discharge 795 to 1,240 cusecs per square mile.

46 per cent. is passed under the canal by culverts and siphons. Discharge 600 to 2,400 cusecs per square mile.

10 per cent., the quantity for the Bhimbar torrent, is diverted to the river. Discharge 108 cusecs per square mile.

The quantity passed into and down the canal is 1,200 cusecs, or less than 0·2 per cent., and is negligible. Typical cross-drainage works will now be described.

Figs. 18, Plate 4, show Suketur No. 1 level crossing. The work consists of a canal inlet—a weir for the torrent with counter-balanced Stoney gates—and a canal regulator with steel gates. The counterbalances are heavier than the gates, and each group of four gates can be operated by two to four men working on one winch. All the weir-gates can be fully raised or lowered in ½ hour. The torrent attains full height in that time, but the ponding capacity is sufficient to contain the maximum supply for ¼ hour. The designs for Suketur No. 2 and the Jabah torrent are similar to that of Suketur No. 1, except that the latter is provided with a release-mechanism by means of which compressed air can be passed from storage-cylinders along the gas-pipe hand-rails to release any group of four gates, or the entire thirty-three.

Coming next to culverts and siphons, of which there are forty-nine, the siphon of seven barrels at R. D. 313,200 feet Upper Jhelum canal is illustrated as a typical example (Figs. 19, Plate 4). The losses of head in imparting velocity, overcoming entrance resistance, and friction in the barrels were equated to the total loss of head, after the manner adopted[1] by Dr. W. C. Unwin, F.R.S., Past-President Inst. C.E. This resulted in expressions for the mean velocity and discharge in terms of the head. The ruling maximum velocities are 15 to 20 feet per second for the liberal maximum discharges provided for. These high velocities were adopted for reasons of economy and to obviate silting. The floods continue for a very short time, and the question of wear need not be considered. The barrels are very long, and it was much cheaper to make the works strong enough to resist high velocities than to increase the number of barrels. The high velocities just mentioned only obtain in the siphons and culverts. The hydraulic gradients given on the sections show the necessity for guarding against the inlet and outfall floors being blown up. The revetment side walls and floors are provided with weep-holes, filled with quarry chips and gravel in varying sizes. All the torrents bring down large quantities of sand, and the siphons are liable to receive deposits of silt from subsiding floods, and from small ones; high floods are liable to descend with great rapidity, and these deposits must be cleared out before the maximum discharging-capacity can come into operation To guard against disaster the outfall bed has been kept below a point two-thirds up the barrels, a liberal amount of up-stream freeboard has been provided to give ponding-capacity, and, in the worst cases, the outfall channel has been contracted by long stone-protected groynes, so as to admit of low floods maintaining an open channel. In the particular example illustrated, contraction of the outfall was unnecessary.

The Upper Chenab canal-drainages are in flat country, and the actual discharges could be carefully observed. The aggregate quantity passed over the canal is less than 20,000 cusecs, and the works are small compared with those on the Upper Jhelum canal. The same remarks apply to the few cross-drainage works on the Lower Bari Doab canal.

Design of Canal-Regulators.

Regulators are required where important branch canals take off, and they are usually built at sites where they can be combined with road-bridges, and probably also with falls. Figs. 20, Plate 4,

[1] *Encyclopædia Britannica*, 9th ed., vol. xii, article "Hydromechanics," §§69–78 (11th ed., vol. xiv, article "Hydraulics," §§ 72–84).

show the regulator constructed on the main line of the Upper Chenab canal where the Raya branch takes off. In the design of regulators the principles observed were to bring the gates well forward; to leave no spaces in which silt-banks might form; to provide cisterns in order to lessen the wear of floors; and to give ample down-stream protection to bed and banks. It remains to add on the right bank a head regulator for the Nokar branch, to the design shown in Figs. 20.

Design of Canal-Falls.

Figs. 21, Plate 4, illustrate a work of this class. Notches are constructed on the crest-wall to obviate acceleration and scouring of bed and banks. Trapezoidal notches can be made exact for two points in the depth, and if these are at one-half and three-quarters of full-supply depth for large canals, and at two-thirds and full-supply depth for small ones and for distributaries, the acceleration or heading-up for other depths will be inappreciable. Cisterns are required for protection of the down-stream floor, and ample protection is needed for bed and banks.

Design of Canal-Bridges.

Canal-bridges of four types were used, namely, those for trunk roads (21 feet width of roadway between parapets), district roads (12 feet to 18 feet), village roads (10 feet to 11·6 feet), and foot-paths (4 feet). The number of each class depended on the tract to be traversed. The average distance apart of works of all four classes is 1·6, 1·5, and 3·4 miles for the Upper Jhelum, Upper Chenab, and Lower Bari Doab canals respectively; in the last case the longer average interval is due to the tract being a prairie one, where the village boundaries are conterminous with the canal-channels, there being no severance of estates. Figs. 22, Plate 4, show a design for a village road-bridge. Flat arches were used to reduce the heights of ramps; wheel-guards are essential, since Indian cartmen are careless drivers, and are often asleep. The parapets project beyond the face-walls so as to save cost. Mean waterway was allowed for ½-to-1 side slopes.

General Remarks.

Works for branch canals are similar in design to those for main canals. The channels carrying less than 250 cusecs are known as distributaries, and the design of these will be considered later.

The spoil-banks and other spare lands on main and branch canals are usually planted with trees, etc., by broadcast sowing, while the roads on the tops of banks are usually provided with avenues.

At most of the important falls Government flour-mills will be constructed, and will be let on annual leases.

Furnished inspection-houses have been constructed over the entire canal system at convenient sites, the average distance apart being about 10 miles. Ceaseless supervision, efficient arrangements in the distribution of water, close touch with the cultivators, and prompt attention to all complaints, have marked irrigation administration in India in the past and are essential for continued success in the future.

Canal telegraphs are in general use for the prompt and effective control of water-supply.

Design of Distributaries and Watercourses.

The distributaries were located on the subsidiary ridges, and were graded so as to afford perfect command.

Watercourses are owned and maintained by the landowners, and the former practice in the case of proprietary lands was for Government to leave their construction to the people who used them. This led to unsatisfactory alignments, to slow development of irrigation, and to retention of all the old fields of irregular sizes and shapes, which gave trouble in the assessment of water-rates. The modern practice is for the land to be subdivided by Government into rectangular plots, each of 1 acre, and for the same agency to locate and construct the watercourses, the alignments being usually chosen along field-boundaries. This practice was generally followed in the case of the three canals now under consideration. The Upper Jhelum and Lower Chenab canals chiefly irrigate proprietary land, considerable portions of which were irrigated from wells, and some departures from the system just mentioned were made in order to avoid supersession of the well irrigation.

In the case of the Lower Bari Doab canal most of the tract was a prairie one, and Government had a perfectly free hand. The original contoured map prepared from cross-section lines 2,000 feet to 2,500 feet apart was unsuitable for the requirements of land-allotment and watercourse-construction. Base-lines were laid out from traverse data furnished by the Indian Survey Department. The tract was divided into blocks 4,400 feet by 3,960 feet, and these were subdivided into sixteen subsidiary blocks, each 1,100 feet by 990 feet (= 25 acres), which are of suitable sizes for allotment purposes. The sides of these smaller rectangles were levelled over, and a contoured map was prepared for use in land-allotment and watercourse-construction. At the same time detailed surveys were made of the soil and also of the depths to spring-level.

The information thus rendered available, and the discovery of a more plentiful perennial supply in the Jhelum river than originally estimated, rendered it advisable to reconsider the distribution of the annual irrigation. In the case of the Upper Jhelum and Upper Chenab canals the tracts with a high spring-level were found to be more extensive than originally estimated, and this called for some increase of *kharif*, and for a corresponding decrease of *rabi*. The conditions were the reverse on the Lower Bari Doab canal, where it was found advantageous to increase the *rabi* and to decrease the *kharif* area. The tract was subdivided into three parts, namely, Zone A, with spring-level below 40 feet, was allowed irrigation for 65·5 per cent. of the culturable area, while Zone B, with spring-level at 25 feet to 40 feet, was allowed 56·5 per cent. of irrigation; Zone C, with spring-level at less than 25 feet, was not allowed any irrigation.

The net changes for all three canals are shown in the following Table:—

INCREASE (+) AND DECREASE (−) OF FINAL AREAS.

Scheme.	Upper Jhelum.	Upper Chenab.	Lower Bari Doab.	Total.
		Area of Annual Irrigation.		
Original	344,960	648,367	882,528	1,875,855
Final	351,472	645,631	874,203	1,871,306
Difference	+6,512	−2,736	−8,325	−4,549
		Variations in Areas of Crops.		
Kharif	+14,586	+39,019	−88,385	−34,780
Rabi	− 8,074	−41,755	+80,060	+30,231
Total . . .	+ 6,512	− 2,736	− 8,325	− 4,549

The net results of the changes were: to provide some extra carrying-capacity in each of the canals; to admit, on the Lower Bari Doab canal, of the ratio of *kharif* to *rabi* area being reduced from 1 : 1 to 1 : 1½; and to show an apparent small diminution of the aggregate annual irrigation of 4,549 acres, or 0·2 per cent., which is negligible, more especially as an increase of at least

7 per cent. over the conservative estimates may be expected. The excess carrying-capacity of the Lower Bari Doab canal will serve to admit of linking-up the Sidhnai canal—a measure which is now much required. The low supplies and all Ravi river seepage at the crossing are now largely lost in the 130 miles of river-bed, 1,500 feet in width, which has to be traversed before the Sidhnai offtake is reached.

Design of Distributaries.

The design of distributaries with watercourses is exemplified by Distributary No. 14, Left Bank, Lower Bari Doab canal (Figs. 23 and 24, Plate 4). The main channel and the two branches have been aligned on the principal and subsidiary ridges. The watercourses are located where they will have command on one or both sides, and they are specially designed to deliver water with adequate command at the highest point of each 25-acre rectangle. In this case the gross area is 60,905 acres, and the "soil survey," coupled with the 5 per cent. deduction for roads and village-site, give the culturable area as 54,253 acres. As all the tract is in Zone A, the annual irrigation is 65·5 per cent. of this area, or 35,536 acres, while the *kharif* area, being two-fifths of this, will be 14,214 acres. The average *kharif* supply at the head of the distributary for 100 duty will be 14,214/100 = 142 cusecs, and the maximum supply will be $\frac{5}{4} \times 142 = 178$ cusecs. A branch distributary carrying 15 cusecs takes off near the head, and $178 - 15 = 163$ cusecs is the capacity of the first long reach. As far as possible the watercourses are designed to carry about 2 cusecs, and they are given the same capacity from head to tail, since the cultivators subdivide by time, while the whole supply is usually all going to one estate of 25 acres. The watercourses are designed to carry 1 cusec for every 100 acres of *kharif* irrigation, or in other words, for every 1,000 acres of culturable irrigable area in Zone A,

$$\tfrac{2}{5} \times 1{,}000 \times \frac{65\cdot 5}{100} \div 100 \text{ duty} = 2\cdot 62 \text{ cusecs},$$

and similarly 2·26 cusecs in Zone B: it is assumed that the loss in the main and branch distributaries will balance the 25 per cent. excess of maximum over average supply allowed in these channels. There are usually two watercourses for each village, with an irrigable area on each of about 800 acres. The usual size of a village is 1,200 to 1,800 acres. The watercourse areas determine the village boundaries, the principle being that the same village community can arrange for subdivision of the water among themselves, but that no watercourse should be shared by two or more villages. Each village has a service road leading to every 25-acre rectangle, and also a road to every adjoining village, while all watercourse crossings of these roads are provided with culverts. The widths of roads are: district 110 feet, main through 88 feet, inter-village 33 feet, intra-village 16·5 feet.

Each rectangle of 25 acres is accurately subdivided into twenty-five plots, each of 1 acre. The main watercourses branch out into others on entering a 25-acre rectangle, and these channels are usually aligned along the sides of the subsidiary acre plots. All demarcation and channel construction inside the 25-acre rectangle is carried out directly by the landowner.

The cost of demarcation, soil-surveys, watercourse- and culvert-construction amounts to about 2 rupees (about 2*s.* 8*d.*) per acre, and is recovered from the landowners.

Rapid development of irrigation is encouraged by initial remission of charges for the water; on the Upper Chenab canal, where cultivation was already fully developed, the remission of half rates for one crop resulted in the extent of irrigation for that crop being half of the area estimated to be ultimately obtainable. On the Lower Bari Doab canal the same remission of charges is likely to be made for old villages, but for "colony" lands full remissions of all charges for two crops are contemplated.

Remarks on the Execution of Works.

The works were executed departmentally, either by petty contractors employed on brief work-orders not amounting to contracts—only a rate, and neither quantity nor time being specified—or by daily labour. In the execution of earthwork the carrying was done largely by donkeys on the larger channels, and by coolie labour on the smaller ones. In the heavy cuttings on the Upper Jhelum canal tram-lines with wagons operated by miniature locomotives, or on the shorter lines by coolies, were used for carrying earth to spoil, the getting being done as usual by manual labour. In the case of the first great cutting at the head of the Upper Jhelum canal the getting was done partly by manual labour and partly by steam-navvies, the carrying to spoil being effected by broad-gauge locomotives, tramways, steam hoists, or donkeys, according to the length of lead and other conditions.

The masonry works were mostly constructed of concrete and brickwork, the bricks being burnt locally with Bengal coal. For the first 50 miles of the Upper Jhelum canal, 30 miles of the

Upper Chenab canal, and the headworks of the Lower Bari Doab canal, branch railways were constructed to admit of stone being brought from distant quarries over the North Western Railway system to the largest works requiring that material in large quantities. With the exception of a few contracts for gates and gearing given to home manufacturers, the iron and steel work was executed in the Irrigation Department Central Workshops, at Amritsar.

The staff engaged had to overcome great difficulties in finding the requisite labour to carry on the works satisfactorily. The ravages of plague were persistent, and the province lost 10 per cent. of its population, or about two million persons. The three great projects were competing with each other throughout, and most of the labour was imported, and, working only for a season, invariably deserted the works at harvest-time. In the 8 years 1905–6 to 1912–13, when all three projects were vigorously under execution, the strength of the labour forces gradually increased to a maximum in 1911–12 of upwards of 76,000 men and 13,000 animals, with an average for that year of 43,000 men and 7,000 animals.

Particulars.	For 8 years 1905–1913.		In 1911–1912.
	Average.	Maximum.	
Expenditure . . .	£626,000	£959,000	£959,090
Number of men . .	23,000	39,000	76,000
Number of donkeys .	4,000	8,000	13,000

As a carrier one donkey is equivalent to about three coolies. Lübeck excavators were tried, but it was found that these machines could not work as economically as coolie and donkey labour. Rapid execution is very desirable, and, for schemes to follow, there would be a great future for machinery which would be equivalent to thousands of labourers, without costing more in working when all charges are taken into account.

The triple canal project was sanctioned on the 17th January, 1905; it was contemplated that 9 years would be occupied in execution, and the results have been as follows:—

The official opening of the Upper Jhelum canal has not yet been announced, but this is a formality, and it is understood that the actual opening was in December, 1914.

The Upper Chenab canal was opened in April, 1912.

The Lower Bari Doab canal was opened in April, 1913.

The programme has therefore been worked up to, in spite of plague reducing the 22,000,000 population by 10 per cent. since the works were commenced, and labour-rates rising by about 50 per cent.

Water-Rates.

Irrigation is charged for on the area irrigated, according to schedules of rates for the different crops that are grown. Except in the case of first and last waterings for *rabi*, which apply to only a small part of the whole area, the charges are independent of the number of waterings and of the quantity of water used. Water is usually in great demand, and as only a moiety of the irrigable area can be watered by the available supply, the people can be relied on to spread it over as large an area as is advantageous for themselves and for Government.

Liberal or total remissions of charges are allowed for failure of crops, and especially for shortage of supply, blight, hail, locusts, or other calamities. Justice to the people, their advantage, and their contentment are the leading considerations underlying the schedules of rates and the rules for remissions. The average *kharif* and *rabi* rates for the triple canal system are:—

Canal.	Occupier's Rate per Acre.	Enhanced Land Revenue per Acre.	Total per Acre.	
			Indian Currency.	English Currency.
	R. A. P.	R. A. P.	R. A. P.	£ *s.* *d.*
Upper Jhelum . . .	3 12 0	1 8 0	5 4 0	0 7 0
,, Chenab . . .	3 9 0	1 5 0	4 14 0	0 6 6
Lower Bari Doab . .	3 12 0	1 4 0	5 0 0	0 6 8

Assessments and remissions are carried out by the Irrigation Officers and collection by the Revenue Officers. There are miscellaneous revenues from water-power, etc., which need not be considered in this Paper.

Financial Aspect of the Triple Canal System.

The original estimate was sanctioned in 1905. In 1910 it was found that the estimate would be exceeded, the principal reasons being the enhancement of labour-rates due to the great mortality caused by plague, the increased demand for agricultural labourers in the development of previously-executed works, and the simultaneous execution of three large works; further, the cost of cross-drainage works on the Upper Jhelum canal had been underestimated.

A revised estimate was sanctioned in 1910, which compares as follows with the original estimate of 1905:—

Estimate of.	Estimated Cost.	Area of Irrigation.	Net Revenue.	Return on Capital Cost.
	£	Acres.	£	Per Cent.
1905	5,215,928	1,875,855	519,859	9·97
1910	6,912,132	1,871,306	518,550	7·50

The work is to be completed within the estimate of 1910. The original estimate of 1905, amounting to about £5,216,000, is to be exceeded by about £1,696,000, or by 32·5 per cent.; this excess reduces the originally estimated return of about 10 per cent. to 7·5 per cent.; if the annual irrigation attains 2,000,000 acres the return will become 8 per cent.

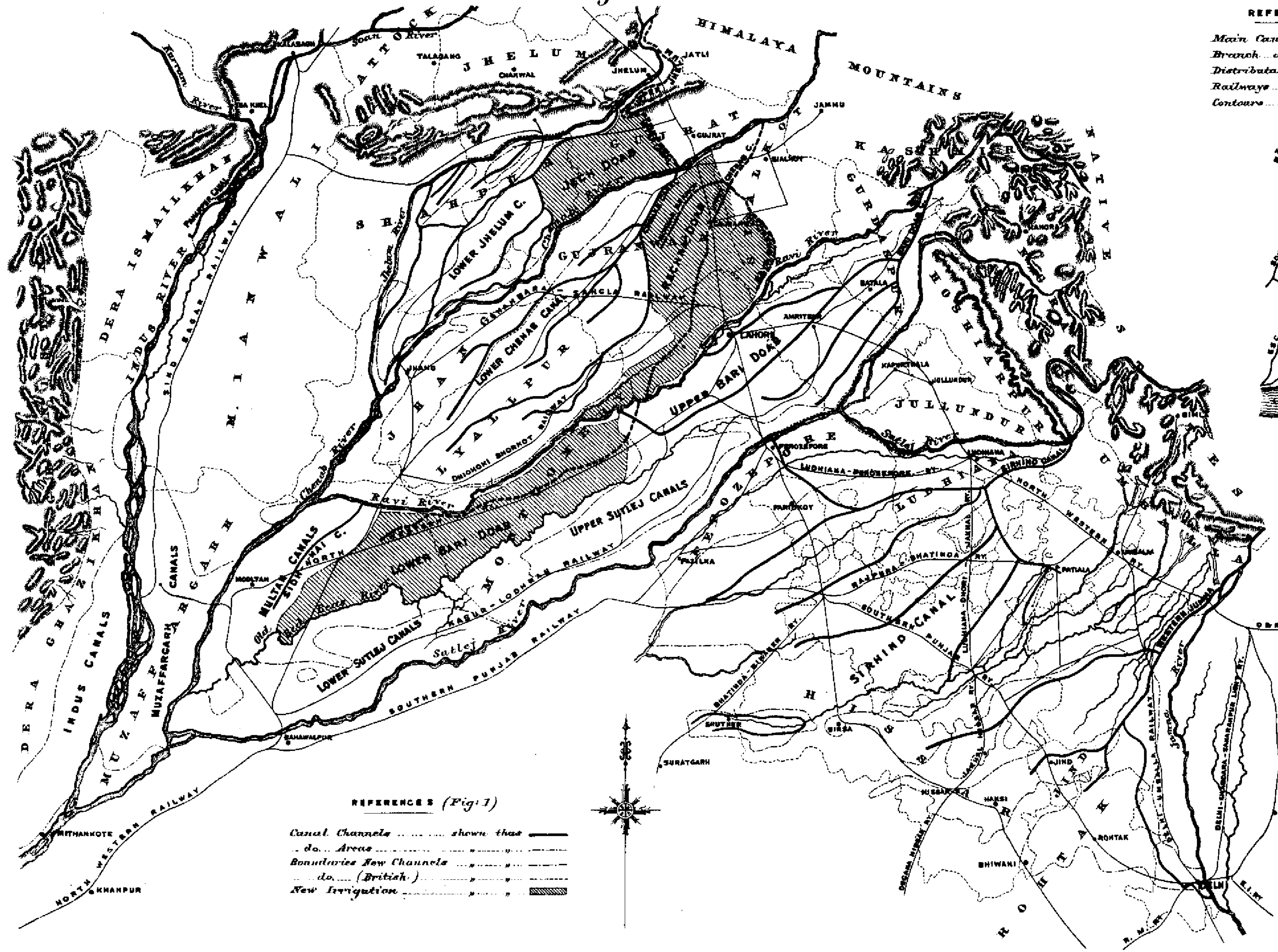
The returns just mentioned relate solely to those credited to the irrigation-works; there will be increased returns in other departments which will not be credited to the new canals, but which would not have been realized if these had not been executed. The surplus produce from the tracts under the new canals will be carried by the existing Government railways to the port of Karachi, and the net profit to the Railway Department, after deducting 50 per cent. for working-expenses, will be about as much as the net revenues of the Irrigation Department; all that is likely to be said about this great windfall, when it occurs, will be that the railways are doing very well. There will be increases of revenue in other departments. The net effect to Government will be that money borrowed at not over 4 per cent. for the execution of the works will bring in about 7·5 per cent. in the Irrigation Department and about as much in the Railway Department, not to mention increased revenues in other departments.

The Paper is accompanied by thirty-five tracings and drawings, from which Plates 1–4 and the Figures in the text have been prepared.

THE PUNJAB TRIPLE CANAL SYSTEM.

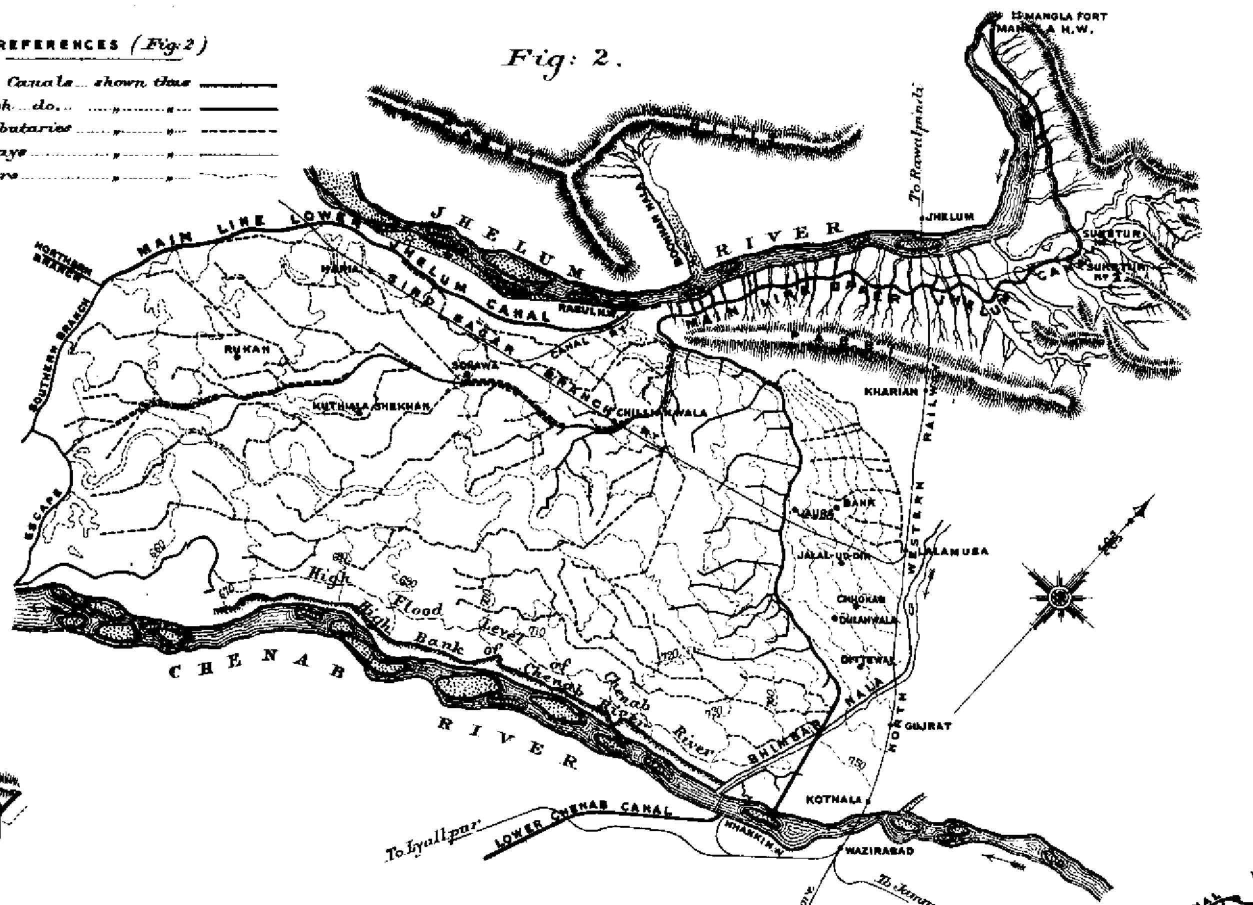
PLATE 1.
PUNJAB CANALS

Fig: 1.



GENERAL MAP OF THE PUNJAB.

Fig: 2.



GENERAL PLAN, UPPER JHELUM CANAL.

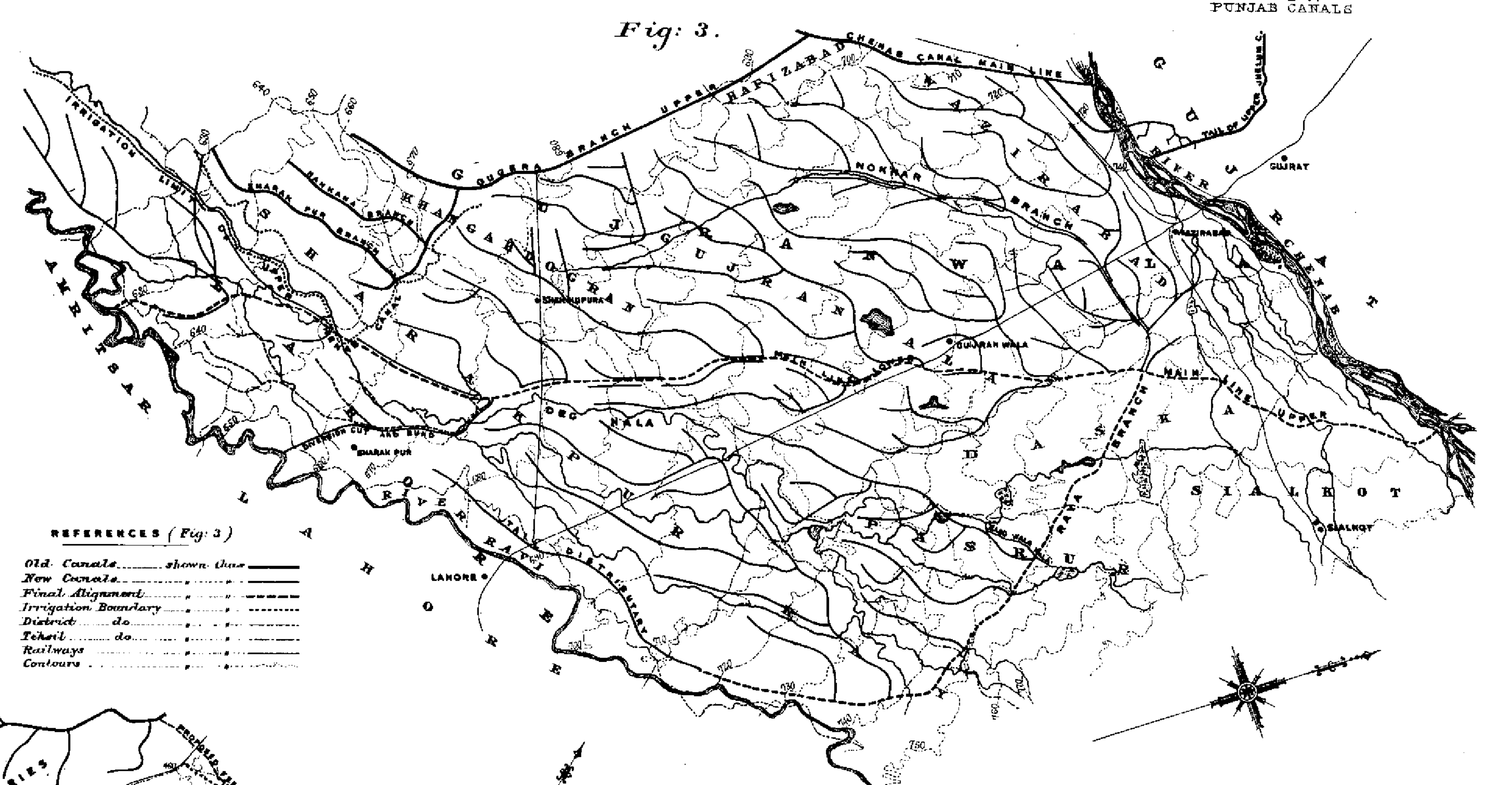
SCALES

Fig: 1 ...... 1 Inch = 50 Miles.

Fig^s 2 & 3 ... 1 Inch = 12 Miles.

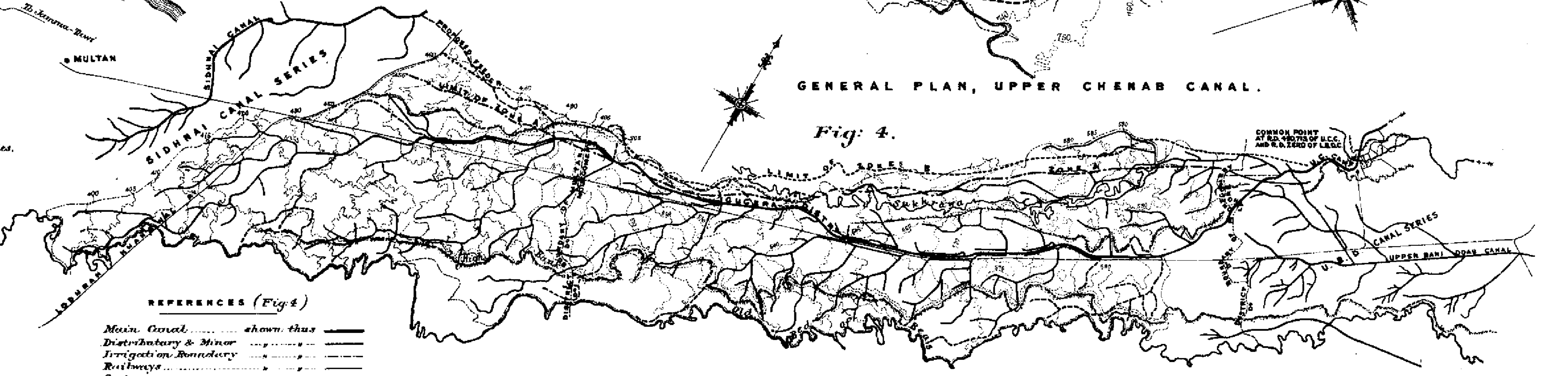
Fig: 4 ...... 1 Inch = 16 Miles.

Fig: 3.



GENERAL PLAN, UPPER CHENAB CANAL.

Fig: 4.



GENERAL PLAN, LOWER BARI DOAB CANALS.

SIR J. BENTON.

THE PUNJAB TRIPLE CANAL SYSTEM.

PLATE 2.
PUNJAB CANALS.

SIR J. BENTON.

THE PUNJAB TRIPLE CANAL SYSTEM.

UPPER JHELUM CANAL: MANGLA HEAD REGULATOR

LOWER BARI DOAB CANAL: HEADWORKS

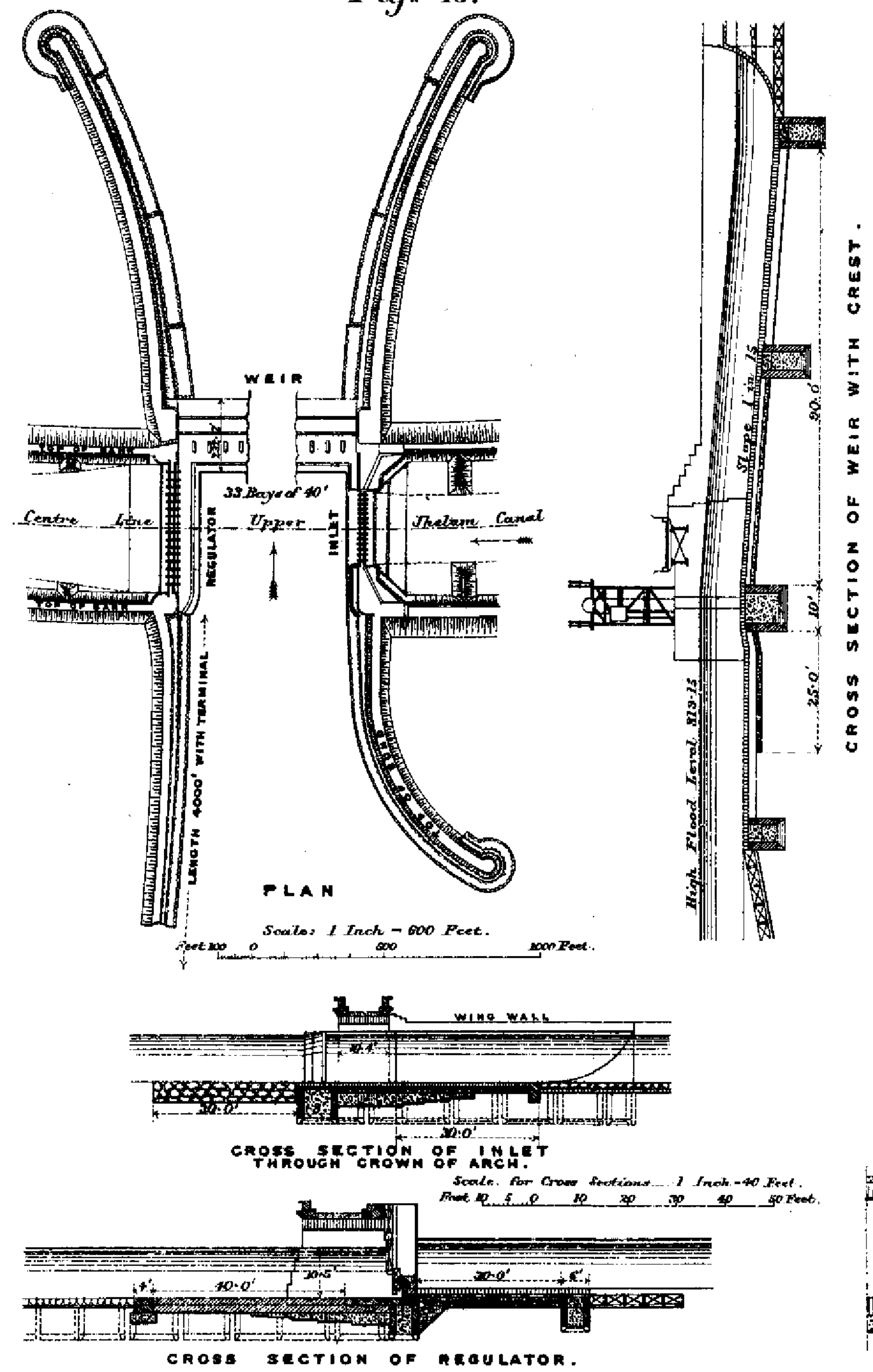
SIR J. BENTON.

WATERLOW BROS & LAYTON, LTD. LITH.

Minutes of Proceedings of The Institution of Civil Engineers. Vol. CCI. Session 1915-16. Part I.

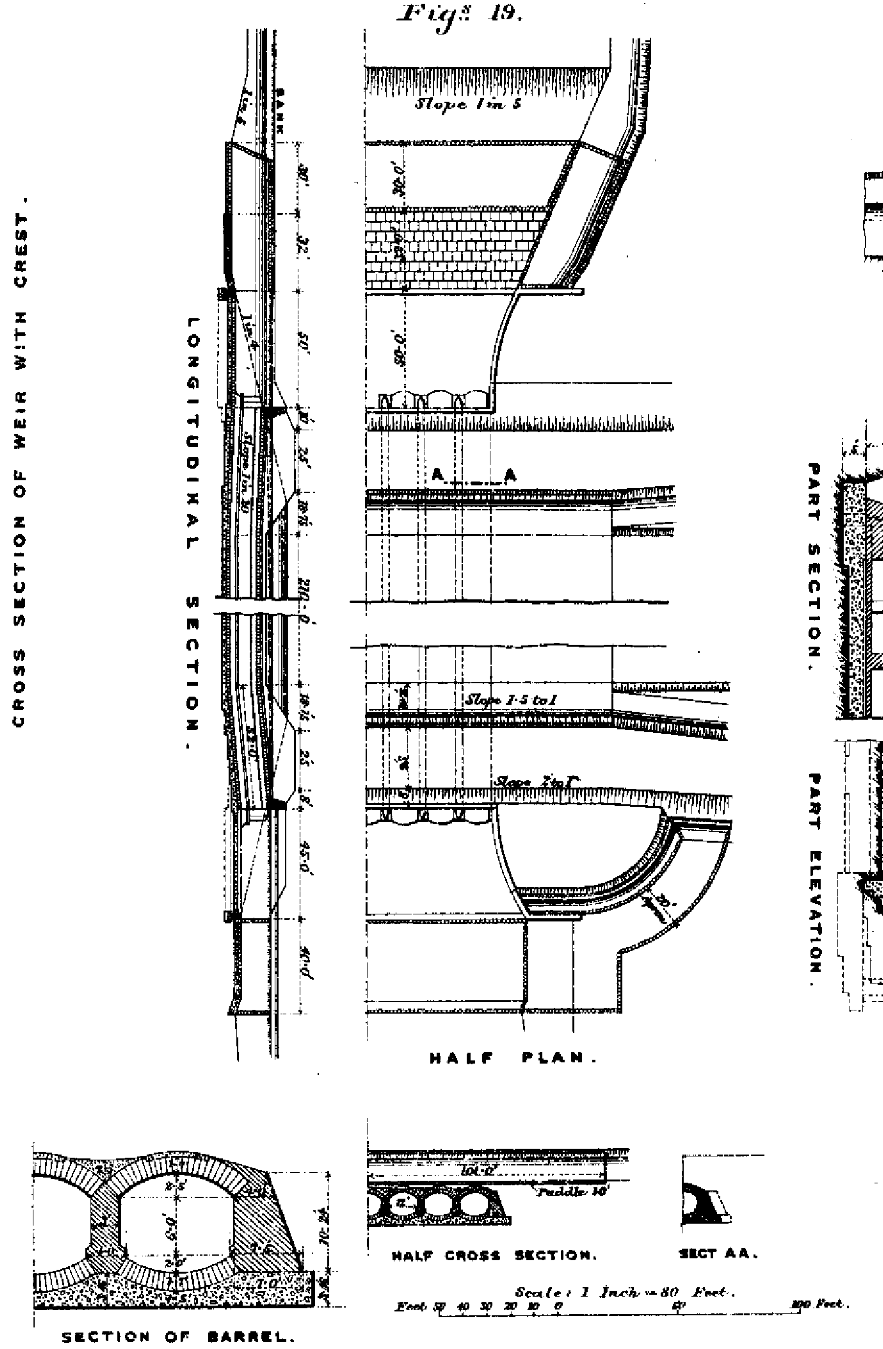
THE PUNJAB TRIPLE CANAL SYSTEM.

Fig. 18.



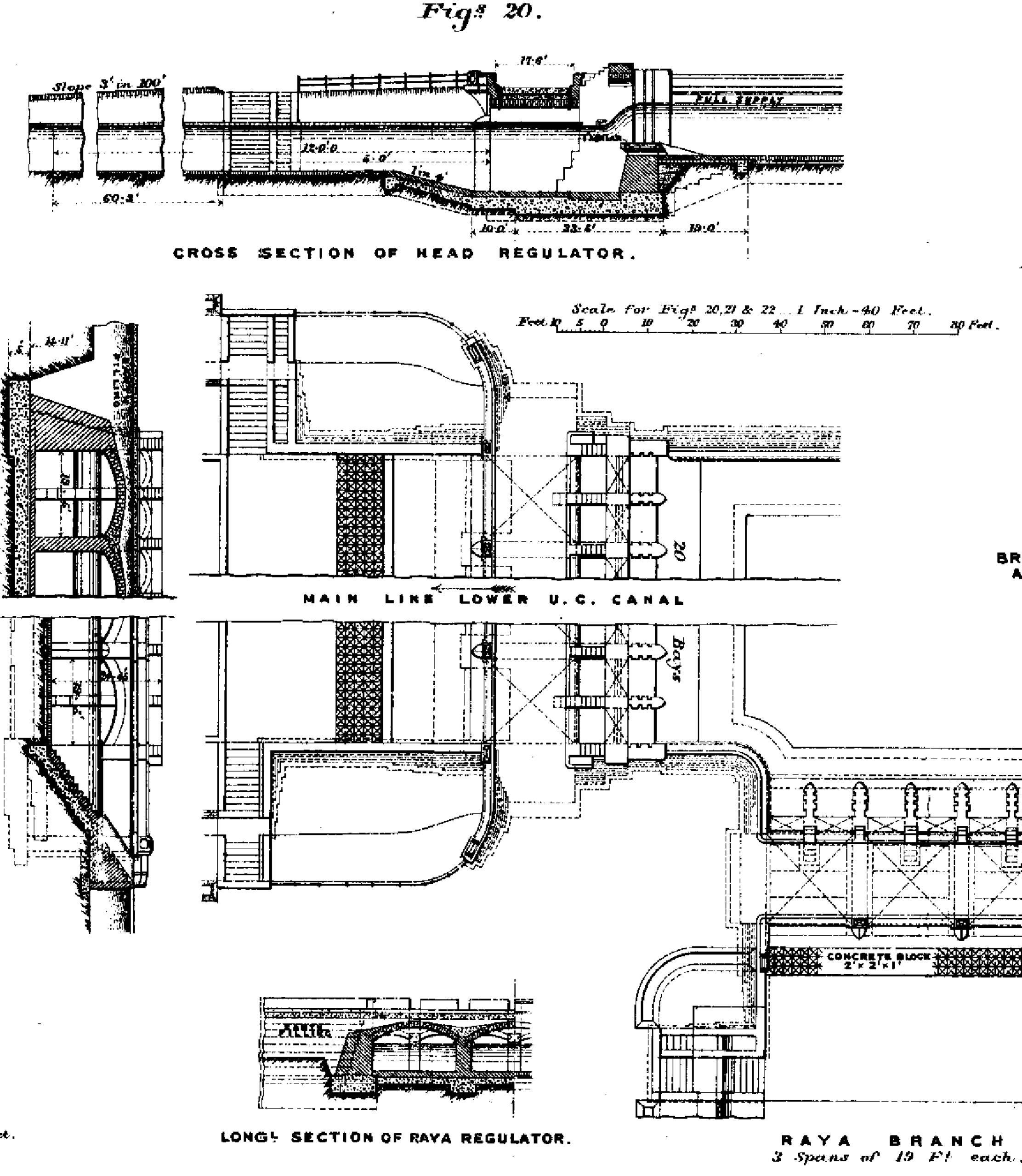
SUKETUR Nº 1 LEVEL CROSSING.

Fig. 19.

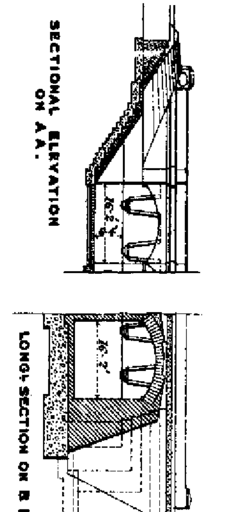


UPPER JHELUM CANAL: SIPHON AT R.D. 313,000 MAIN LINE.

Fig. 20.



UPPER CHENAB CANAL: HEAD REGULATOR OF MAIN LINE LOWER.



L.B.D. CANAL, DISTRICT ROAD BRIDGE & 7.75 FALL AT R.D. 6,12,500

Fig. 21.

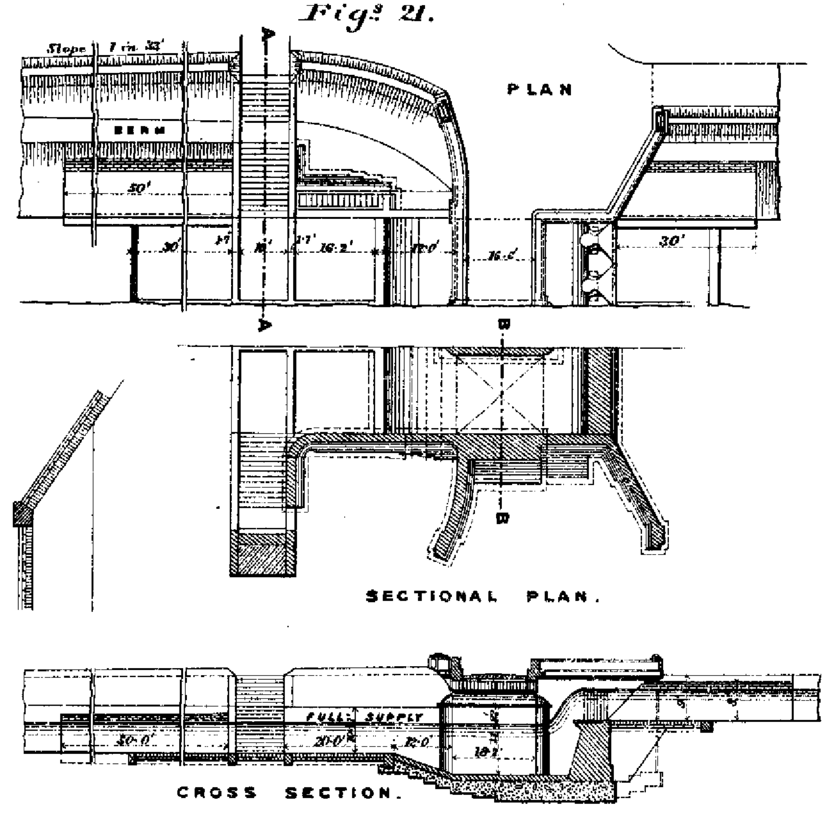
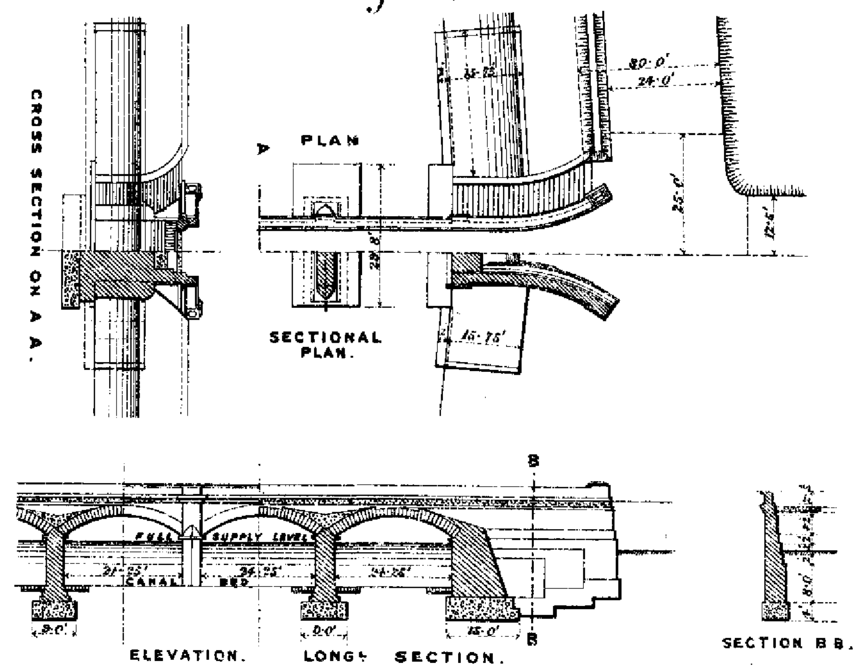
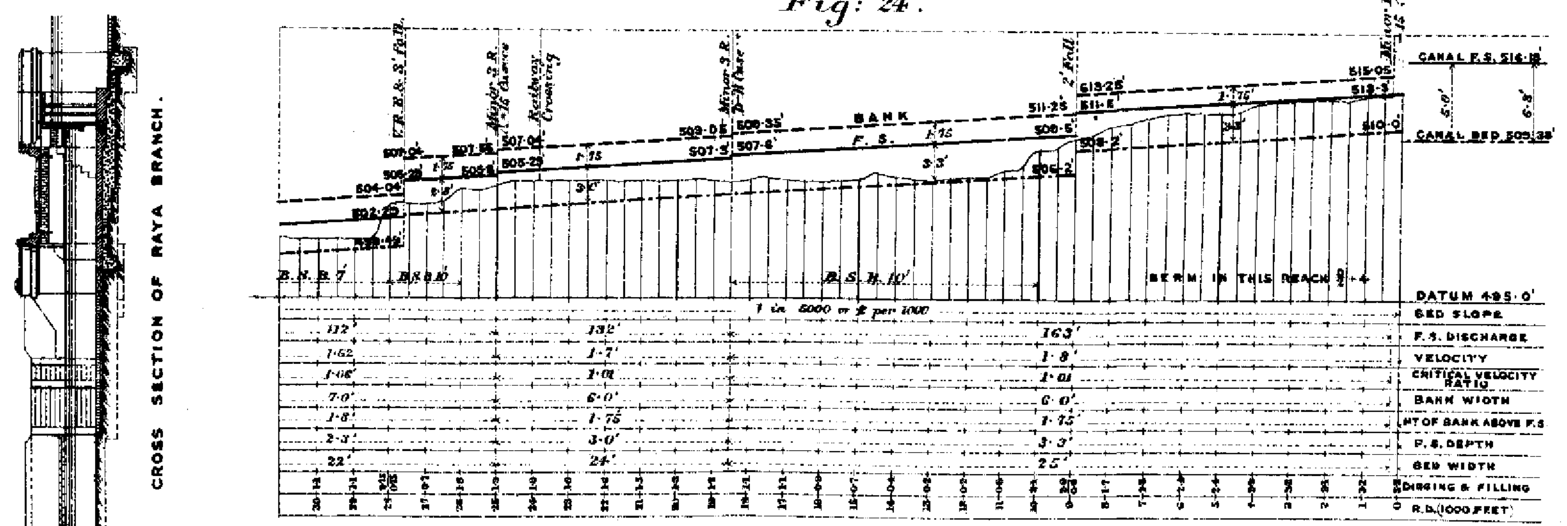


Fig. 22.



UPPER JHELUM CANAL: VILLAGE ROAD BRIDGE AT R.D. 3,66,415 MAIN LINE.

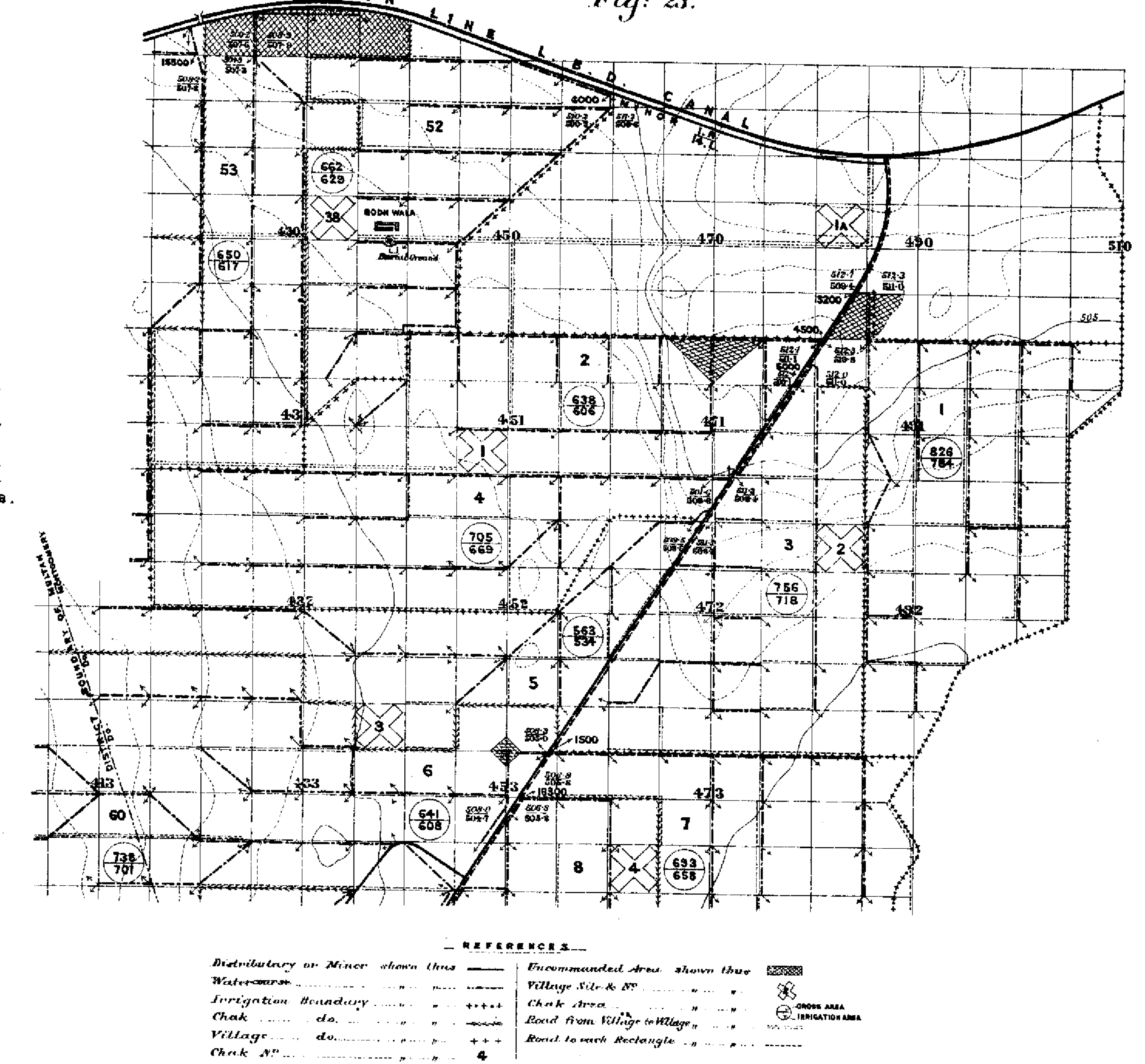
Fig. 24.



LOWER BARI DOAB CANAL: LONGITUDINAL SECTION OF 14 L. DISTRIBUTARY.

Scale for Fig. 23.

Fig. 23.



LOWER BARI DOAB CANAL: PART PLAN OF WATERCOURSE SCHEME OF 14 L DISTRIBUTARY.