PAPER No. 197.

WATERLOGGING ON THE UPPER CHENAB CANAL— ITS CAUSES AND CURE.

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Part I.

Introductory.

The Upper Chenab Canal, with a Full Supply discharge of 12,000 cusecs, is the central link of the Triple Project and carries the waters of the Chenab River across the Rechna Doab to feed the Lower Bari Doab Canal. The alignment crosses all the drainage lines of the Doab and on this account there was always an apprehension of waterlogging in the minds of its designers. As a preventive measure it was decided to divide the commanded area into three zones, called A, B and C on the basis of the depth of spring level below ground surface and to provide different intensities of irrigation in these zones, thus :—

	Depth to spring level.		*Intensity of Irrigation.*
Zone A	.. More than 35 ft. ..	75%	Perennial.
Zone B	.. Between 30 and 35 ft.	60%	,,
Zone C	.. Less than 30 ft. ..	25%	Non-perennial.

In Zone B, though the irrigation was proposed to be perennial, well lands were not allowed any canal irrigation, the object being to keep the well irrigation intact. There were, however, practical and administrative difficulties in excluding well areas in Zone B and the Zones A and B were later amalgamated into one with a uniform intensity of 60 per cent.

There are only the Perennial and Non-perennial zones existing at present.

Plan No. 1 shows the zones A, B and C into which the area was divided originally.

The canal was opened for irrigation in 1912, but high supplies were not run until 1916. Indications of waterlogging first became

manifest in 1918 when it was reported that owing to high supplies in the canal considerable area was damaged along the Main Line Upper. Damage by waterlogging was also reported in the same year near Chichoki Mallian Rest House. From this year onwards the waterlogged area went on increasing on both sides of Main Lines Upper and Lower. In 1923 waterlogging was reported to have taken place in the following reaches :—

Main Line Upper	R.D.	20,690— 35,800
		57,500—130,000
Main Line Lower		71,500—240,000
		240,000—266,000
		421,000—456,000

The total length affected was about 65 miles. Seepage drains within canal boundary were provided for all these reaches and these continued to be widened and deepened as the damage went on increasing.

The evil of waterlogging went on spreading and became very serious in 1925. There were complaints from the public and from the Civil authorities not only in respect of this canal but some other canals as well, such as Upper Jhelum, Lower Jhelum, etc. Several meetings and conferences of Civil and Irrigation Officers were held to discuss the situation and devise methods of overcoming the trouble. A Waterlogging Enquiry Committee consisting of one Engineer, one Chemist and one Revenue Officer was ultimately appointed by Government to prepare an estimate of the area damaged, investigate the causes and advise Government on the most suitable measures to be adopted to arrest further rise of the water table.

Various estimates of the damaged area were reported by Settlement Officers, local Enquiry Committees and the Irrigation Department. The Waterlogging Enquiry Committee ultimately accepted 28,500 acres as damaged in 1927. This included areas in which efflorescence was believed to have appeared in consequence of the rise of water table and also the areas in which water table was within 4 ft. of the ground.

Various remedial measures (to be described later) were undertaken by the local officers, some on their own initiative and others on the advice of the Waterlogging Committee. A close and constant watch on the situation and a systematic treatment of the subject were considered essential. This led to the institution of the Waterlogging Board in 1928. This Board with minor changes has since continued to control the Waterlogging policy of Government. The Financial Commissioner, Revenue, is the President of this Board and the Superintending Engineer of the Drainage Circle is in charge of statistics and investigation in connection with all waterlogging problems.

From the 1st map it is clear that :—

(*i*) Maximum rise of water-table since the opening of the canal has taken place in the area below Gujranwala and between Main Line, Upper Chenab Canal and Upper Gugera Branch of the Lower Chenab Canal. This is obviously due to two big irrigation channels running closer to each other in this reach than elsewhere in the tract and also due to the water-table in the tract being originally lower than elsewhere. The lowest points in the water-table would naturally fill up first on the commencement of a general rise.

(*ii*) A rise of over 10 ft. in the area on the left of Main Line, Upper Chenab Canal extends for a maximum distance of about 10 miles. Beyond this the rise is very small. In this case also the influence of main canal is quite obvious.

(*iii*) In the tracts irrigated by the Raya and Nokhar Branches the rise of water-table has been small as compared with the rise in the main line tract. In these two tracts the spring level was already very high, being less than 30 ft., and for this reason Kharif irrigation only was permitted.

If we compare Plan No. 1 showing the distribution of the area over various zones with the Difference Map 1911-35, it will be seen that the maximum rise of spring level has taken place in those areas where it was lowest before the opening of the canal, thus indicating that all the percolation on account of canal and rainfall, etc., went towards filling up of the depressions in the subsoil reservoir, also that the main Kharif channels Raya and Nokhar Branches contributed practically nothing towards the rise of spring level. In fact, a fall in the water-table is visible in the lower reaches of Raya Branch. This shows that the decision of the designers of the canal to allow only Kharif irrigation in tracts, in which the water-table was high, was very wise. The fact that the spring level shows comparatively greater rise in the Kharif irrigated tract contiguous to the Main Canal shows that it is not the Kharif irrigation which ensures immunity from rise of spring level but the absence of a canal constantly flowing throughout the year with a large volume of water.

Part II.

Review of anti-waterlogging measures in the Punjab.

The foregoing narrative of the progress of waterlogging on the Upper Chenab Canal and of the various measures undertaken to combat the evil should enable us to diagnose its causes and to devise a definite policy for guidance in the future so that money may not be frittered away on measures which have practically no effect on the situation. Before doing so a brief review of the anti-waterlogging measures taken in the Province in the past would not be out of place.

Waterlogging as a widespread evil first made its appearance on the Western Jumna Canal in the sixties and seventies of the last century. The conditions on this canal in those days were much worse than those that have so far prevailed at any time in the Chaj and Rechna Doabs. Large areas were entirely given up for cultivation, disease and malaria were rampant and whole tracts of country were abandoned and people migrated to neighbouring districts with better sanitary conditions. The situation was brought effectively under control by realigning the irrigation channels that were obstructing drainages, introducing a more efficient system of distribution of supplies so as to prevent waste and excessive watering, and providing an extensive system of shallow drains throughout the affected area. It is on record that these measures resulted in lowering the water table between 1892 and 1905 to the extent of 5 to 15 feet. No lining of canals was done, no pumping installations were put up and no seepage drains were excavated. Ever since then there has been no serious trouble on this canal and the water-table is more or less in a state of equilibrium.

In the year 1908, serious complaints of waterlogging, accentuated by heavy rainfall in that year, arose on the Lower Chenab Canal and to a lesser extent on other canals. Though the general policy of constructing surface drains found so successful on the Western Jumna Canal was not repudiated, and though some drains were actually provided, much attention appears to have been directed to other newly conceived measures such as lining of main irrigation channels. A vigorous push was given to this new device about the year 1911. Experiments on a grand scale were undertaken on the Sirhind and Lower Chenab Canals to find out the best lining material. By 1918 about 8 lakhs of rupees had been spent on the lining of a total length of about 12 miles scattered over different channels, of which the details are given in the 2nd Supplement to Punjab Irrigation Branch Paper No. 20. It was by this time at last realized that this method was prohibitive in cost and impossible of execution on a large scale besides being uncertain in results. Examination of the lining on Kot Nikka Branch in 1927 by the Waterlogging Enquiry Committee revealed

that it was fissured, cracked and undermined to such an extent that it became quite useless as a water proofing medium. Examination of the lining on Jhang Branch carried out by Mr. Nicholson in 1932 showed a similar state of affairs.

There was a lull in the activities of anti-waterlogging measures between the years 1918 and 1926 owing to financial stringency resulting from the Great War, though the waterlogging situation kept on getting worse in the meanwhile. There were abnormal rains in 1926 and the situation again attracted pointed attention. A Waterlogging Committee consisting of a Chemist, an Engineer and later a Revenue Officer was appointed in that year to prepare an estimate of the area affected by waterlogging and to advise Government on the best policy to be adopted to combat the evil. The nature of the measures adopted on the Upper Chenab Canal was to some extent influenced by advice tendered by this Committee. But it appears that the policy was more dictated by panic than as the result of a well thought-out scheme. Consequently only those areas were taken up where complaints were loudest or damage serious. More attention was directed towards treatment of local areas than towards the larger problem of lowering the spring level over the Doabs as a whole or checking its further rise.

Five Years Plan of Drainage Construction.

It was not till 1933 that a planned scheme of constructing a whole network of drains over the Chaj and Rechna Doabs was taken up at the suggestion of the author who was responsible for working out the preliminary proposals. These proposals comprised Main Drains only and their construction was planned to be spread over 5 years with the result that more progress with drainage construction has been made during the last 3 years than during the previous 15 years. The Upper Budhi Nalla and the Bikhu Drain on the Upper Jhelum Canal, Lower Raniwah Drain and Mona Outfall Drain on the Lower Jhelum Canal, the Rechna Drain extension, the Marh Chiniot Drain on the Lower Chenab Canal, Nikki Deg Drain and tail Main Line diversion on the Upper Chenab Canal are all instances of recent activity under the auspices of the 5 years Drainage Programme. There had been a long standing complaint of waterlogging in the Sutlej Khadir near Machhiwara and Ludhiana, etc. This has also been removed during the last three years by opening up of the Budha Nala. Similarly there was a century old complaint of waterlogging in Dasuya Tehsil, seriously affecting the health of the people. There was a heavy death rate from malaria and plague which has become endemic. This is due to a large area of marshes caused not by the rise of spring level owing to any irrigation channels, but by the floods brought down by hill torrents. A drain is now being excavated through this area and half the area, nearly 400 acres in extent, has already been reclaimed and the spring level in the area close to the drain has fallen by nearly 5·0 ft.

The Causes of Waterlogging.

Plan No. (17) is a section showing levels of ground surface and water-table across the Province approximately along what is called the Provincial Well line No. 1 (see Plan No. 16). The line runs through Panipat, Nabha, Tarn Taran, Amritsar, Gujranwala and Pabbi hills, *i.e.* the tract which is more or less badly affected by waterlogging specially the western portion. If we look at the shape of the water-table on this section in Chaj and Rechna Doabs before the advent of the canals, *i.e.*, in the year 1908, we find that it is in the form of a trough, the bottom level of which is lower than that of the two surrounding rivers.

It may be safely assumed that in the pre-canal period the water-table was in a state of equilibrium. There is no doubt that its level fluctuated with the amount of rainfall from year to year and sometimes very violently, but there is nothing to show that it was continuously rising. There would be a sudden rise in a year of heavy rainfall, but it would adjust itself in a subsequent dry year. If we look at Fig. 1 of Punjab Irrigation Research Institute Memoir called " An investigation of the rise of water-table on the Upper Chenab Canal area," we find that there was sudden rise of the water-table in 1908-09 owing to heavy rainfall amounting to 33 inches in that year, but it dropped again to the level of 1907-08 in the year 1911-12 when there was only about 12 inches of rainfall. If observations were available for a large number of years for the pre-canal period, it would be found that after centuries of fluctuations, the subsoil water-table had attained a state of equilibrium. If it were continuously rising, the whole country would have been waterlogged long before the advent of canals. On the other hand if it were continuously falling, the water-table would have gone down indefinitely.

Before the canals are constructed in a Doab, there are the following factors tending to raise the level of the water-table —

(*i*) Infiltration from rivers towards bottom of the trough.

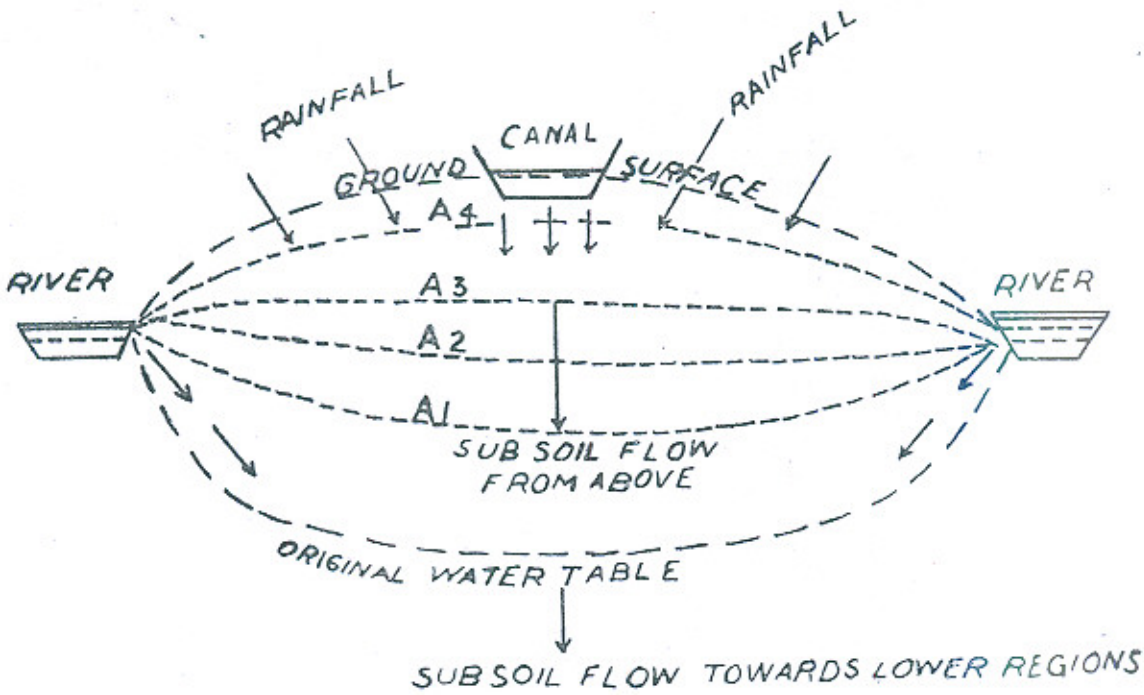
(*ii*) Absorption of rainfall.

(*iii*) Subsoil flow from upper regions of the doab.

All these may be called the " inflow."

The only factor tending to lower the water-table is the subsoil flow towards the lower regions. This may be called the " outflow."

The sketch below illustrates what is actually happening :—



A correct idea of the subsoil flow can be formed from Plan No. (18) which is a section through Rechna Doab ending in the confluence of the two rivers Chenab and Ravi. The line along which this section has been taken is marked on the Index Plan of the Punjab No. (16). The lines for the different years on the section show how the water-table went on rising from year to year.

As the water-table in the pre-canal period was in a state of equilibrium, it can be safely deduced that the inflow and outflow must be equal, *i.e.*, the subsoil drainage was sufficient to cope with the inflow from all the various sources enumerated above. A canal is then constructed in the Doab in the position shown in the sketch. For the sake of convenience, we may omit the branches and distributaries from consideration and assume that the collective seepage of all the irrigation channels takes place from the canal. By the construction of the canal a new source of constant inflow into the subsoil is introduced. The subsoil drainage was just sufficient to deal with the sources of inflow previously operating, but is incapable of dealing with the additional inflow caused by the seepage from the canal. This naturally results in a continuous rise of water-table. The rise, however, is not uniform every year. In a year of heavy monsoon the rise would be abnormal, which would have gone down to its original level, had there been no canal, but owing to the continuous inflow from the canal, the original level would never be attained and some of the rise would become permanent.

As the water-table rises, the inflow from the rivers decreases owing to the reduction in head, while the outflow, *i.e.*, the sub-soil flow towards the lower reaches of the doab increases owing to the steepening of the gradient. This explains why the rise in water-table is rapid in the early years of the opening of a canal. The inflow from both the rivers and the canal would be obviously maximum when the bottom of the trough is lowest. A_1, A_2, A_3 and A_4 in the sketch represent the levels of the water-table in the various stages of the rise, subsequent to the opening of a canal. When this level rises to the same level as the rivers, the inflow from the rivers ceases, while the inflow from other sources continues practically unabated. As soon as the level of the water-table rises above the level of the rivers, outflow starts from the water-table towards the rivers. In these conditions the sources of inflow are :—

(*i*) Absorption from rainfall
(*ii*) Subsoil flow from upper regions
(*iii*) Seepage from Canal

while the sources of outflow are :—

(*i*) Infiltration into the rivers
(*ii*) Subsoil flow to the lower regions of the doab.

The volume of outflow from both these sources will continue increasing as the water-table rises, until a stage is reached when the outflow becomes equal to the inflow. This means that in every doab the rise of spring level must come to a stop at a certain level, when the water-table attains a state of equilibrium. What this level below ground surface will be depends on the height of the water-table above the rivers, and the slope of the ground towards the rivers. The greater the height and the steeper the slope, the greater the depth below ground at which equilibrium is attained.

The above explanation of the causes of waterlogging in the different doabs of the Punjab can be demonstrated with the help of the two sections one across the Province along Well line No. 1 (Plan No. 17) and the other through the Rechna Doab (Plan No. 18). The former plan shows that the shape of the water-table in Rechna Doab in 1908, *i.e.*, before the advent of Canal was in the form of a trough and below the level of the two rivers. The Canal was opened in 1915 and the water-table for the year 1920 shows a sudden rise which pushed up its level above that of the surrounding rivers. After this year the rise is slow and the levels of 1935 are not very much higher than those of 1928 and 1932. An inspection of Plan No. (3) will show that the water-table in the Upper Chenab area had practically reached a condition of equilibirum in 1926. After this year, there has been no permanent rise, but only fluctuations due to rainfall.

How the subsoil flow from upper regions of the doab affects the rise of water-table or is affected by it is clear from Plan No. (18). Lyallpur is situated above 2/3rd the distance down the Doab. The rise here has been about 50 feet since the opening of Lower Chenab Canal and about 40 feet after the opening of the Upper Chenab. It is difficult to say whether the rise in this tract would have been the same even if there had been no local irrigation channels, but the probability is that the difference would have been very small, though the progress might have been slower. It is clear that if the water table is lowered by some means in the upper reaches of the doab, it will automatically go down in the tract near Lyallpur. Thus before any local measures are considered, it is essential that immediate measures should be taken in the upper reaches to lower the water table as far as possible.

The other significant phenomena in connection with the rise of water-table that are noticeable from this plan are :—

(*i*) that no rise of water-table has taken place in the upper reaches of the doab above Raya Branch owing to absence of any irrigation channels and steepness of the country ;

(*ii*) that the maximum rise has taken place under Upper Gugera Branch which is the oldest large sized channel in the tract. The slope of the ground changes at the crossing of this channel.

(*iii*) that no rise has taken place a few miles above the confluence of the rivers Ravi and Chenab. The spring level lines for all the years join here and come out at the confluence.

Now, let us examine the conditions in the various doabs of the Province as exhibited in the Section along Provincial Well Line No. I (Plan No. 17). It will be noticed that a state of equilibrium in the water-table has already been reached several years back in certain tracts of the Western Jumna Canal, on the whole of the Sirhind and Upper Bari Doab Canals and seems to be nearing it in the Chaj Doab.

It is noteworthy that no preventive measures against waterlogging have ever been taken on the Sirhind Canal uplands, and yet no waterlogging has occurred and the water-table is in a state of equilibrium. The section through the doab clearly shows that this is due to the enormous height of the water-table above the two rivers on each side of the doab and therefore the outflow being sufficiently great to balance the inflow from canal and rain.

In the Bari Doab the water-table is also at a great height above the river on the Beas side and the water-table on this side is consequently in a state of equilibrium. On the Ravi side the height is comparatively less and the rise of water-table is still noticeable in the area between Main Canal and Lahore Branch.

On the Western Jumna Canal there is practically no rise in the area between the Main Line and Jumna River, but between the Main Line and Sirsa Branch the water-table is still rising, as it is in the shape of a trough and consequently there is no outflow from it to the sides. The comparatively slow rise is due to the fact that inflow is small being only from the distributaries of the Western Jumna Canal. The trough expands laterally in its travel down as the rivers diverge.

The shape of the water-table under the Western Jumna Canal is significant. Left of the Main Canal it does not follow the N. S. contour. This is a definite indication that this crest is due to canal only.

Now consider the conditions in the Bist Doab, *i.e.*, between Sutlej and Beas Rivers. In this doab the water-table has actually fallen since 1913-14 and its level is lower than that of the two surrounding rivers. The shape of this doab and its levels represent the same conditions as existed in the Chaj and Rechna Doabs before the introduction of canal irrigation. The fall is obviously due to the sinking of excessive number of irrigation wells during recent years, which means that the outflow became greater than the inflow, the only source of which is the rainfall. If canals were introduced in this area, there is no doubt at all that water-table would rise and there might even be waterlogging.

In describing the factors responsible for the rise of water-table the author has omitted to mention one important fact, *i.e.*, the increase in inflow to the water-table from rainfall due to increase of absorption resulting from the breaking up of new areas for cultivation after introduction of canal irrigation. Dr. McKenzie Taylor maintains that local rainfall is responsible for about 93 per cent. of the rise of water-table on the Upper Chanab Canal. Rainfall was always there and did not cause water-logging. The only additional factor of recent occurrence appears to be the increase in absorption due to breaking up of new areas which might contribute towards this rise. The following figures of cultivated area in Gujranwala and Wazirabad Tahsils, however, show that there has been an increase of about 30 per cent. only in the cultivated area after the advent of the canal. Other Tehsils have not been considered as their boundaries have changed after the opening of the canal :

Year.	*Gujranwala.*	*Wazirabad.*	*Total.*
1912 (before canal) ..	.. 308,323	160,380	468,703
1921-22 (6 years after canal)	.. 436,721	168,303	605,024
			136,321

It does not appear possible that a 30 per cent. increase in cultivation would increase the absorption of rainfall to such an extent as to make it responsible for the rise of water-table to the extent of 93 per cent.,

especially when we remember that most of the area under cultivation was *chahi* and the introduction of canal irrigation could not have made any appreciable difference in the system of *watbandi* (field dowels).

It has been shown above, that it is the amount of inflow from various sources throughout the year that is responsible for the rise of the water-table and not rainfall alone during the monsoon months. Any correlation that might be established between the monsoon rainfall and the yearly fluctuations of the water-table cannot explain the persistent rise of the water-table that takes place from year to year. Appendix C gives the contribution of the rainfall and the canals to the water-table in a normal year in the Rechna Doab. To compare the inflow in the various portions of the doab the whole doab has been divided up roughly into 4 Regions according to the amount of rainfall, depth of water-table below ground, etc., as marked on Index Plan No. (16). Foot-notes on the statement explain the method of preparing the statement and how the absorption and seepage have been calculated. The statement shows that in Region I, *i.e.*, the uppermost Region, rainfall contributes 11·13 inches to the water-table and canals 19·10 inches. In the II Region rainfall contributes 7·26 inches and canals 17·10 inches.

Similarly, in the other two Regions, *i.e.*, as we go down the doab, the contribution of rainfall decreases comparatively to that from the canal. In the lowest Region, rainfall contributes only 5·14 inches, while canals contribute 10·27. In the uppermost Region the contribution from both the rainfall and the canals is the heaviest. This explains the comparatively greater rise of water-table in the upper reaches of the doab.

Cure of Waterlogging.

It is obvious from what has been stated above under " Causes of Waterlogging " that the water-table can be definitely lowered, if the amount of " inflow " into the subsoil can be reduced. The water-table being in a state of equilibrium, the outflow and inflow balance each other. Reduce the inflow and the outflow will get reduced automatically so as to maintain equilibrium. For a reduced outflow, the head above the rivers must become less, which means a fall in the level of the water-table. Therefore, the problem before us is how to reduce the amount of inflow. Out of the factors which constitute the sources of inflow, *i.e.*

(*i*) Irrigation.

(*ii*) Canals.

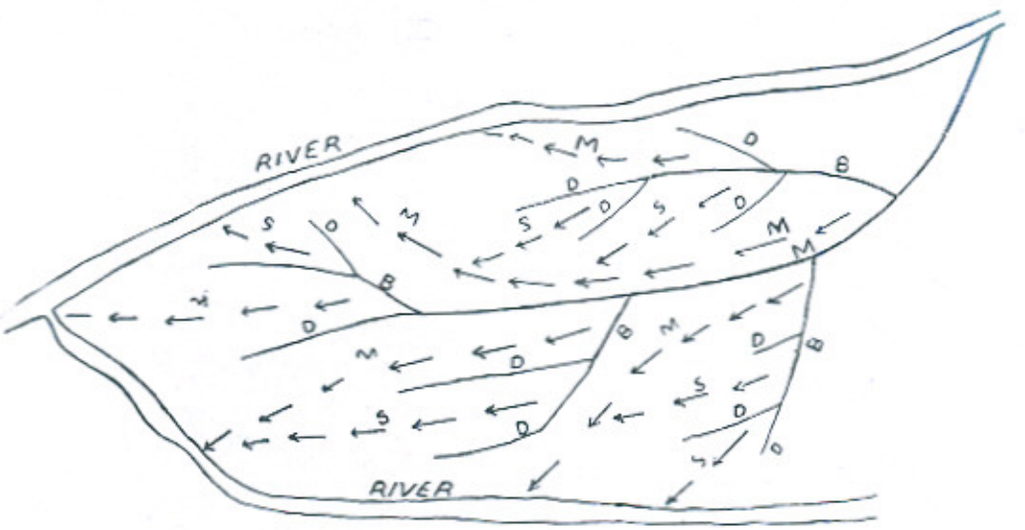
(*iii*) Subsoil flow from upper regions.

(*iv*) Rainfall,

no reduction is possible in the case of irrigation. Seepage from canals can only be reduced if we can render our channels waterproof. Up to this time no lining material has been found which would be effective as well as durable, cheap and capable of being applied within the time available during short closures. About 8 lakhs have been spent on experiments with various materials but without success. Further experiments are at present in progress in the Research Institute with sodium carbonate. If found successful, it will no doubt prove highly useful as likely to reduce not only the seepage into the subsoil, but to save vast quantities of water which is wasted in this manner.

Similarly we cannot stop the subsoil flow from the upper reaches of the doab. This is a natural phenomenon, which plays an important part in any attempts at lowering the water-table.

Thus as far as our present scientific knowledge is concerned, we are only left with rainfall for a source of relief. Fortunately, the general configuration of the doabs in this Province and their levels relatively to the surrounding rivers render it possible to get rid of a large proportion of the rainfall without use of pumps or other lifting arrangements. The general shape of a doab is as sketched below.



The black lines represent watersheds along which the canals and distributaries are generally constructed :—

M denotes Main Canal.

B denotes Branch Canal.

D denotes Distributaries.

The arrows represent the natural drainage lines.

M denotes Main Drainages.

S denotes Subsidiary Drainages.

Thus the country is made up of water sheds and drainages with almost scientific regularity. This is nature's method of keeping a country in a state of sanitation at the same time enabling man to produce food for his living. In the course of our operations in connection with agriculture, etc., nature's provisions are disregarded. The natural drainage lines are obstructed by construction of water courses, embankments, field dowels, etc., with the result that rainfall does not flow off along these lines, but keeps standing in pools and depressions and gets ultimately absorbed in the ground. All rainfall in excess of what is required for the transpiration of crops adds to the inflow to the water-table (ignoring evaporation). It should be our attempt to get rid of this excess as quickly as possible and before it has had time to enter the soil. This can best be affected by opening up the natural drainage lines as marked on the sketch. Artificial channels of suitable size should be provided along these lines so as to carry away the storm water rapidly to the rivers without causing undue flooding in the surrounding area. The capacity for which the drains should be designed is a big subject requiring a Paper to itself. It need not be discussed here. It is obvious that the greater the number of subsidiary and branch drains, the greater will be the quantity of rainfall, that will be removed. In a badly waterlogged area it may be necessary to provide drains round every field and even inside them.

It is clear that the provision of storm water drains can only be beneficial in a tract where the amount of rainfall is sufficient to contribute substantially to the water-table. In tracts where the rainfall is small, so that hardly any inflow reaches the subsoil, or the subsoil drainage is able to deal with it the construction of drains would be useless. In such tracts the factors mostly responsible for the inflow are the subsoil flow from upper regions and the local irrigation channels. The proper treatment for waterlogging in such cases would be the lowering of water-table in the upper reaches of the Doab and if that is not sufficiently effective, the lining of local irrigation channels will have to be carried out. The provision of storm water drains in the tract proposed to be irrigated by the Haveli Project is, in the author's opinion, not likely to serve any useful purpose. It is difficult to lay down any general rule for the treatment of all tracts. Each case should be examined and dealt with on its merits according to the local conditions. It has been proved from calculations that in tracts with rainfall less than 9 inches spread over the whole year, provision of storm water drains would be of no use whatever.

Before leaving the subject of drains it would be interesting to discuss the type of drains which are likely to be most useful and economical. Deep seepage drains have been favoured by some well-known engineers in the Department on the idea that such drains are more effective than shallow drains for lowering the water table. There can be little doubt that any removal of subsoil water, however small, would increase the outflow and thus tend to lower the water-table. Deep seepage drains should, therefore, be useful, but the cost of excavating and then maintaining such drains is almost prohibitive. The bed of a seepage drain is always 2 or 3 feet below the prevailing spring level and on this account springs coming out in the bed are always blowing sand and tending to raise the bed. This sand must be cleared out constantly if the effectiveness of the drain is to be maintained. As it is not possible to do this by manual labour, Dragline Excavators have to be continuously working on the drain, not only for initial construction but for subsequent maintenance and this is very expensive. As shown above, it is possible to lower the water-table by rapid removal of rain water and for this purpose shallow drains are all that is required. There is, therefore, no necessity to go to the expense and trouble of providing deep seepage drains. Such drains are only justified in areas, in which water-table has risen so close to the ground surface that cultivation is rendered impossible. Such areas are ordinarily situated along main canals and parallel seepage drains are required to keep the area dry and fit for cultivation. These drains have been provided on the Upper Chenab Canal in addition to the lowering of canal supply levels. When providing these drains care has to be taken that they are not dug too close to the canal, otherwise there is a danger of their increasing the percolation head from the canal and thus increasing the amount of seepage. Experience shows that 1,000 ft. from the canal is a suitable distance for locating the drains. Surface drains need not be more than 3 to 4 ft. below ground level, so that all ordinary rainfall is disposed of without the drains overflowing their banks.

It may be mentioned here that on the Western Jumna Canal, where the spring level was lowered 8 to 15 feet by the provision of a drainage system, no seepage drains were provided. All the drains are shallow and wide and require very little expense in maintenance.

Summary.

1. The paper puts forward a simple theory explaining the causes of waterlogging with special reference to the area commanded by the Upper Chenab Canal. This theory is based on actual observations of spring level at site over a number of years and not on any statistics, which are liable to be influenced by the personal factor of the man working them up.

2. According to this theory waterlogging is to a large extent due to seepage from the canal system and to a small extent due to increased absorption of rainfall resulting from breaking up of new areas for cultivation.

3. Water-table can be definitely lowered by the provision of a suitably designed system of drains in the area affected.

4. Provision of storm water drains in areas with rainfall less than 9 inches is practically useless and the remedy would appear to lie in the rapid removal of rainfall in the upper reaches of the doab and if necessary in the lining of irrigation channels.

5. Seepage drains are useful in areas where spring level is above ground surface, but are not recommended for areas where cultivation is possible without such drains. As a means of lowering the water-table, their utility is vitiated owing to the high cost of construction and maintenance.

6. Lowering of full supply levels in a canal has a purely local effect which does not extend beyond half a mile. As a means of lowering general water-table it is a useless measure.

7. Tube well pumping, as a means of lowering the water-table, has a purely local effect, which does not extend beyond half a mile radius, and which does not last after the pumping stops.

8. Restriction of supply for irrigation has very little effect on the water-table and must not be resorted to at the cost of cultivation.

9. Pumping from ponds is very useful for control of water-table locally near large towns and villages, but quite useless for lowering the general water-table.

APPENDIX A.
UPPER CHENAB CANAL.
Statement showing Seepage Drains with their Cost and Length.

Item No.	Works.	Expenditure to end of 1932-33	Length in miles.
1	Seepage Drain along Canal boundary ..	1,31,876	35·00
2	Adorai Drain	30,314	14·17
3	Ghanoki Drain..	44,504	12·26
4	Sohian Drain	6,656	4·00
5	Mari Thakran Drain	9,688	1·43
6	Harpoki Drain	1,01,345	12·08
7	Kot Nallah Drain	36,307	15·40
8	Drajki Drain	13,367	3·24
9	Joyanwala Drain	12,691	6·28
10	Inspection House Branch Drain ..	..	3·03
11	Drain along Main Line Lower R. D. 193,000 to 216,000	3,605	4·60
12	Santpur Seepage Drain	45,383	7·42
13	Sheikhwan Drain	13,249	2·55
14	Lil Seepage Drain	35,376	3·47
15	Seepage Drain from R. D. 232,000 Main Line Lower to Lil Drain.. ..	18,691	2·60
16	Storm water spill drain from Lil Drain to Nikki Drain	2,313	1·35
17	Kathianwala Seepage Drain ..	5,597	1·68
18	Seepage Drain from R. D. 258,000 Main Line Lower to Nikki Deg North of Railway Line	3,332	1·03
19	Seepage Drain from R. D. 260,700 Main Line Lower to Khanpur Pond South of Railway Line	2,352	0·65
20	Seepage drain from R. D. 15,703 Sheikhwan Distributary to Nikki Deg ..	1,434	0·60
21	Sheikhupura Seepage Drain ..	18,292	1·80
22	ChichokiChaudhal SeepageDrain R.D. 305,000 to 347,000 Main Line Lower	1,59,910	18·00
23	Chichoki Chaudhal Seepage Drain R.D. 253,000 to 305,000 Main Line Lower.		
24	Kala Gujar Seepage Drain..	26,099	11·00
	Total ..	7,22,381	163·64

APPENDIX B.

UPPER CHENAB CANAL.

Statement showing falls of which crests were lowered including Distributaries of which heads were shifted.

Item No.	Works.	Total Expenditure.	Remarks.
1	Lowering F. S. Level 0—17,000 ..	27,731	
2	Lowering F. S. Level 40,500—71,500 ..	65,797	
3	Lowering Railway Bridge at 97,132 M. L.L.	34,064	
4	Lowering Fall R. D. 139,165 and protecting apron of fall R. D. 128,000 M.L.L.	25,091	
5	Dismantling intermediate piers of footbridge R. D. 107,500 M.L.L. ..	221	
6	Lowering F. S., M.L.L. 715 to 128,000	1,01,814	
7	Lowering floor of footbridge R. D. 107, 833 M.L.L.	13,162	
8	Shifting head of Naushera Distributary	95,141	
9	Lowering crest of fall R. D. 139,000 to 165,000 M.L.L.	75,915	
10	Lowering full supply in Canal 164 to 232,000	4,228	
11	Shifting head of Chichoki Distributary	28,108	
12	Eliminating notched fall R. D. 244,000	6,349	
13	Lowering fall at bridge R. D. 42,015	25,267	
14	,, ,, ,, ,, R. D. 249,550	29,162	
15	,, ,, ,, ,, R. D. 258,000	30,587	
16	,, ,, ,, ,, R. D. 275,000	27,052	
17	,, ,, ,, ,, R. D. 24,400	27,100	
18	,, ,, ,, ,, R. D. 251,000	34,781	
19	,, ,, ,, ,, R. D. 266,000	26,950	
20	Lowering raised cill fall R.D. 284,000	531	
	Total ..	6,78,691	

APPENDIX D.
LIST OF PLANS.

No. of Plans.	Heading of Plans.	Remarks.
1.	Plan showing proposed Irrigation Zones in 1910.	
2.	Index plan of U. C. Canal showing pipe lines.	
3.	Graphs showing average depth of water table in various tracts of U. C. Canal.	
4.	L. Section of M. L. L., U. C. C. from 0 to 284215 showing bed and W. S. during the year 1927-1935.	
5.	Cross Sections along pipe lines in Sheikhupura Division (from 1928 to 1935, June).	
5-A.	Cross Sections along pipe lines in Marala Division (from 1925 to 1935, June).	not printed.
5-B.	Cross Sections along pipe lines in Gujranwala Division from 1930 to 1935, June).	not printed.
6.	Layout plan of Hydrautomat drains and R. C. Filters at Bambanwala.	
7.	Site plan of Chianwali R. H. and Hydrautomat.	
8.	Plan of Gujranwala City showing Kachi Chhappar and wells and pipes under observations.	
9.	Graph showing average depth to spring level of various groups of wells at Gujranwala.	
10.	Site plan of Sheikhupura town and wells under observation.	
11.	Graph showing average depth to spring level of wells at Sheikhupura.	
12.	Difference Map U. C.C., June 1911-35.	
13.	Ditto. June 1924-35.	
14.	Ditto. June 1930-35.	
15.	Difference Map of area along M. L., June 1930-35.	
16.	Index Map of Punjab showing lines along which sections taken.	
17.	Cross Section along Provincial Well line No. 1 showing spring level.	
18.	L. S. of Rechna Doab showing subsoil water table 1904-35.	

APPENDIX C.

Additions to the Subsoil water-table in the Rechna Doab due to Canals and Rainfall.

Tract.	Gross area.	Discharge utilized at distributary heads.	Absorption in Distys., water courses and fields. (46% of Col. 3).	Absorption losses in main line & branches.	Total absorption from canal (Cols. 4 and 5).	Equivalent depth over gross area on account of absorption from canals.	Mean rainfall.	Rainfall absorption (50% of Col. 8).	Total absorption from canal and rainfall (Cols. 7 & 9).
1	2	3	4	5	6	7	8	9	10
	Acres.	Cusecs.	Cusecs.	Cusecs.	Cusecs.	Inches.	Inches.	Inches.	Inches.
Region I.—Marala, Gujranwala and Raya Divisions.	1,192,000	4,126	1,898	724	2,622	19·10	22·25	11·13	30·23
Region II—Sheikhupura and Upper Gugera Divisions.	993,652	2,773	1,276	680	1,956	17·10	14·52	7·26	24·36
Region III—Hafizabad Division ..	436,011	1,236	569	668	1,237	24·64	18·75	9·38	34·02
Region IV—Lower Gugera, Burala Lyallpur and Jhang Divisions ..	1,864,967	6,286	2,890	536	3,426	15·96	10·27	5·14	21·10

Column 2.—Figures have been taken from 1933-34 Statistics for working of Distributaries, etc.

Column 3.—Figures have been taken from 1933-34 Statistics for working of Distributaries, etc.

Column 4.—*Vide* pages 372 and 350 of Buckley's Pocket-book the losses due to evaporation and absorption as a percentage of discharge at head of canal are :—

(1) For Distributaries 6 % (2) For watercourses 21 % and (3) For fields 25%. Assuming the discharge at distributary heads to be 80 per cent. of the discharge at canal head and the evaporation losses as (1) 10% for Distributaries (2) 10% for watercourses and (3) 50 % for fields of total losses due to absorption and evaporation, the total losses due to absorption alone come to 46 % of the water utilized at the distributary heads.

Column 5.—The absorption losses in Main Canal and Branches have been taken at 8 cusecs (less 10% for evaporation) per million square ft. of wetted perimeter of average canal sections. The actual discharges for this purpose were obtained by multiplying the authorized full supply discharge with mean capacity factors actually obtaining on the various canals during the last 10 years.

Column 7. $= \frac{\text{Col. } 5 \times 36.5 \times 24 \times 60 \times 60}{\text{Col. } 2 \times 43560} \times 12.$

Column 8.—Average of the mean rainfall of all rain-gauging stations in the area was taken as given in the 1933-34 Statistics for working of Distributaries, etc.

UPPER CHENAB CANAL

PLAN SHOWING PROPOSED IRRIGATION ZONES IN YEAR 1910

SCALE 1=8 MILES

PLAN No I

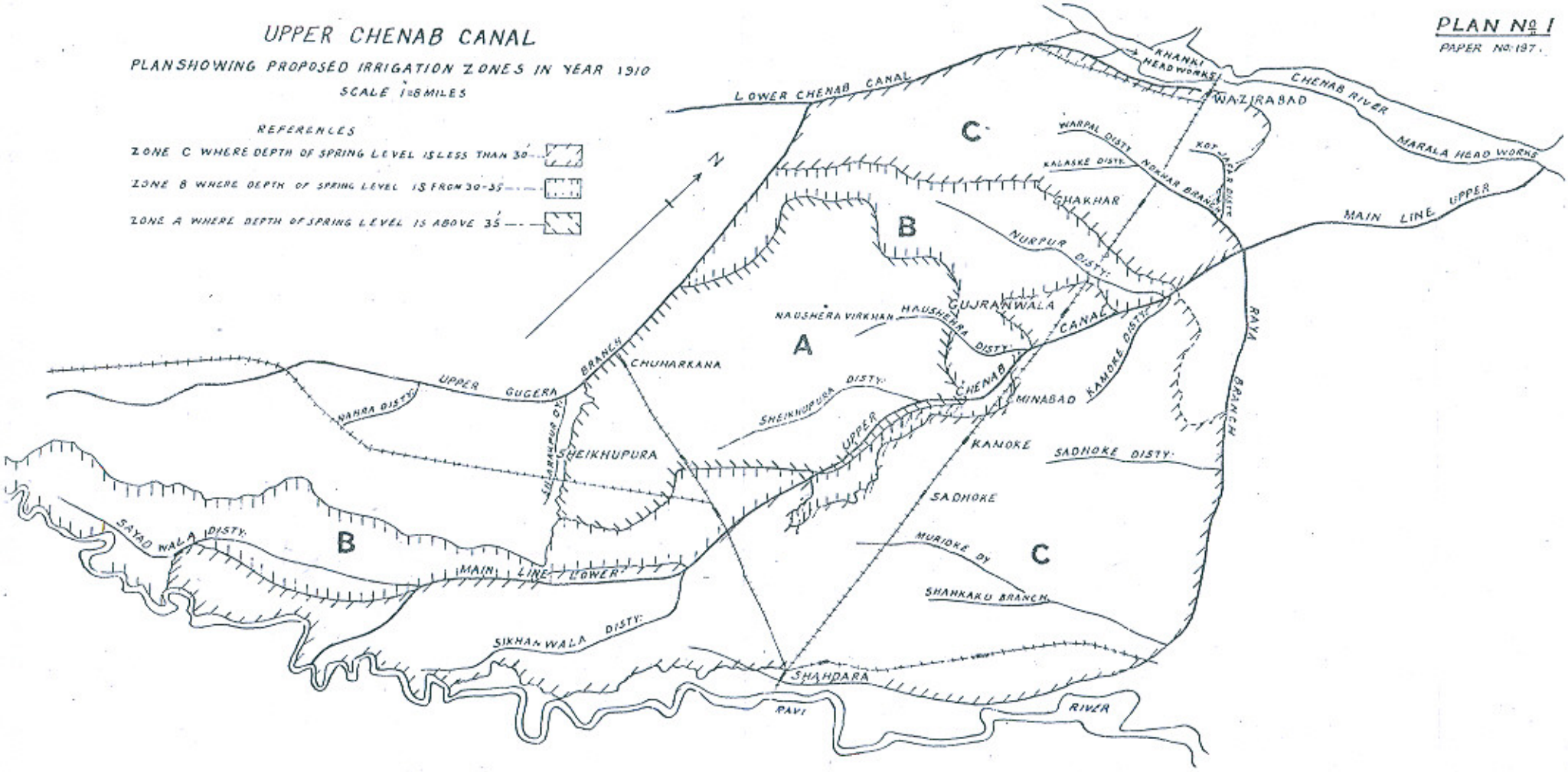
PAPER No: 197.

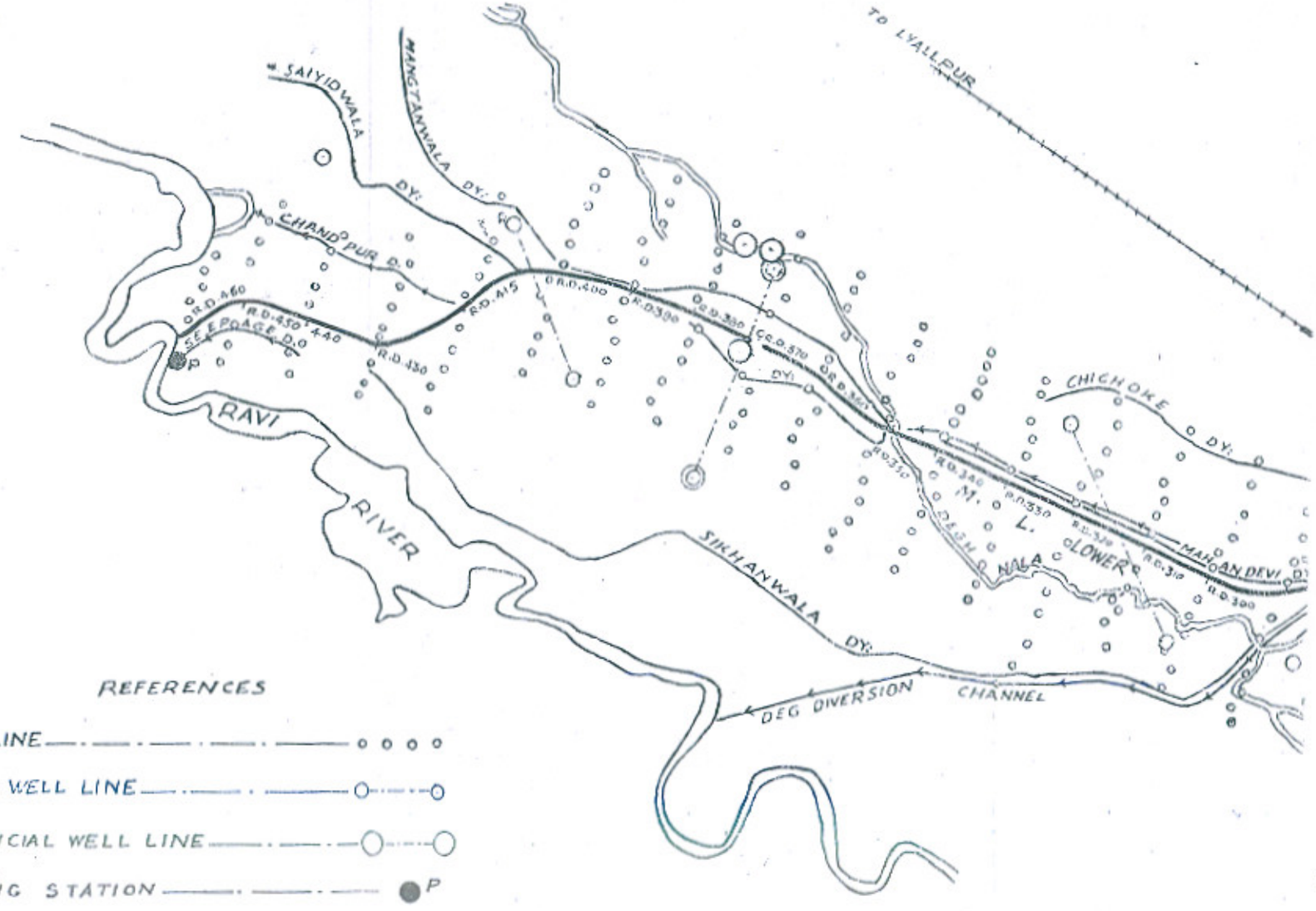
REFERENCES

ZONE C WHERE DEPTH OF SPRING LEVEL IS LESS THAN 30'

ZONE B WHERE DEPTH OF SPRING LEVEL IS FROM 30-35'

ZONE A WHERE DEPTH OF SPRING LEVEL IS ABOVE 35'




TO LYALLPUR
SAIYIDWALA DY.
MANGTANWALA DY.
CHANDPUR D.
R.D.460
R.D.450
440
SEEPAGE D.O
R.D.430
R.D.415
R.D.400
R.D.390
R.D.380
R.D.370
R.D.360
DY.
RAVI
RIVER
CHICHOKE DY.
R.D.340
R.D.330
M. L.
LOWER
NALA
MAHOAN DEVI
R.D.320
R.D.310
R.D.300
SIKHANWALA DY.
DEG DIVERSION CHANNEL
REFERENCES
PIPE LINE
CIRCLE WELL LINE
PROVINCIAL WELL LINE
PUMPING STATION
P

UPPER CHENAB CANAL

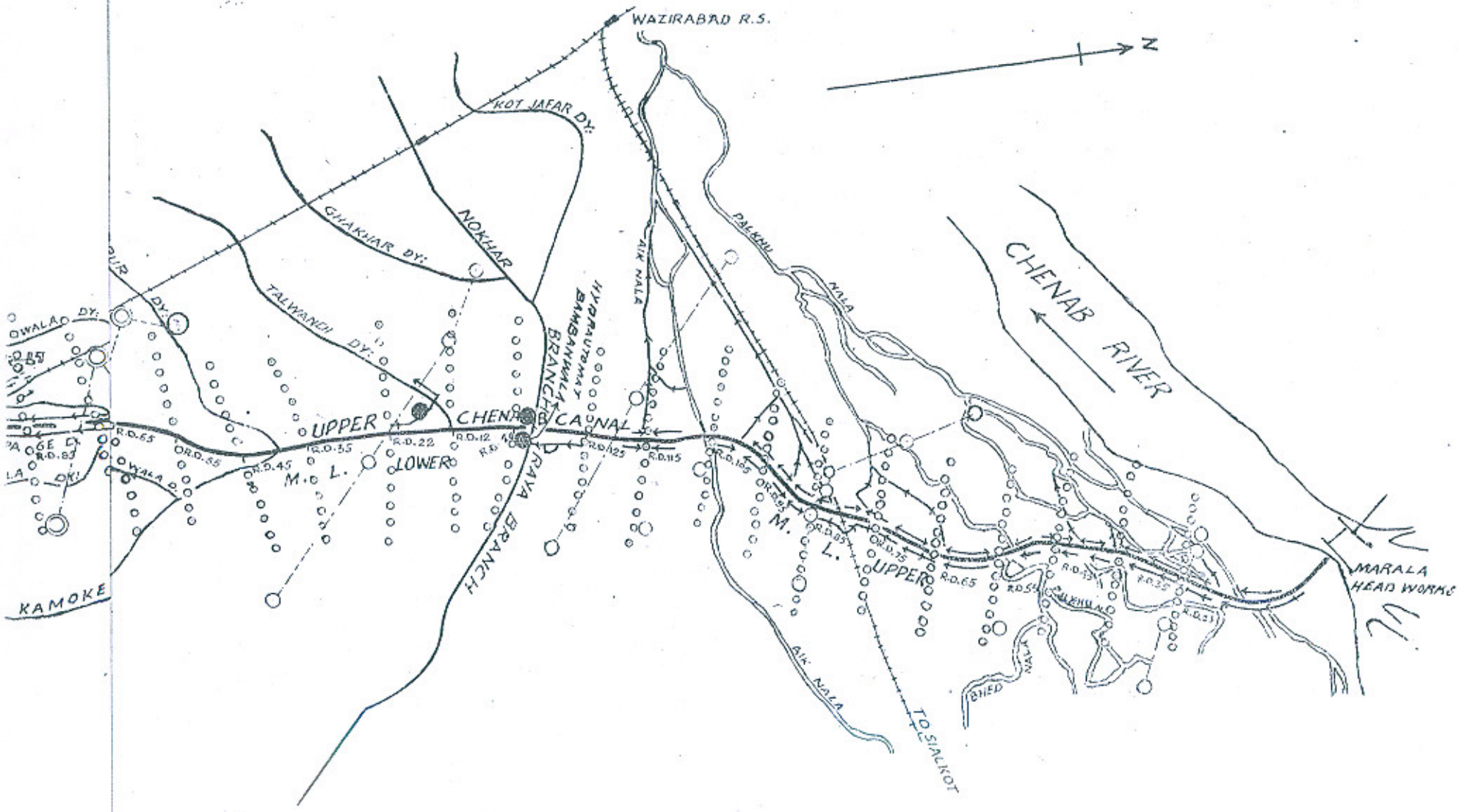
INDEX PLAN SHOWING PIPE LINES.

SCALE 1" = 4 MILES.



PLAN No. 2.

PAPER NO: 197



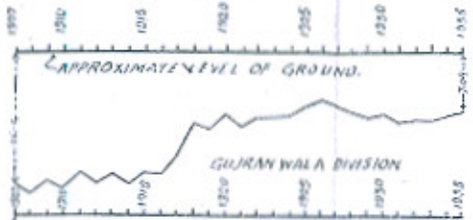
UPPER CHENAB CANAL

PLAN No. 3.
PAPER No. 157.

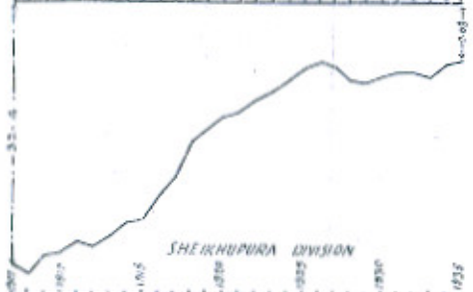
GRAPHS SHOWING APPROXIMATE AVERAGE DEPTH OF WATER TABLE IN VARIOUS TRACTS OF THE CANAL.

TRACT I WITH IN 3 MILES ON EACH SIDE OF MAIN CANAL

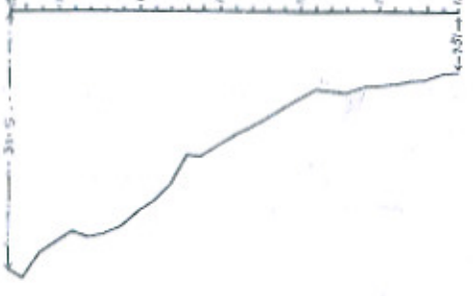
MARALA DIVISION



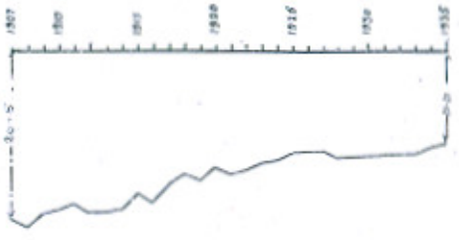
GUJRANWALA DIVISION



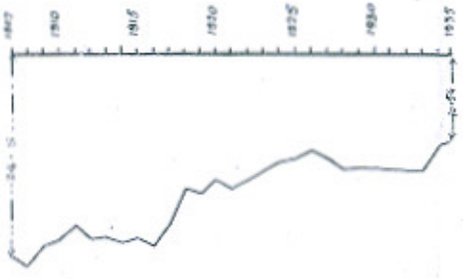
SHEIKHUPURA DIVISION



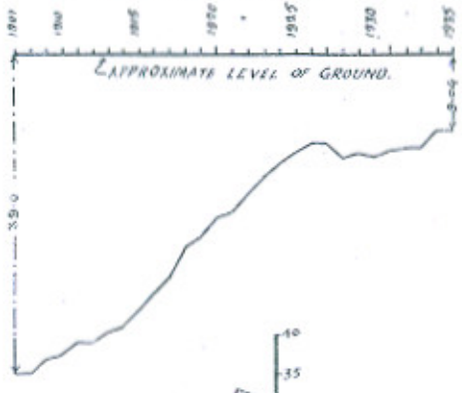
TRACT II BETWEEN RAYA BRANCH & MAIN CANAL

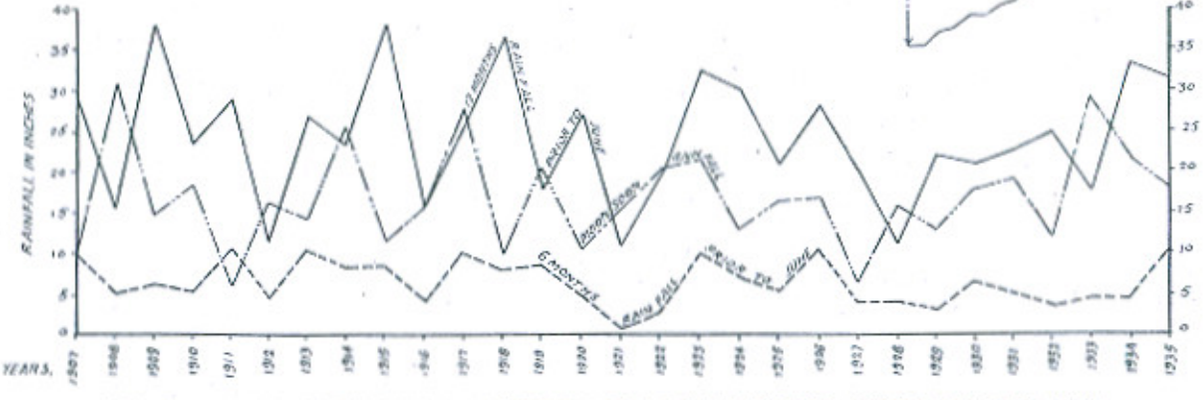


NOKHAR BRANCH TRACT III



TRACT IV ON RIGHT SIDE OF MAIN CANAL (EXCLUDING NOKHAR BRANCH)



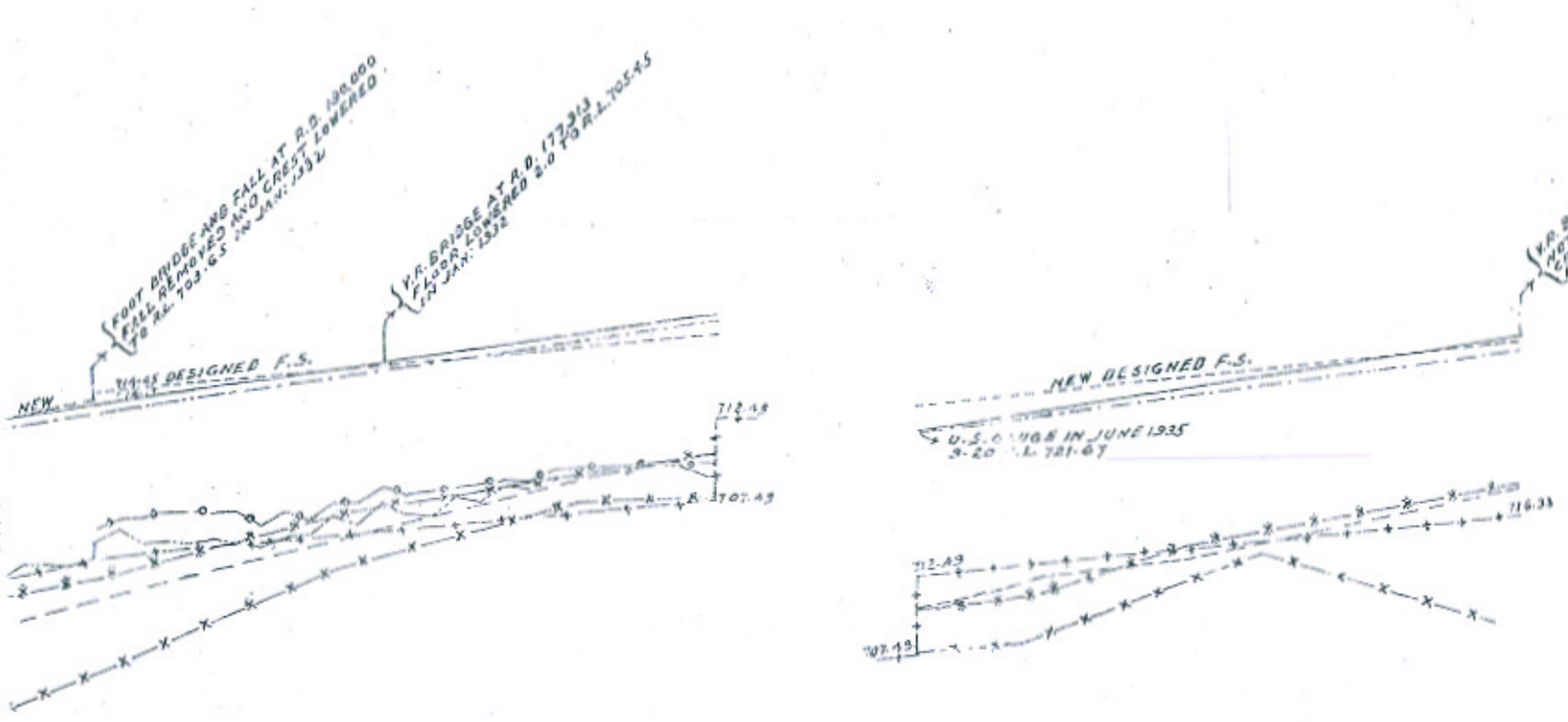


RAINFALL GRAPH OF GUJRANWALA STATION FOR 6 & 12 MONTHS PERIOD PRIOR TO JUNE ALSO MONSOON RAINFALL FROM 1907 TO 1935.

DINAL SECTION OF MAIN LINE LOWER, UPPER CHENAB CANAL, FROM R.D. 0 TO R.D 2,84,215

SHOWING BED & W.S. DURING THE YEAR 1927-1935

SCALE { VER:= 1/100'
NOR:= 1" 1 MILE

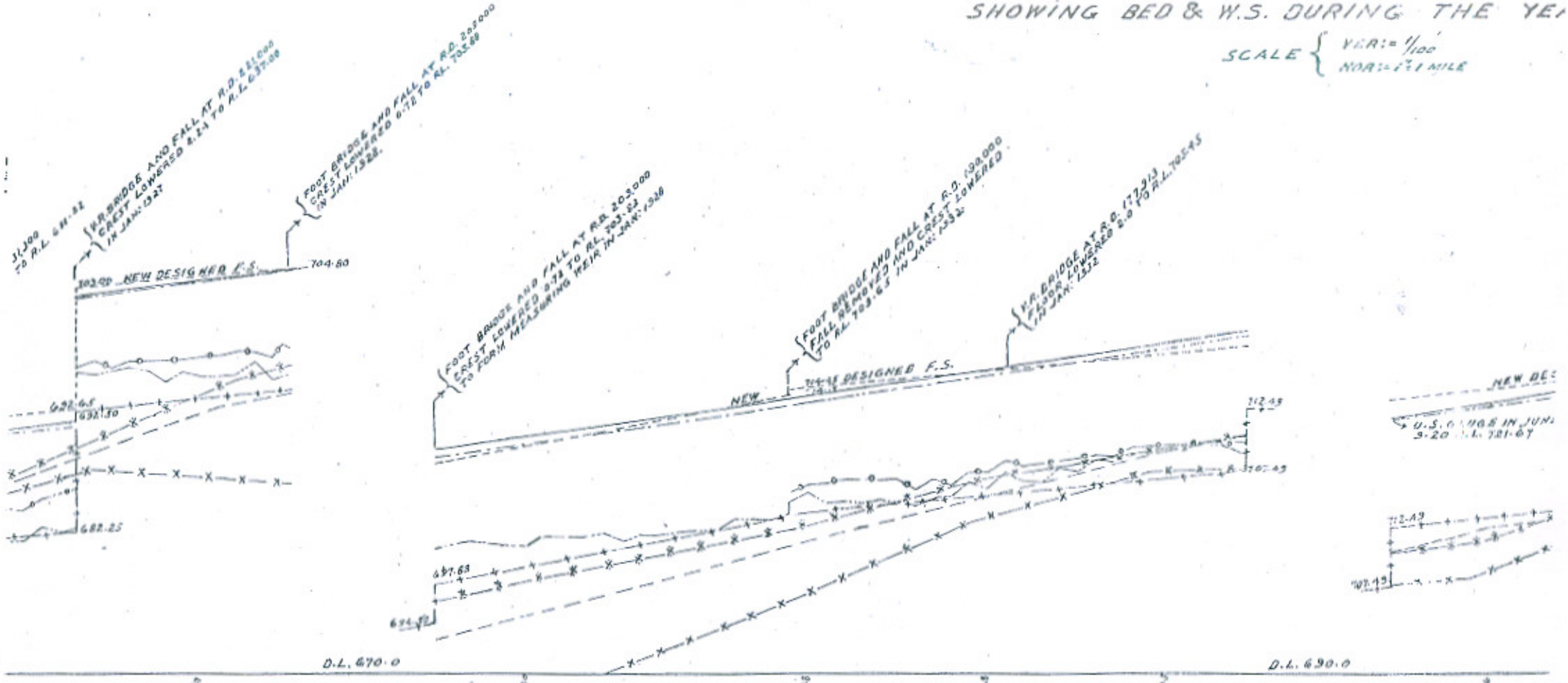


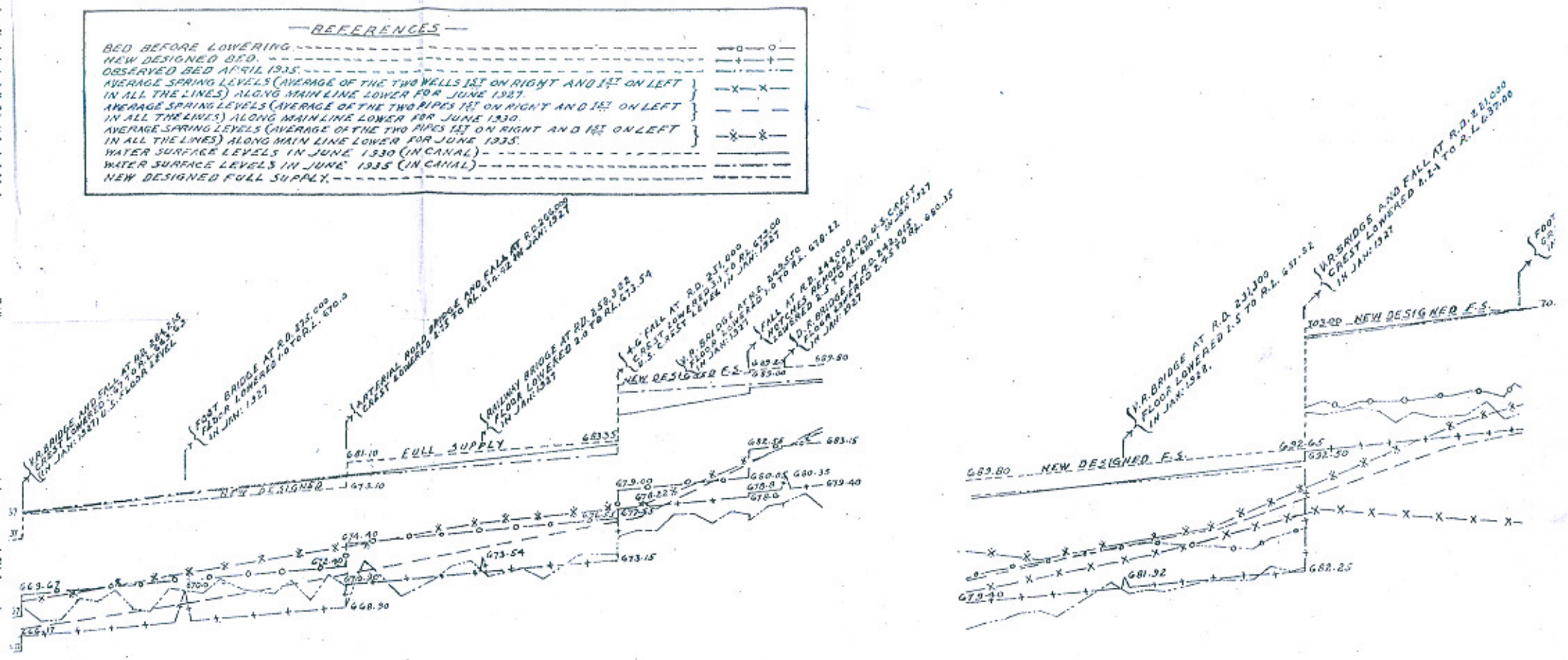
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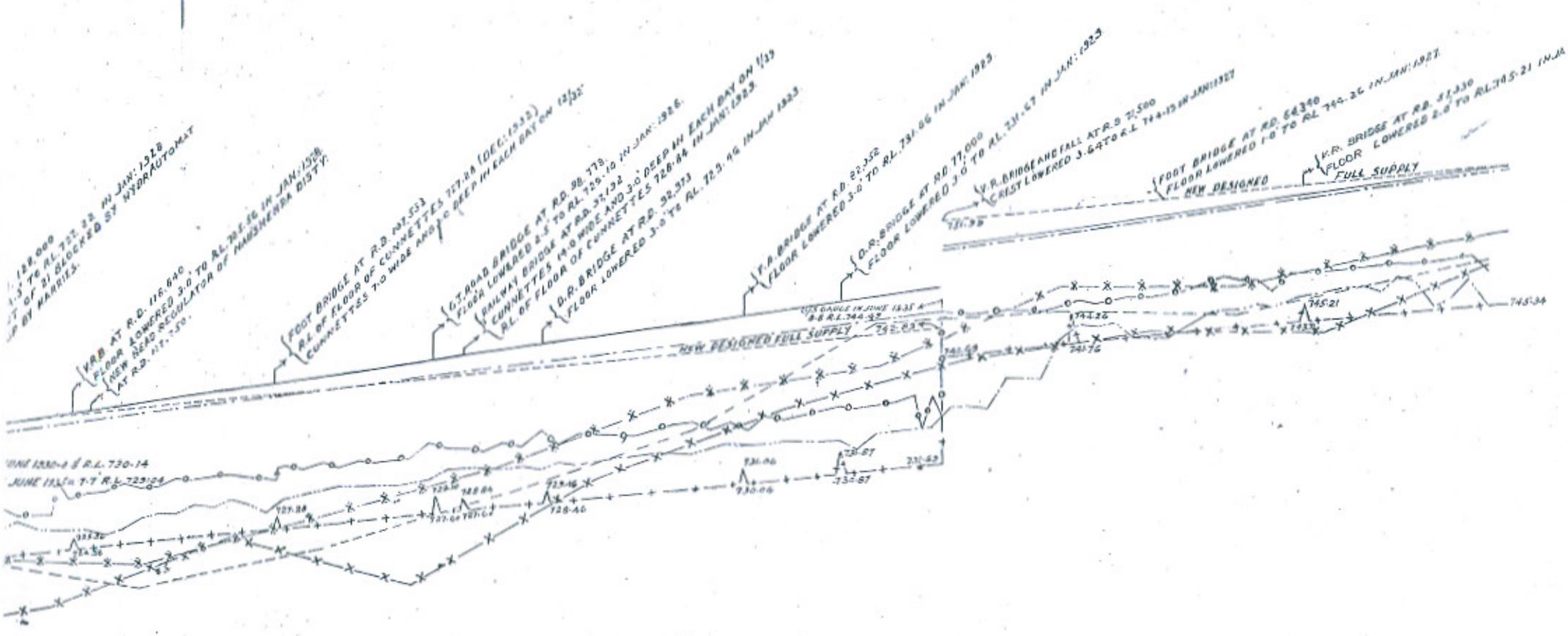
LONGITUDINAL SECTION OF MAIN LINE LOWER, UPPER CA

SHOWING BED & W.S. DURING THE YE

SCALE { VER:= 1/100
HOR:= 1 MILE

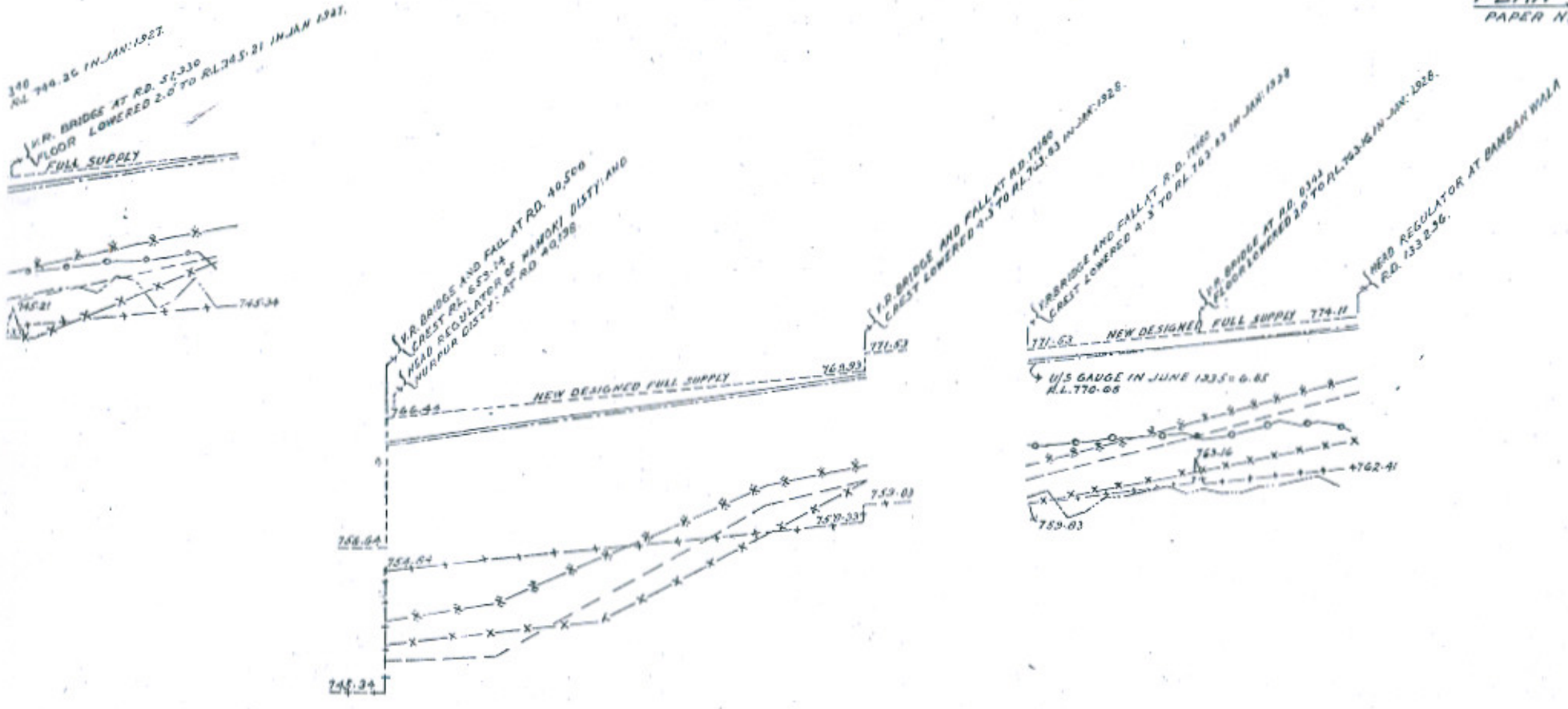



REFERENCES
BED BEFORE LOWERING
NEW DESIGNED BED.
OBSERVED BED APRIL 1935.
AVERAGE SPRING LEVELS (AVERAGE OF THE TWO WELLS 1ST ON RIGHT AND 1ST ON LEFT IN ALL THE LINES) ALONG MAIN LINE LOWER FOR JUNE 1927.
AVERAGE SPRING LEVELS (AVERAGE OF THE TWO PIPES 1ST ON RIGHT AND 1ST ON LEFT IN ALL THE LINES) ALONG MAIN LINE LOWER FOR JUNE 1930.
AVERAGE SPRING LEVELS (AVERAGE OF THE TWO PIPES 1ST ON RIGHT AND 1ST ON LEFT IN ALL THE LINES) ALONG MAIN LINE LOWER FOR JUNE 1935.
WATER SURFACE LEVELS IN JUNE 1930 (IN CANAL)
WATER SURFACE LEVELS IN JUNE 1935 (IN CANAL)
NEW DESIGNED FULL SUPPLY.
V.R. BRIDGE AND FALL AT R.D. 231,000 CREST LOWERED 2.5 TO R.L. 671.92 IN JAN: 1927 U.S. FLOOR LEVEL 673.42
FOOT BRIDGE AT R.D. 235,000 FLOOR LOWERED 1.0 TO R.L. 670.3 IN JAN: 1927
ARTERIAL ROAD BRIDGE AND FALL AT R.D. 236,000 CREST LOWERED 2.5 TO R.L. 671.92 IN JAN: 1927
RAILWAY BRIDGE AT R.D. 238,322 FLOOR LOWERED 2.0 TO R.L. 673.54 IN JAN: 1927
A.C. FALL AT R.D. 241,000 CREST LOWERED 2.5 TO R.L. 673.54 U.S. CREST LEVEL IN JAN: 1927
V.R. BRIDGE AT R.D. 242,500 FLOOR LOWERED 2.5 TO R.L. 673.00 IN JAN: 1927
FALL AT R.D. 244,000 HATCHES REMOVED AND U.S. CREST LOWERED 2.5 TO R.L. 670.1 IN JAN: 1927
D.R. BRIDGE AT R.D. 245,015 FLOOR LOWERED 2.5 TO R.L. 680.35 IN JAN: 1927
NEW DESIGNED F.S.
FULL SUPPLY
NEW DESIGNED F.S.
V.R. BRIDGE AT R.D. 231,000 FLOOR LOWERED 2.5 TO R.L. 671.92 IN JAN: 1928.
V.R. BRIDGE AND FALL AT R.D. 231,000 CREST LOWERED 2.5 TO R.L. 671.00 IN JAN: 1927
NEW DESIGNED F.S.
D.L. 660.0
OLD DESIGNED BED BEFORE LOWERING


V.R.B AT R.D. 116.640
FLOOR LOWERED 3.0 TO RL. 728.56 IN JAN: 1928
NEW HEAD REGULATOR OF HARISHENDRA DISTY.
AT R.D. 117.350.
FOOT BRIDGE AT R.D. 98.533
R.L OF FLOOR OF CUNNETTES 727.88 (DEC: 1933)
CUNNETTES 7.0 WIDE AND 3.0 DEEP IN EACH BAY ON 1/32
G.T. ROAD BRIDGE AT RD. 98.779
FLOOR LOWERED 2.5 TO RL. 729.10 IN JAN: 1936.
RAILWAY BRIDGE AT RD. 97.132
CUNNETTES 14.0 WIDE AND 3.0 DEEP IN EACH BAY ON 1/32
R.L OF FLOOR OF CUNNETTES 728.84 IN JAN: 1923
D.R. BRIDGE AT RD. 92.313
FLOOR LOWERED 3.0 TO RL. 725.46 IN JAN 1923
V.R. BRIDGE AT R.D. 82.356
FLOOR LOWERED 3.0 TO RL. 731.96 IN JAN: 1923
D.R. BRIDGE AT RD 77.000
FLOOR LOWERED 3.0 TO RL. 734.67 IN JAN: 1923
V.R. BRIDGE AND FALL AT R.D 71.500
CREST LOWERED 3.64 TO R.L 744.13 IN JAN: 1927
FOOT BRIDGE AT RD. 64.340
FLOOR LOWERED 1.0 TO RL 745.36 IN JAN: 1927
V.R. BRIDGE AT RD. 51.330
FLOOR LOWERED 2.0 TO RL 745.21 IN JA
NEW DESIGNED
FULL SUPPLY
NEW DESIGNED FULL SUPPLY
U/S GAUGE IN JUNE 1935 =
B.B R.L 744.45
JUNE 1930 = 8' R.L. 730.14
JUNE 1935 = 7.7 R.L. 729.24
744.26
745.21
745.84
741.69
741.76
731.66
730.66
731.67
731.43
728.46
727.84
727.64
727.62
729.46
728.84
724.36
723.36
O.L. 71
BED LE
BEFORE

PLAN No 4

PAPER No 197



| | | |

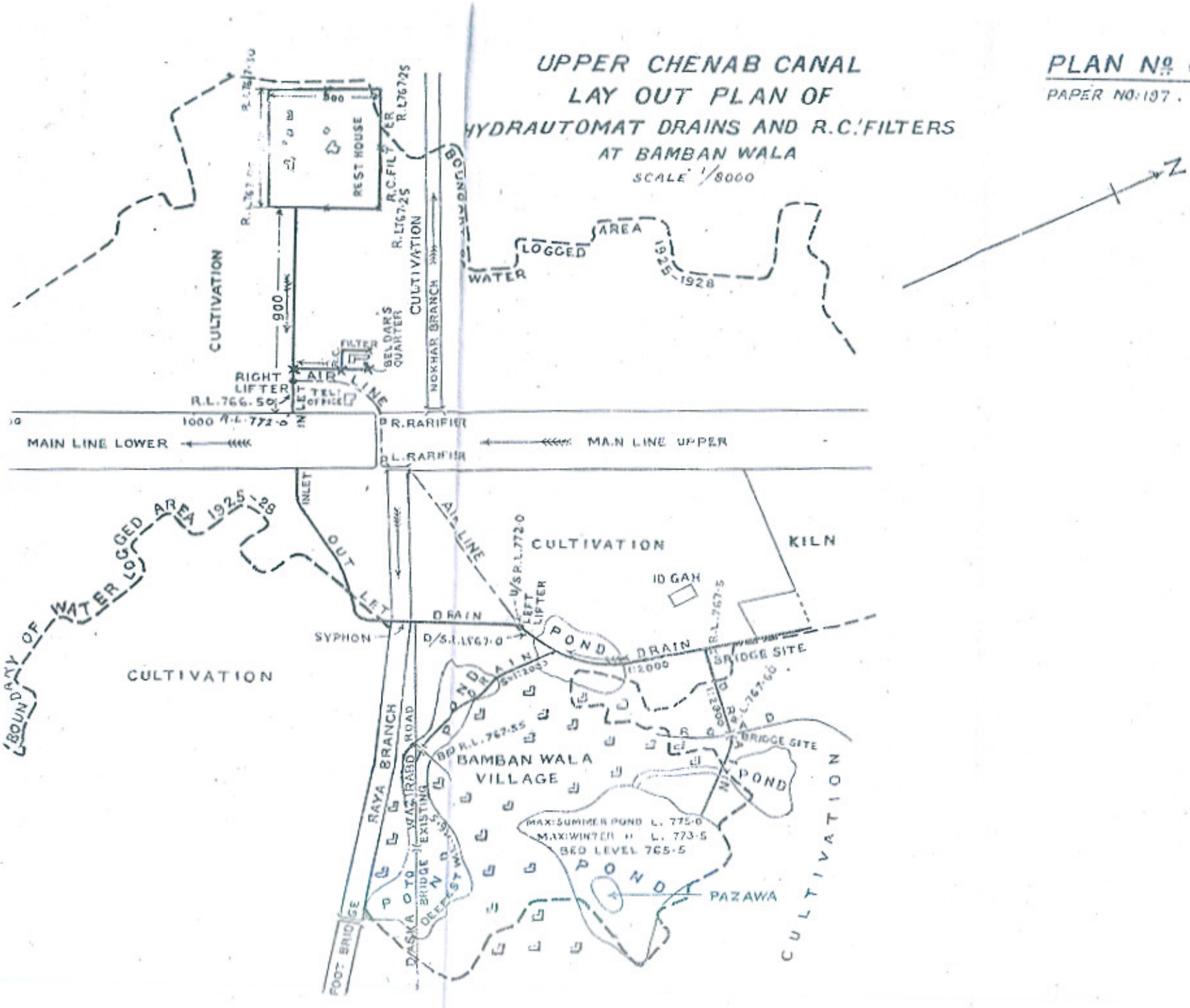
PLAN No. 5 NOT PRINTED.

UPPER CHENAB CANAL
LAY OUT PLAN OF
HYDRAUTOMAT DRAINS AND R.C. FILTERS
AT BAMBAN WALA

SCALE 1/8000

PLAN No. 6

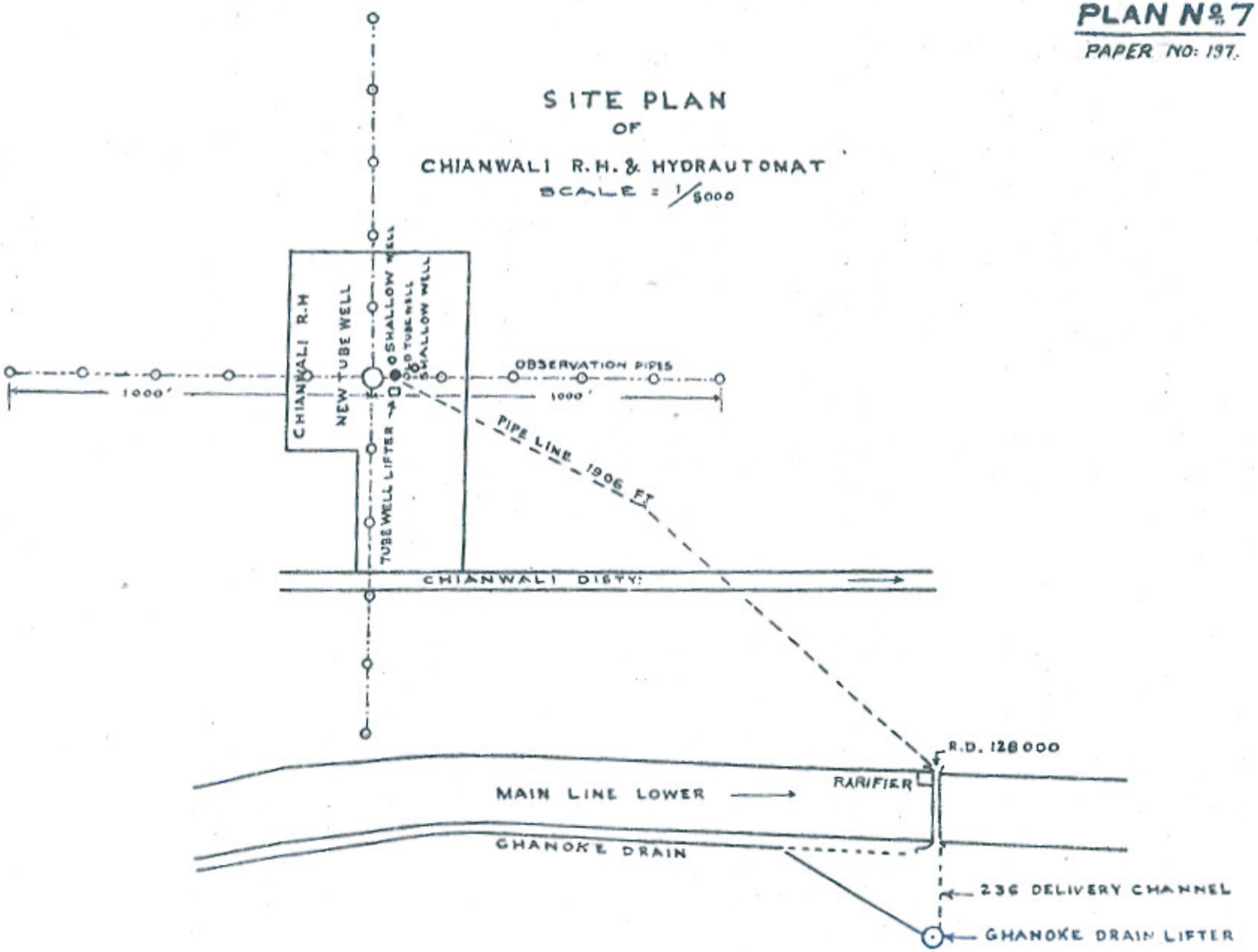
PAPER NO. 197.



PLAN No. 7

PAPER NO: 197.

SITE PLAN
OF
CHIANWALI R.H. & HYDRAUTOMAT
SCALE = 1/5000



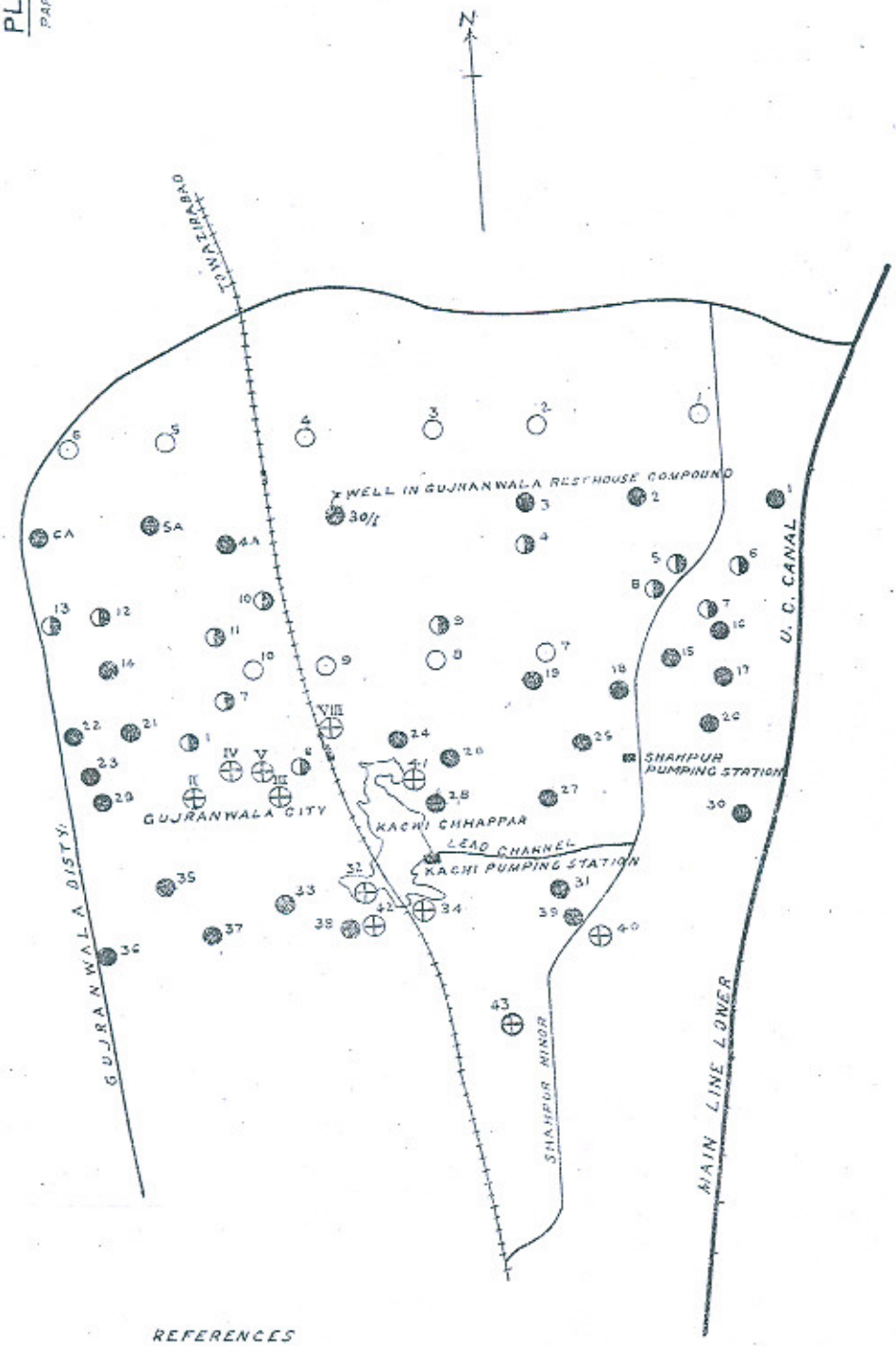
PLAN No. B

PAPER NO: 197.

PLAN OF GUJRANWALA CITY

SHOWING KACHI CHHAPPAR & WELLS & PIPES UNDER OBSERVATION

SCALE 2" = 1 MILE



REFERENCES

MONTHLY OBSERVATION OF WELLS ---

DAILY OBSERVATION OF WELLS -----

NOT OBSERVED ----------

PIPES ----------

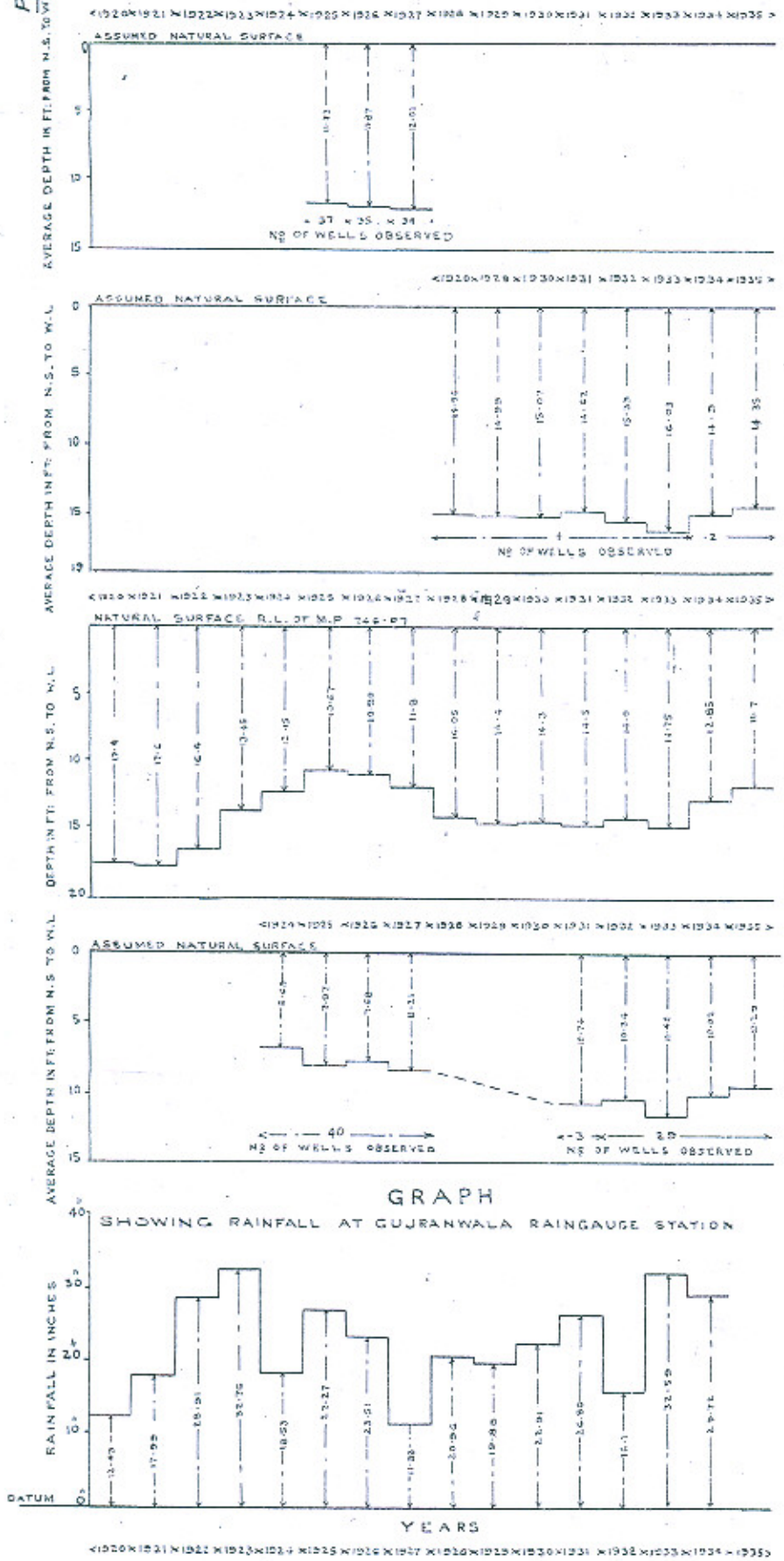
PUMPING STATION ----------

PLAN No 9

GRAPHS

SHOWING AVERAGE DEPTH TO SPRING LEVEL OF VARIOUS GROUPS OF WELLS AT GUJRANWALA

YEARS [JUNE]



GRAPH

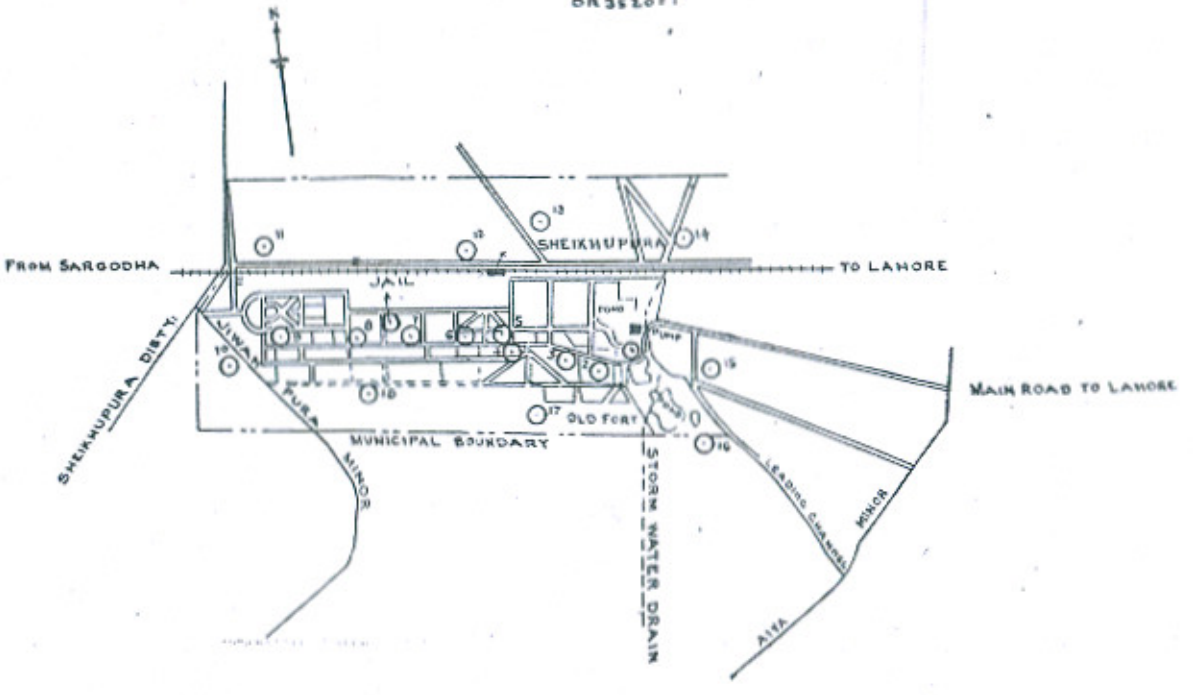
SHOWING RAINFALL AT GUJRANWALA RAINGAUGE STATION

PLAN No. 10

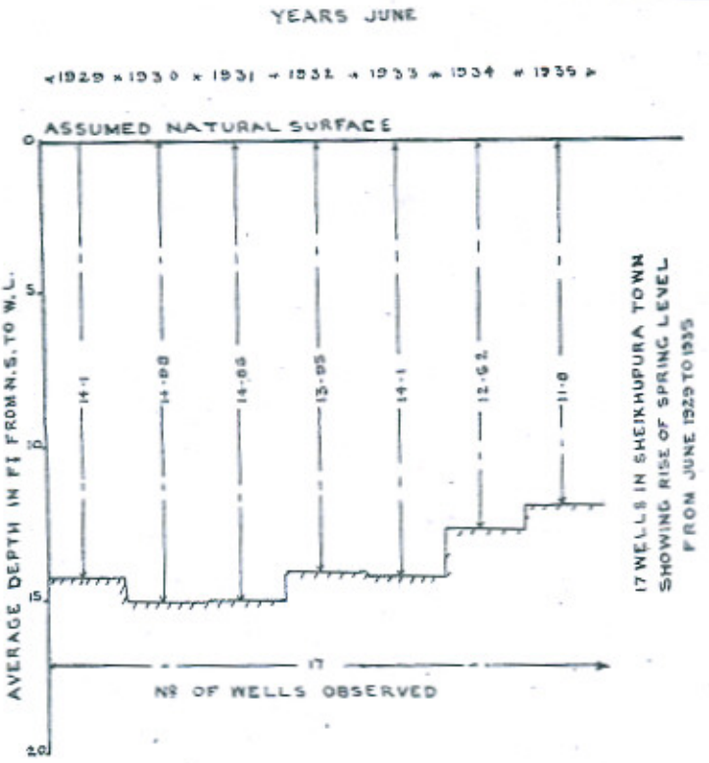
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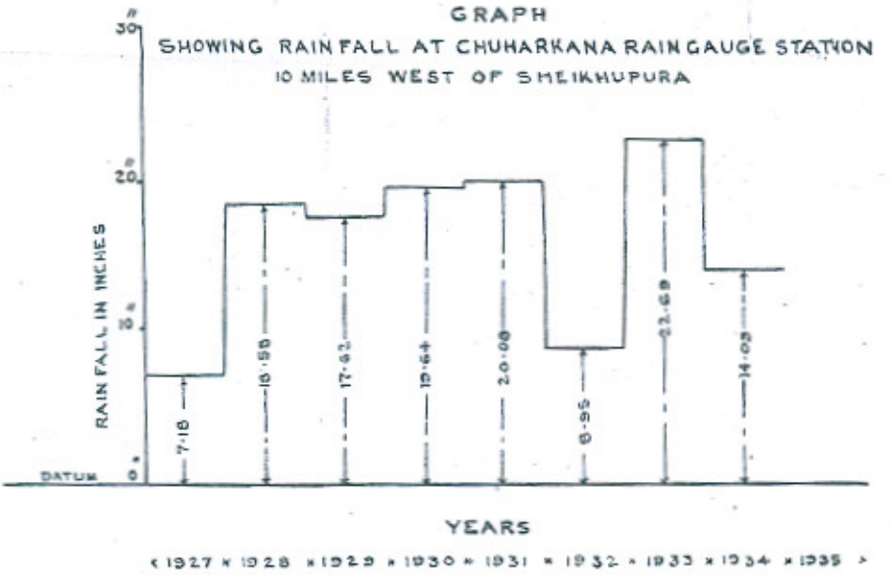
SITE PLAN
OF
SHEIKHUPURA TOWN
AND WELLS UNDER OBSERVATION

SCALE 0·79 MILE = 1"
OR 3520 = 1



PLAN I
PAPER NO.





DIFFERENCE MAP UPPER CHENAB CANAL

JUNE 1911 – 1935

SCALE 1" = 8 MILES

PLAN No. 12

PAPER NO: 187.

REFERENCES

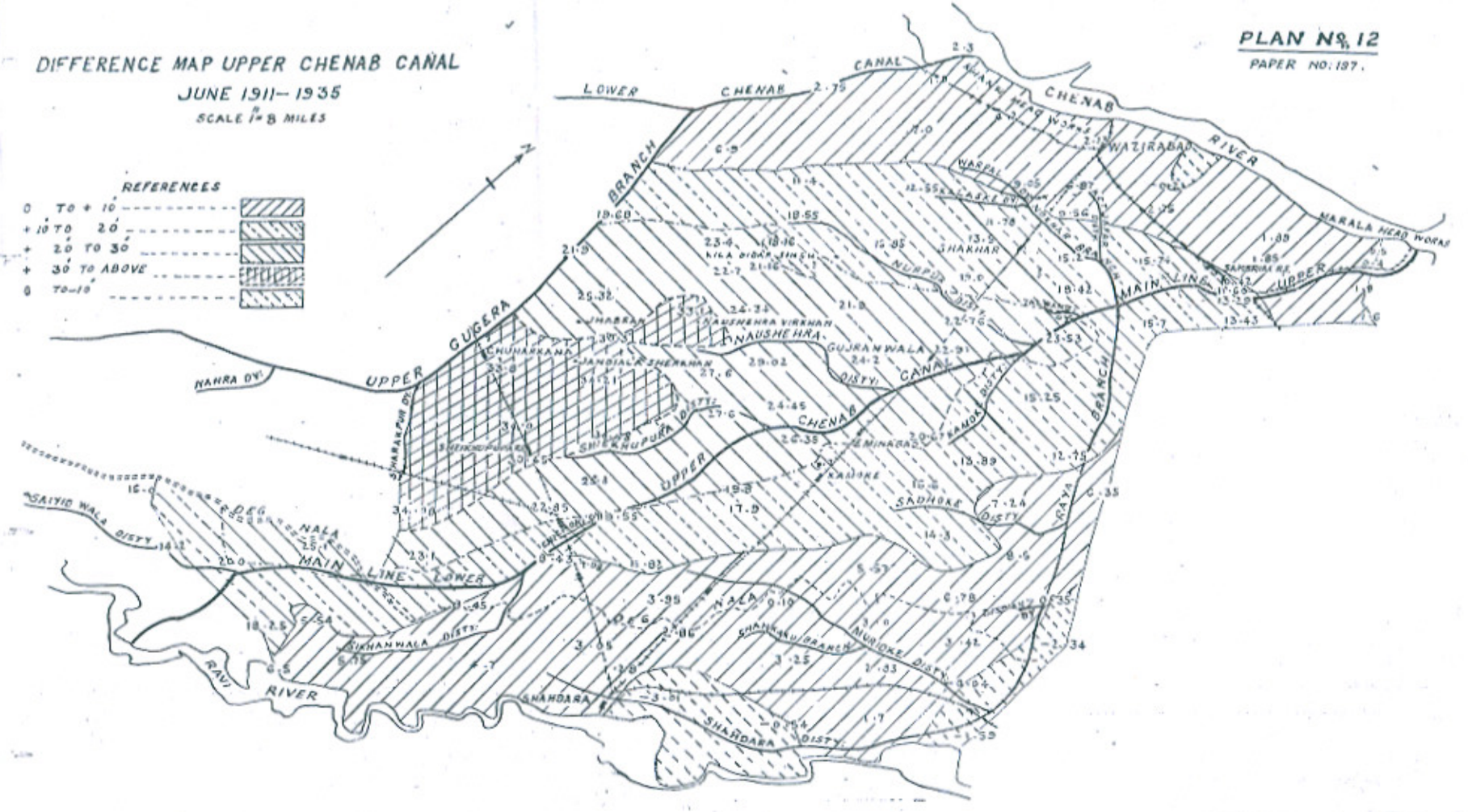
0 TO + 10'

+ 10' TO 20'

+ 20' TO 30'

+ 30' TO ABOVE

0 TO -10'



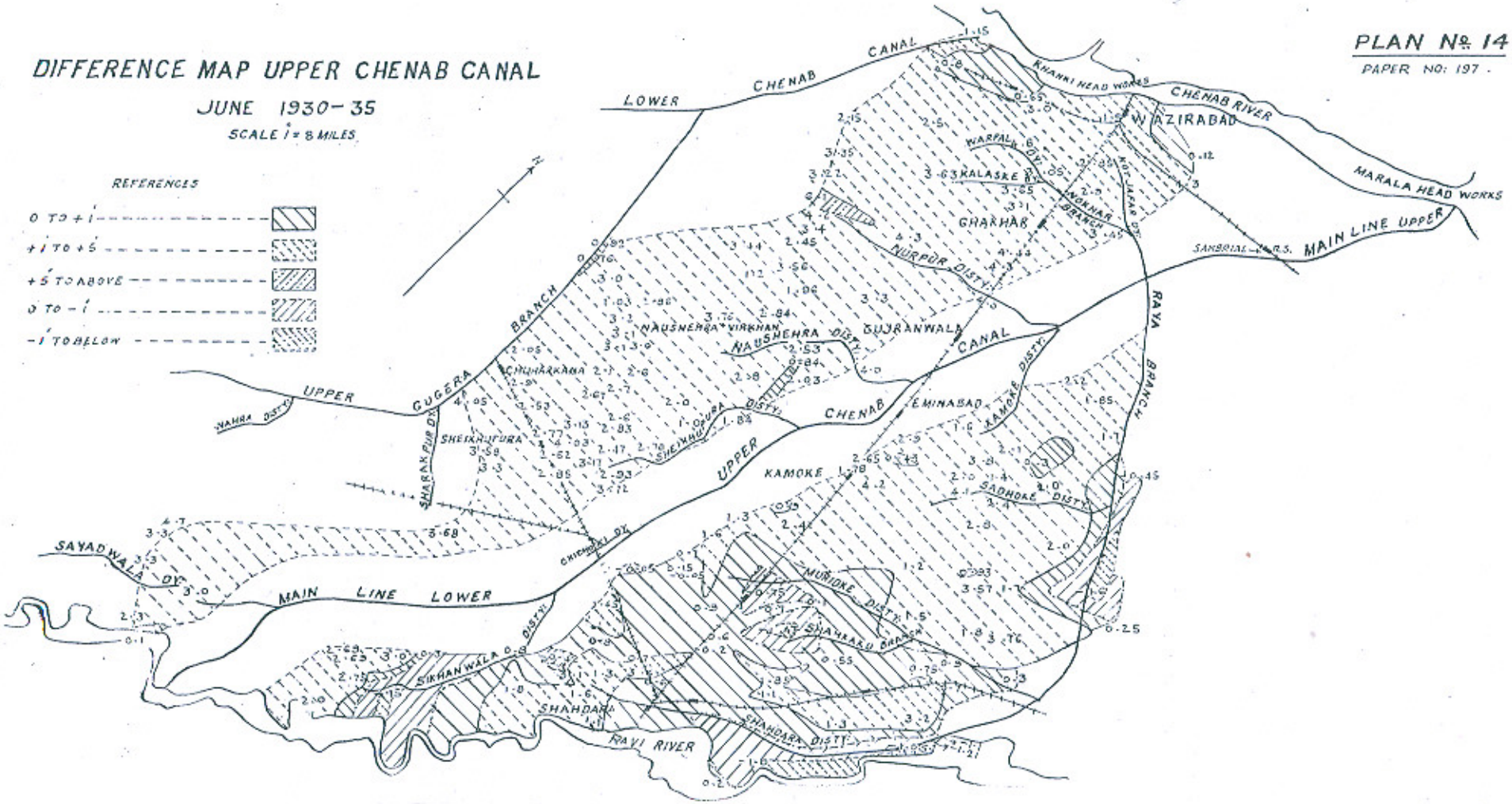
DIFFERENCE MAP UPPER CHENAB CANAL

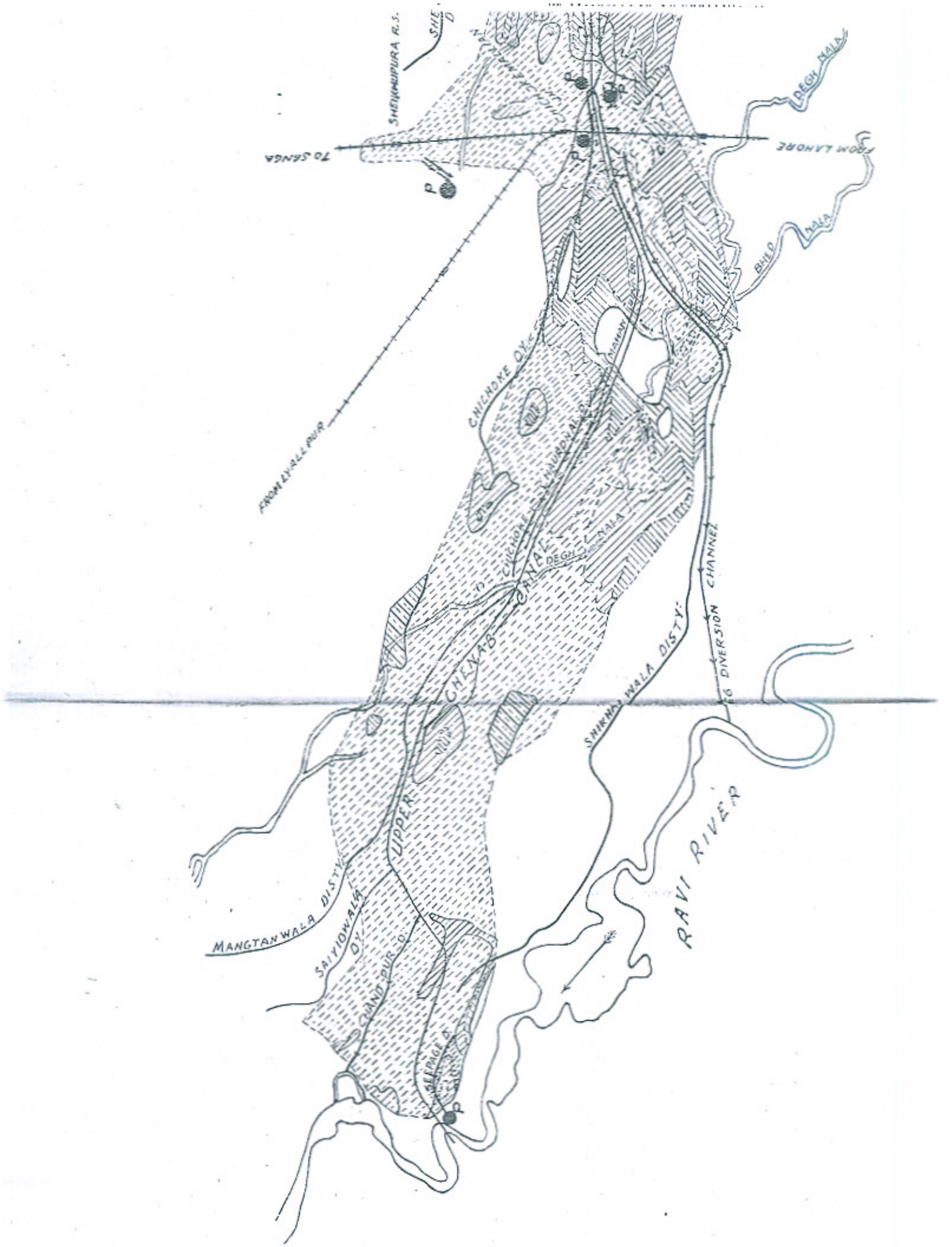
JUNE 1930–35

SCALE 1" = 8 MILES

PLAN No. 14

PAPER NO: 197.



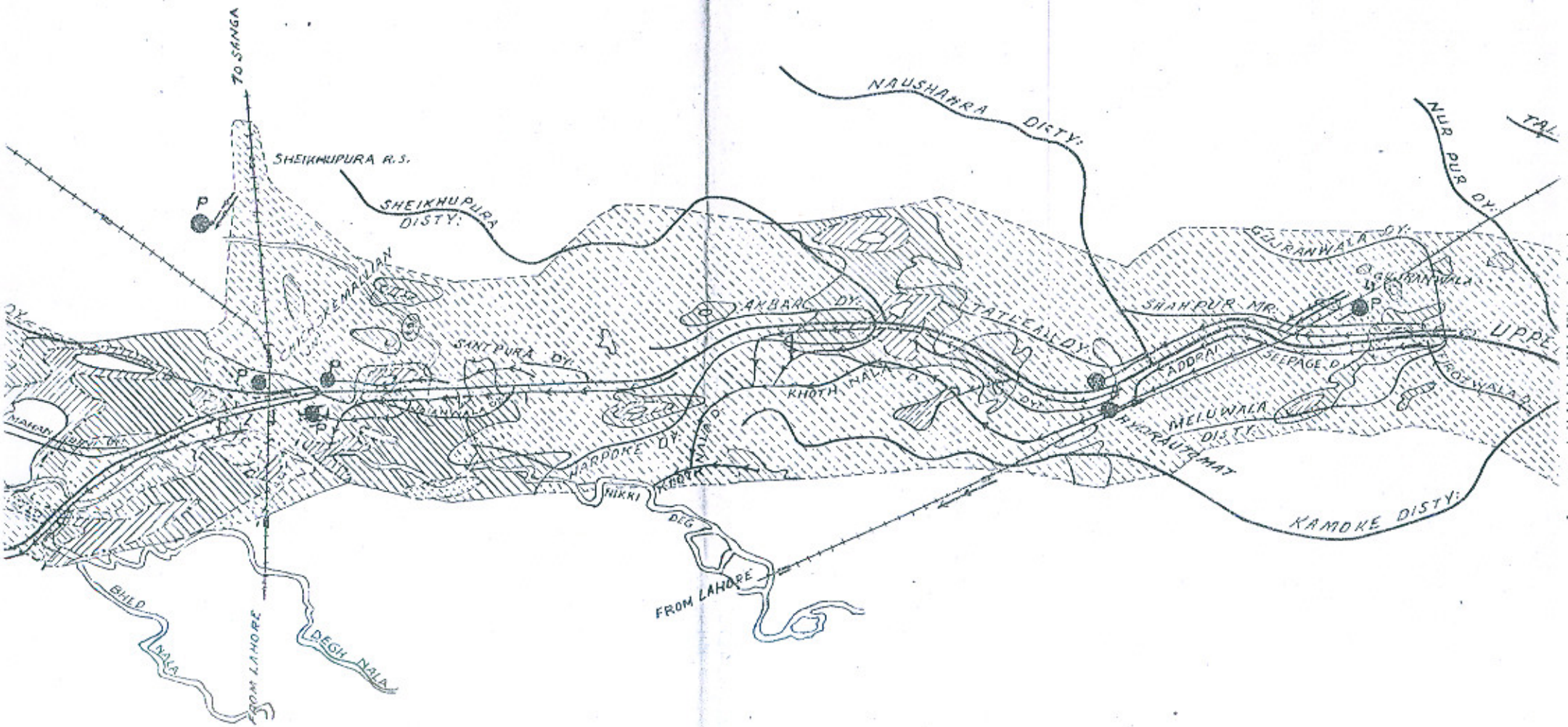

SHEIKHUPURA R.S.
TO SANGA
FROM LYALLPUR
DEGH NALA
FROM LAHORE
BHEDA NALA
CHICHOKE DY.
THURDWALA
CHICHOKE DEGH NALA
UPPER CHENAB CANAL
SHIKHUPURA DISTY:
G DIVERSION CHANNEL
MANGTANWALA DISTY:
SAIYIDWALA DY.
CHAND PUR D.
SEEPAGE
RAVI RIVER

UPPER CHENAB CANAL

DIFFERENCE MAP OF AREA ALONG MAIN LINE (3 MILES ON EACH SIDE).

JUNE 1930–35

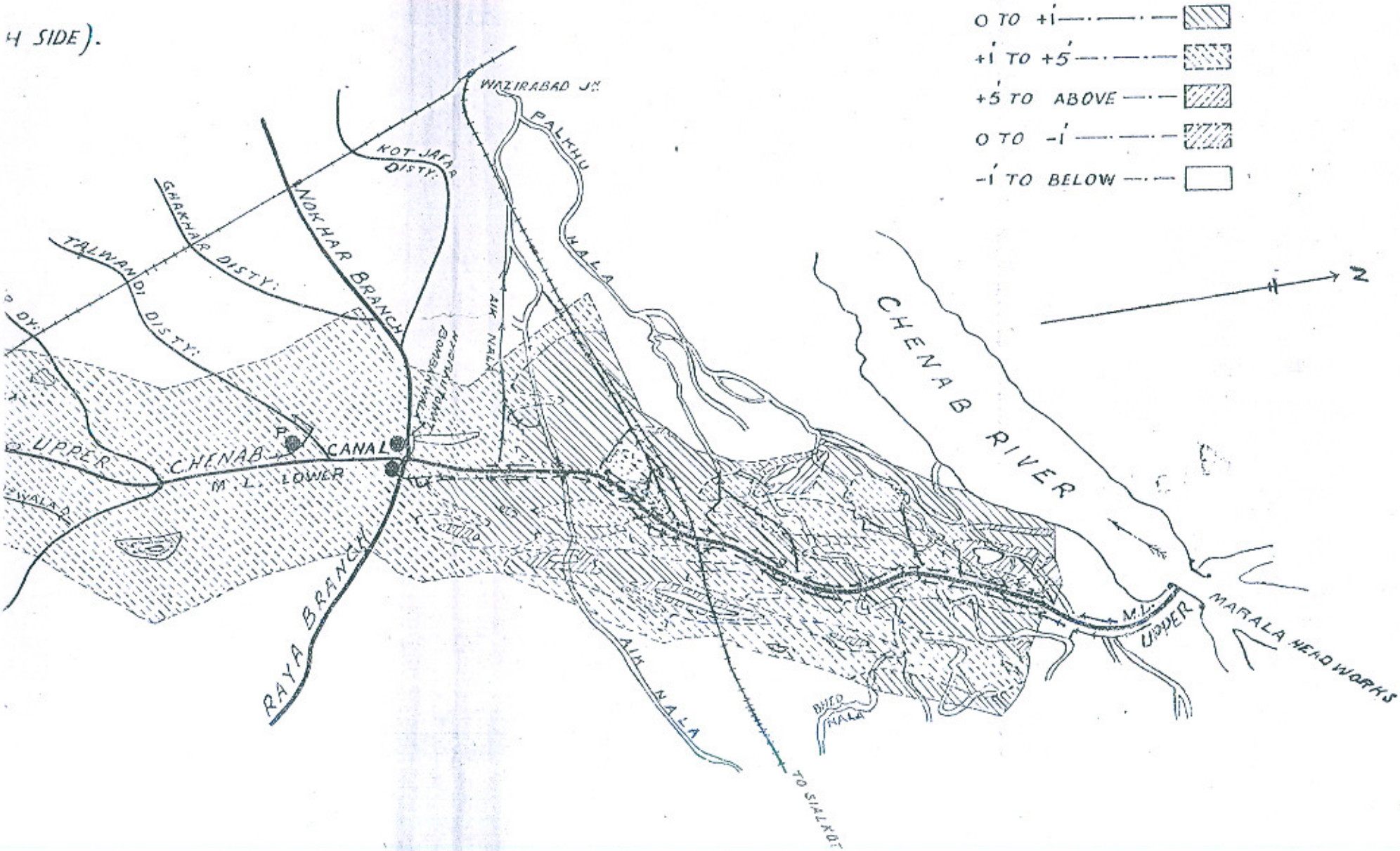
SCALE 1" = 4 MILES.



4 SIDE).

PLAN No. 15

PAPER NO: 197.



PLAN No. 16.

PAPER NO: 197.

INDEX MAP OF PUNJAB

SHOWING PROVINCIAL WELL LINES AND SECTION LINE THROUGH RECHNA DOAB

SCALE 1" = 80 MILES

REFERENCES

EXISTING NORTHERN & PROVINCIAL LINE'S.

NEW PROVINCIAL LINES PROPOSED BY MR: WOODS.

LINE OF LONG SECTION IN RECHNA DOAB

REGIONS OF RECHNA DOAB (I) (II) (III) (IV)

