PAPER No. 124.

THE TREATMENT OF WATERLOGGED OR THREATENED AREAS BY CHANGES IN DISTRIBUTION AND SUPPLY OF IRRIGATION WATER.

By Bernard Howell Wilsdon, M.A., B.Sc. (Oxon.)

This contribution is written in the hope of provoking discussion by those who have intimate knowledge of the manner in which irrigation water is employed by the zemindar under the diverse conditions met within the Province. It is hoped therefore that members of the Agricultural Department may have some opinions to express.

Of the possible methods available for fighting waterlogging the most easily applied and the most flexible is rigid control of the irrigation and agricultural practice. If it can be shown what will be the effects of restrictions of irrigation water at different times of year, and if the required restrictions can be enforced without too greatly interfering with the agricultural regime, we have a weapon which will produce effects much more rapidly than large construction works such as lining or hydro-electric pumping can hope to do. Moreover it seems entirely wrong to attempt to bolster up by artificial means methods of agriculture which are fundamentally wrong and wasteful. Severe operation by the engineer, either with drainage works or otherwise, may ultimately be necessary, but the prospect of such treatment does not absolve us from treating symptoms and looking after the general health of the patient.

It is the usual experience of anyone discussing with the zemindar the question of economy or restriction of irrigation water to be met with a demand for more water and an absolute refusal to consider the possibility of doing with less than the amount to which he has become accustomed. Undoubtedly in many tracts zemindars would be willing to pay greatly enhanced rates if given 50 per cent. more water. Mr. Roberts of Khanewal states that he would gladly pay double the present water rates if given a 50 per cent. increased discharge. The farms of the Agricultural Department itself are not loth to take as much water as they can get. But in waterlogged tracts we can set aside any such arguments. There the water-table is so near the surface that both on account of the capillary draw of the soil and the possibility of working wells, great modifications in the usual agricultural regime are possible. With the conservatism and inertia of our average zemindar such modifications as are advisable are not accepted with alacrity. Only economic pressure seems to disturb established procedure, and this more often than not in the wrong direction. A restriction of *kharif* area and concentration of water on the rice crop is the well-known reaction to waterlogged conditions.

2. After examining briefly the conclusions which the statistical study of the reaction of the water-table to irrigation water and rainfall

forces on us, we shall be in a position to discuss practicable methods of effecting the economies demanded. Some of these results, which I had the privilege of describing at last year's Congress, have now been printed in a memoir.* Subsequent work has confirmed the general nature of the relations brought to light. As a result of my latest investigations it is now possible to state these relationships more generally since the calculations have now been carried out by the analysis of statistics for canals as a whole instead of for single distributaries. In this way it is possible to use as the unit of time a 5-daily mean for the irrigation applied instead of a whole month as used previously. The rainfall distribution and the water-table surface is then calculated from the weighted averages of all rain-gauge stations and observed wells within the canal boundary. Such detailed work means a largely increased amount of computation, but at the same time confers greatly improved accuracy on the results. I give below the results for two canals, which are of greatest concern at the moment on account of waterlogging. These are the Lower Jhelum Canal and the Upper Chenab Canal.

It will be as well to state clearly the significance of the results. In Figs. I and II curves (*a*), show the average water distribution calculated

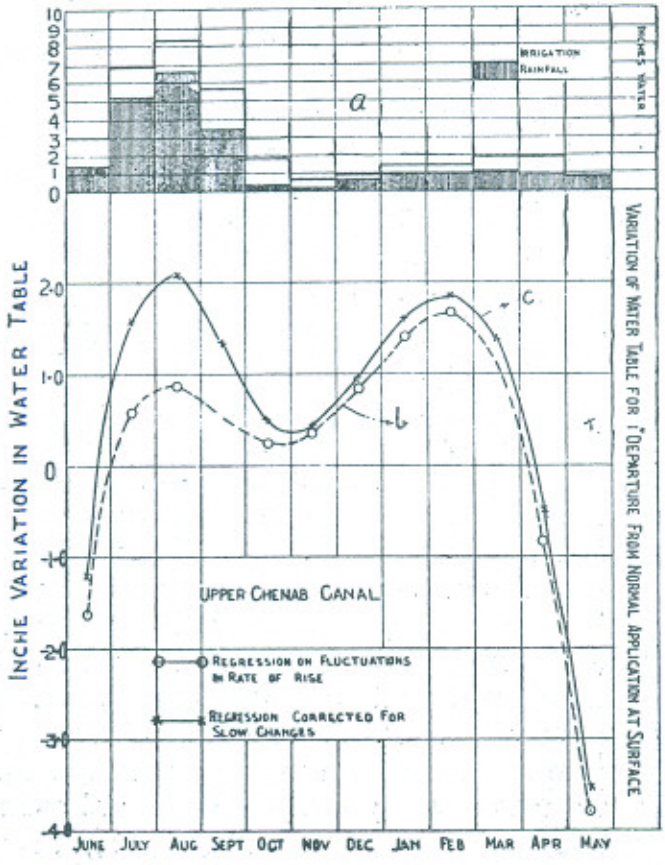


Fig. I.

*Memoirs of the Punjab Irrigation Research Laboratory: Vol. 1, No. 1 (1927). "A statistical examination of the sensitivity of a water-table to rainfall and irrigation."

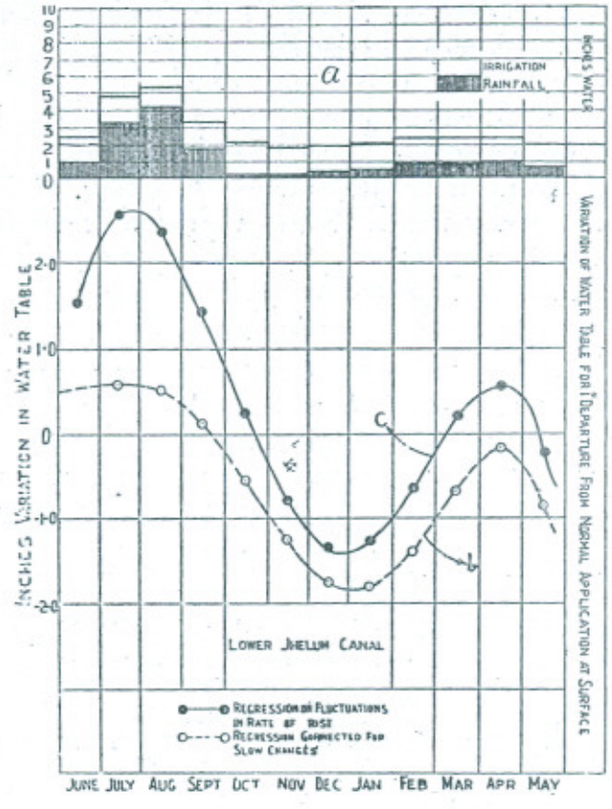


Fig. II.

as inches of water spread on the whole area commanded by the canal for each month of the year. The shaded blocks represent the rainfall and the remainder the irrigation. The irrigation was calculated from the canal-head discharges utilized, assumed to be spread uniformly over the whole area. The rainfall was obtained by averaging and weighting for the areas of which the station is representative every rain-gauge within canal boundary. The water distribution, measured in 5-day periods is then correlated with the area-weighted fluctuations measured in the wells after subtraction of the slow changes, or general trend of the water-table. This gives the curves (*b*) shown dotted, which represent the effect on the water-table of deviations from the normal application of water of one inch occurring in any month. The actual curve of course will give this result for each 5-day period in the year; in the diagram each 5-day period in any month has been averaged. Calculation shows that such a consistency in the observed relations could only be expected by pure chance, once in 370 times for the Upper Chenab Canal and once in 25,000 for the Lower Jhelum Canal. The statistical reliability of the result is much greater in the Lower Jhelum Canal mainly on account of the longer record. In both cases about 60 per cent. of the total variation measured, which will include the errors of measurement, are predictable by the fluctuation of the water applied. There can be no doubt therefore that the results are significant.

3. I may as well emphasize a point here when discussing the reliability of the statistical result. We may accept with blind confidence

the results of the calculations and the statistician would justify such faith. The meteorologist for instance does not attempt to justify physically the extraordinary correlations on which he bases such reasonably successful predictions as monsoon prospects. On the other hand the average man, who usually rather distrusts the statistician, will probably feel more confidence if some rational explanation is forthcoming to account for the conclusions he is asked to accept. I will say at once that it is not at present possible to give a physical explanation of all the results. All I can do is to give an explanation when possible, but I wish it to be clearly understood that our knowledge of all the factors which may contribute to the final result we are studying may be so incomplete that it is really *safer* to trust to the statistical result alone. However we must at some stage adopt a hypothesis on which to base our principles in controlling irrigation, and in view of the urgency of the waterlogging problem the present is not too soon. In what follows I shall attempt to provide explanations, but they are quite likely to be more at fault than the mathematics.

It is to be noted that so far the calculation accounts only for the fluctuations in the average rate of rise. Some proportion of the steady rise must, however be attributed to the water applied on the fields. In order to take it into account the average absorption losses measured in canals and branches have been reduced to a figure corresponding with a rise of so many inches in the soil (actually 5·41 inches in the Upper Chenab Canal and 5·13 inches in the Lower Jhelum Canal). The remaining rise (4·07 inches in the Upper Chenab Canal and 11·43 inches in the Lower Jhelum Canal), has to be distributed between the different months of the year. A rather elaborate calculation which has been performed in only one instance shows that the slow change is probably affected by the time of application of previous years in much the same way as by the annual fluctuations (see Memoir pages 20, 21). Both on this account and on the common-sense standpoint that the percolation will be proportional to the amount added at the surface, the residual slow change has been distributed proportionately to the normal water application in each month. This raises the regression curves as shown in each diagram (Curves C.).

4. In both canals it is clear that water added during the monsoon creates the greatest effect on the water-tables. In the case of the months July, August and September this is easily understood. The intensities of the surface applications are then at their peaks. Moreover the humidity of the atmosphere reduces evaporation to a minimum. This part of the curve will therefore be readily accepted. Even if we neglect the rest this is a sufficiently important result, as it shows a means whereby an actual decrease in the annual percolation to the water-table can be brought about at a time when economy is probably most easy.

The remainder of the curve shows considerable differences in the two cases considered. We get a second maximum in both, but this is much later in the year with the Lower Jhelum Canal than with the Upper Chenab Canal. In discussing these differences we should bear in mind that in the Upper Chenab Canal (1) the water-table has for many years been much nearer the surface ; (2) well irrigation is much more prevalent

and (3) the humidity during the winter months is considerably greater than in the Lower Jhelum Canal. It is then possible to understand that water added to the soil during the winter months will have a greater effect in the Upper Chenab Canal than in the Lower Jhelum Canal where the evaporation is greater. December, January, February and March appear to be the months when too much water has been applied in the Upper Chenab Canal. In the Lower Jhelum Canal excess water appears only with the spring rains. The negative periods of May and June in the Upper Chenab Canal and of November, December, January and February in the Lower Jhelum Canal are more difficult to explain. Excess water in these months will *depress* the water-table as measured in June. We can only suppose that such an effect is produced indirectly by the subsequent demands made on the water-table by the crops. At sowing time the area may be largely affected by timely rains. Winter crops, grown *barani* or with insufficient irrigation water may fail and thus water subsequently applied may be unutilized by the plants and percolate to the subsoil. All the available water may be diverted in uselessly heavy waterings to the crops which have survived.

5. The probable effect of a scientific control of irrigation can best be discussed by combining the regression curves with the variable factor of irrigation water applied.

From the regression curves we can calculate the probable effect on the rate of rise of the water-table, of cutting off or reducing irrigation in each month. The results ($I_k \times \beta_k$) are plotted in curves in Fig. III.

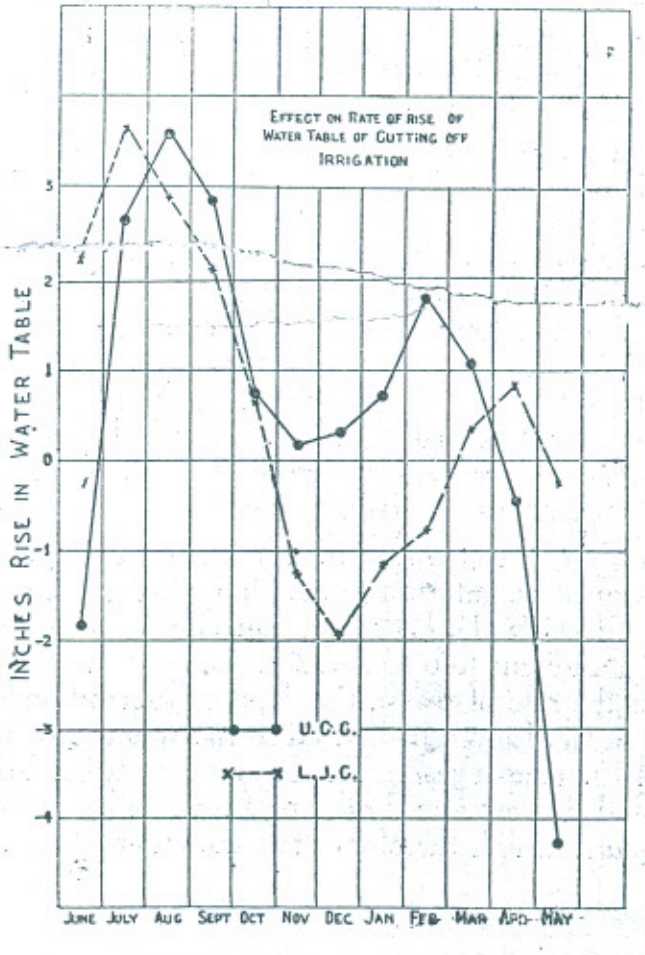


Fig. III.

They differ appreciably but roughly coincide during the months July, August and September, which is obviously the period of the year when applications have the greatest effect on the water-table. If restrictions can be made during these months without seriously affecting agriculture it is obvious we may look for the greatest effects in checking the rise of the water-table. Complete restriction of irrigation during July, August and September will result in reductions in the rate of rise of the water-table of 9·07 inches for the Upper Chenab Canal and 8·73 inches for the Lower Jhelum Canal. This would almost correct the rate of rise (9·49 inches) in the Upper Chenab Canal and largely check that observed in the Lower Jhelum Canal (16·58 inches). This part of the curves calls for little further comment as it is a constant feature in all cases so far examined.

Other parts of the curves are of equal interest although the conclusions to be drawn are different in the two cases. We may consider them in two parts represented by the months April, May and June and the winter months November to March. In the Upper Chenab Canal May and June which may be taken as representative of the time for *kharif* sowings show negative results, while on the Lower Jhelum Canal they are positive. We must conclude that in the Upper Chenab Canal cutting off or reduction of water will result in the water-table rising. I have suggested a possible explanation, the truth of which still remains to be conclusively proved, in referring the negative results such as is shown by the Upper Chenab Canal to the effects of well irrigation. If irrigation water is available during these months an increased area of *chahi* and *barani* crops is likely to be sown which by the subsequent draft on the water-table, either directly or through well irrigation, may actually make such an impression that a lowering persists in the following June. This effect is not observed in the Lower Jhelum Canal or in other cases where there is comparatively little well irrigation, and this would seem to support the hypothesis. In any case we are forced by the statistics, even if we cannot find a complete explanation, to conclude that irrigation should not be discouraged in the Upper Chenab Canal during these months but should be restricted as far as possible in the Lower Jhelum Canal. I think the agriculturist with a knowledge of irrigation in such tracts as the Lower Chenab Canal and Lower Jhelum Canal will agree that in June there is certainly the greatest waste of water. Evidence of what actually happens is given below.

6. Turning to the winter months the results are equally definite. Restrictions must be enforced in the Upper Chenab Canal but will have no positive effect on the Lower Jhelum Canal. During these months the irrigation adds up to 6·73 and 2·41 inches respectively. Restriction would lower the rate of rise in the Upper Chenab Canal by 4·11 inches a year, but in the Lower Jhelum Canal the water-table would rise more rapidly by 4·75 inches a year. This last result is rather difficult to explain. It is suggested that a reduced *rabi* area mya entail heavier sowings in the following *kharif* which therefore effect the water-table measured in June

and also that the failure of crops due to lack of irrigation water may mean the subsequent concentration of available water on surviving crops. Further light will be shed on this point as a result of calculations in progress. For the present we should accept the statistical result and decide that nothing is likely to be gained by restricting the *rabi* irrigation in the Lower Jhelum Canal. This is obviously a case where the conversion of distributaries from perennial to *kharif*, as has been the usual custom, would be entirely wrong.

7. We are now in a position to discuss practicable methods of reducing the rate of rise of the water-table by suitable methods of restricting irrigation. Our deductions from the statistical analysis show that we require :—

(1) As heavy restriction of irrigation as possible in both the Upper Chenab Canal and the Lower Jhelum Canal during July, August and September and during June as well in the Lower Jhelum Canal.

(2) Restriction of *rabi* irrigation during November to March in the Upper Chenab Canal but no change in the Lower Jhelum Canal.

(3) If possible, increased irrigation during May and June in the Upper Chenab Canal which may increase the area of dry crops.

The question is, how are we to do it. Taking the monsoon period first, an actual case has already been considered and administrative action taken in the Kassoki and Jaurian Distributaries of the Lower Chenab Canal. The conditions are in most respects similar to those in the Lower Jhelum Canal. Complete restriction during June, July, August and September would be expected to check the rate of rise by 5·57 inches, but restrictions at other times of the year would have produced little positive effect. At the conference held to consider proposals it was decided to restrict irrigation during the monsoon rather than convert the distributary to a *kharif* channel. The Agricultural Department opposed complete restriction but agreed to a scheme whereby half supplies would be given during June and September, and complete closure applied during July and August, with the proviso that if the rainfall was seriously in defect increased irrigation would be given. This area may be considered a rather favourable case for the adoption of such measures as more than one-third of the area is at present *barani* or *chahi*.

The restrictions to be adopted should slow down the rate of rise by 5·57 and 4·17 inches respectively so that along with the resort to well irrigation which would be the natural result of the proposals, there is every prospect of the annual rise of 5·41 inches being stopped. There seems no reason to doubt that, in threatened areas where waterlogging is not of such long standing that serious damage has been caused to the soil, the easiest and most effective method of checking the rise of the water-table will be by monsoon restrictions along with the encouragement of well irrigation. There seems no reason why such measures might

not be adopted in the Upper Chenab Canal, where there is already a large well area.

There seems little doubt that under present conditions the Lower Jhelum Canal could stand monsoon restrictions with little difficulty, but that no object will be gained by curtailing *rabi* supplies.

As an illustration of the way in which the effect of regulating supplies on the water-table may be calculated, I have taken the year 1925-26 on the Lower Jhelum Canal, and calculated from the irrigation and rainfall the rise in the water-table predicted by the regression curve.

Fig. 4 shows at the bottom, the observed irrigation and rainfall in

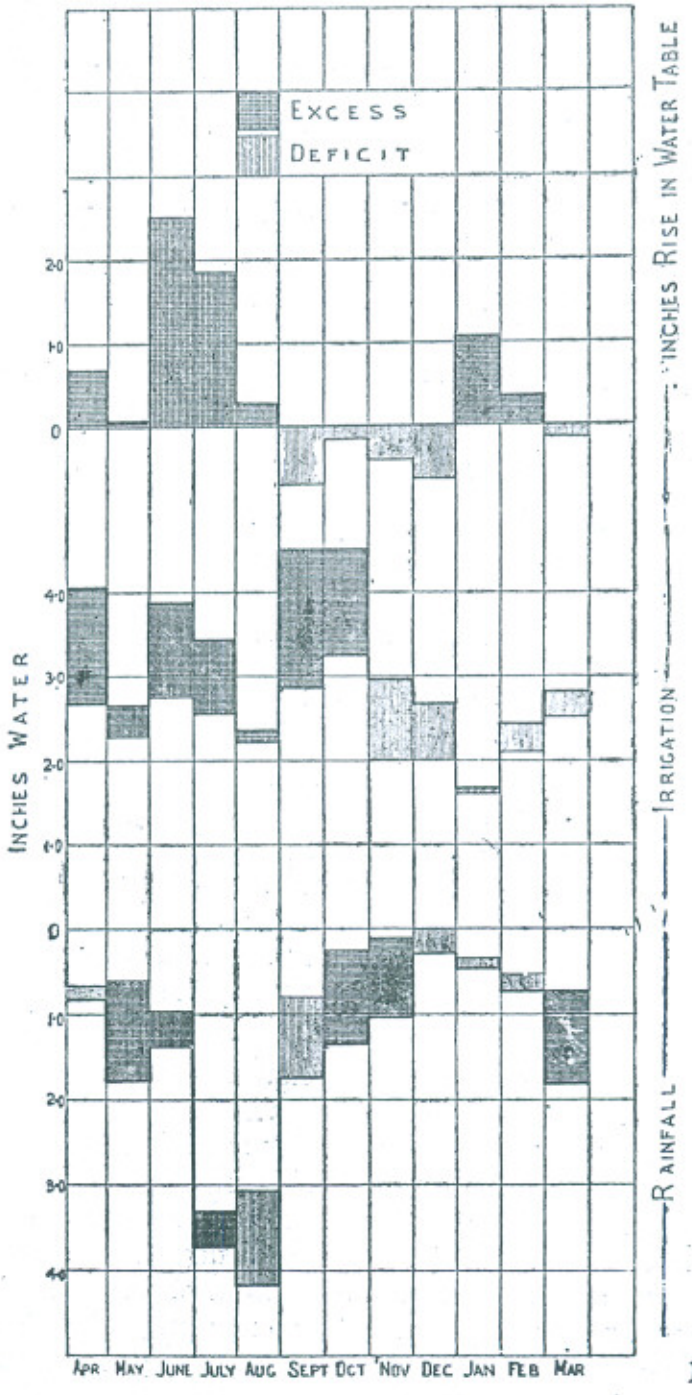


Fig. IV.

which the departures from the normal are shaded differently. At the top the predicted rise attributable to each month is plotted. The sum of the positive or negative effects is 4·89 inches which added to that portion of the slow change attributable to percolation from the canals makes 9·36 inches. The observed mean rise is 10·02 inches, in very reasonable agreement. Of this rise 4·6 inches might have been saved by restricting irrigation during June, July and August to the normal, leaving only 5·4 inches out of the *average* annual rise of 16·56 inches. If the *rabi* irrigation had not been cut down below normal another 1·8 inches would have been saved. It is then obvious that an avoidable rise of the water-table occurred through excess irrigation during the *kharif*.

8. It will now be of interest to calculate the probable effect of the restrictions proposed for the future, on the assumption that the rainfall is normal. Table I, shows for each month the supply factor and the corresponding average discharge. The winter months are calculated according to the years' programme. For the *kharif* supplies I have applied the supply factors now proposed *to the normal supply utilized*, as calculated from the last 10 years' working. If instead the factor were applied to the full-supply capacity of the canal no economy in water would result.

I shows the irrigation in inches calculated from the assumed discharges spread over the whole canal. $\triangle I$ gives the departure of the irrigation from the normal; the next column ($\triangle I_r \times \beta r$) is the predicted effect.

TABLE I.

Effect of Proposed Restrictions on Lower Jhelum Canal.

	Supply factor.	Assumed mean daily discharge (Cusecs).	I (Inches).	$\triangle I$ Inches.	$\triangle I_k \times \beta_k$ Inches.
May	1	2,619	1·456	— ·21	— ·04
June	21/30	2,059	1·108	— ·37	— ·57
July	21/31	2,039	1·134	— ·30	— ·77
Aug.	21/31	1,706	·949	— ·27	— ·64
Sept.	20/30	2,106	1·133	— ·39	— ·55
Oct.	1	3,351	1·863	— ·07	+ ·02
Nov.	½	1,420	·764	— ·82	+ ·64
Dec.	½	1,470	·817	— ·65	+ ·86
Jan.	½	1,630	·906	— ·01	+ ·01
Feb.	½	1,800	·904	— ·31	+ ·19
Mar.	½	1,950	1·085	— ·46	— ·10
Apr.	1	3,080	1·658	+ ·24	+ ·14
			Total ..		— ·81

	Inches.
Residual slow change ..	5·13
Predicted	— ·81
Predicted change ..	4·32

The total effect works out to —0·81 inches which added to the residual slow change leaves an annual rise of 4·32 inches compared with last year's 9·36 inches and the average of 16·56 inches. If *rabi* supplies were left at their normal figure the rise would be reduced to 2·46 inches only.

Provided therefore that the *kharif* restrictions really do reduce the water utilized to the extent required it will be almost possible to hold the water-table.

9. An analysis of the manner in which irrigation water is actually being used is very instructive. As a result of the detailed watercourse observations instituted by Mr. Woods in 1918-19, it is possible to illustrate from typical cases what is happening. Figs. 5 and 6 show in acre-inches the water applied in each 15-day period of the year to the principal crops. The watercourses have been selected at random, one each from the Upper Chenab Canal and Lower Jhelum Canal. Further instances will be shown during the discussion. The black area at the bottom shows water wasted, *i.e.*, in irrigating land not subsequently ploughed or cropped. The areas with black rings shew water unjustifiably used, *e.g.*, for irrigating fields in July in which wheat is subsequently sown despite adequate rainfall, irrigating gram three times in a

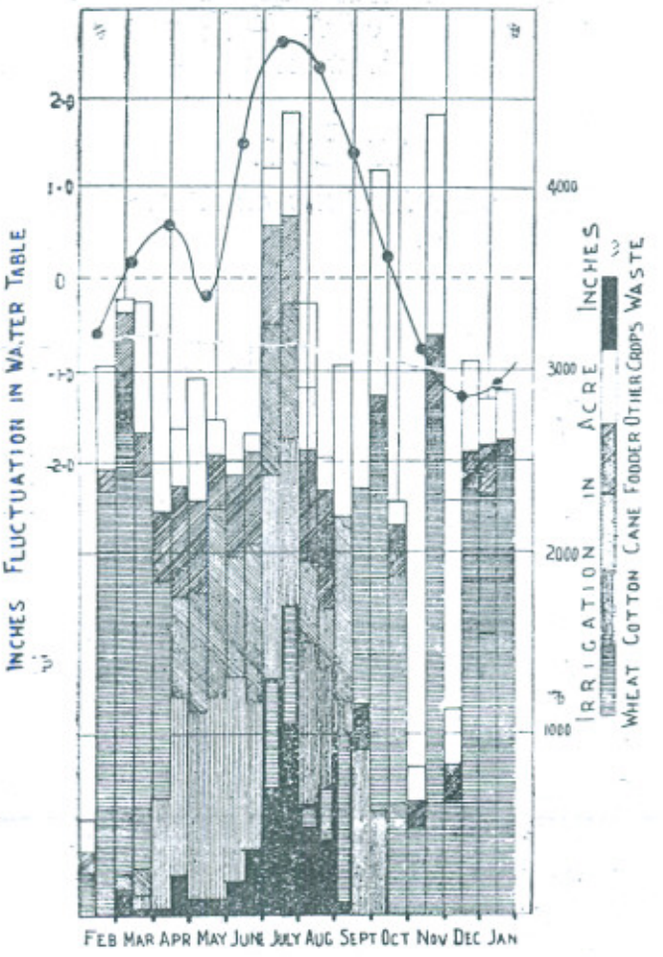


Fig. V.

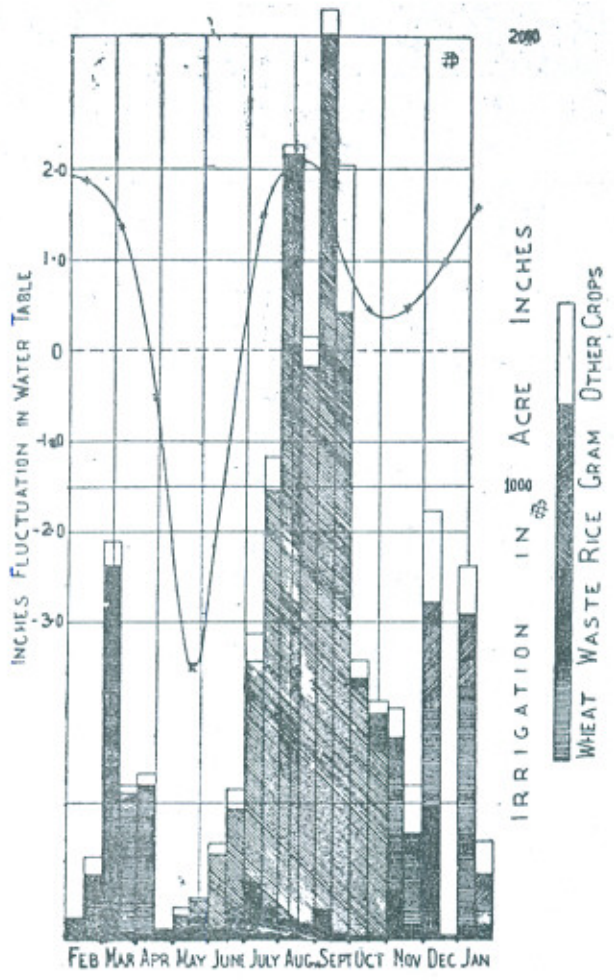
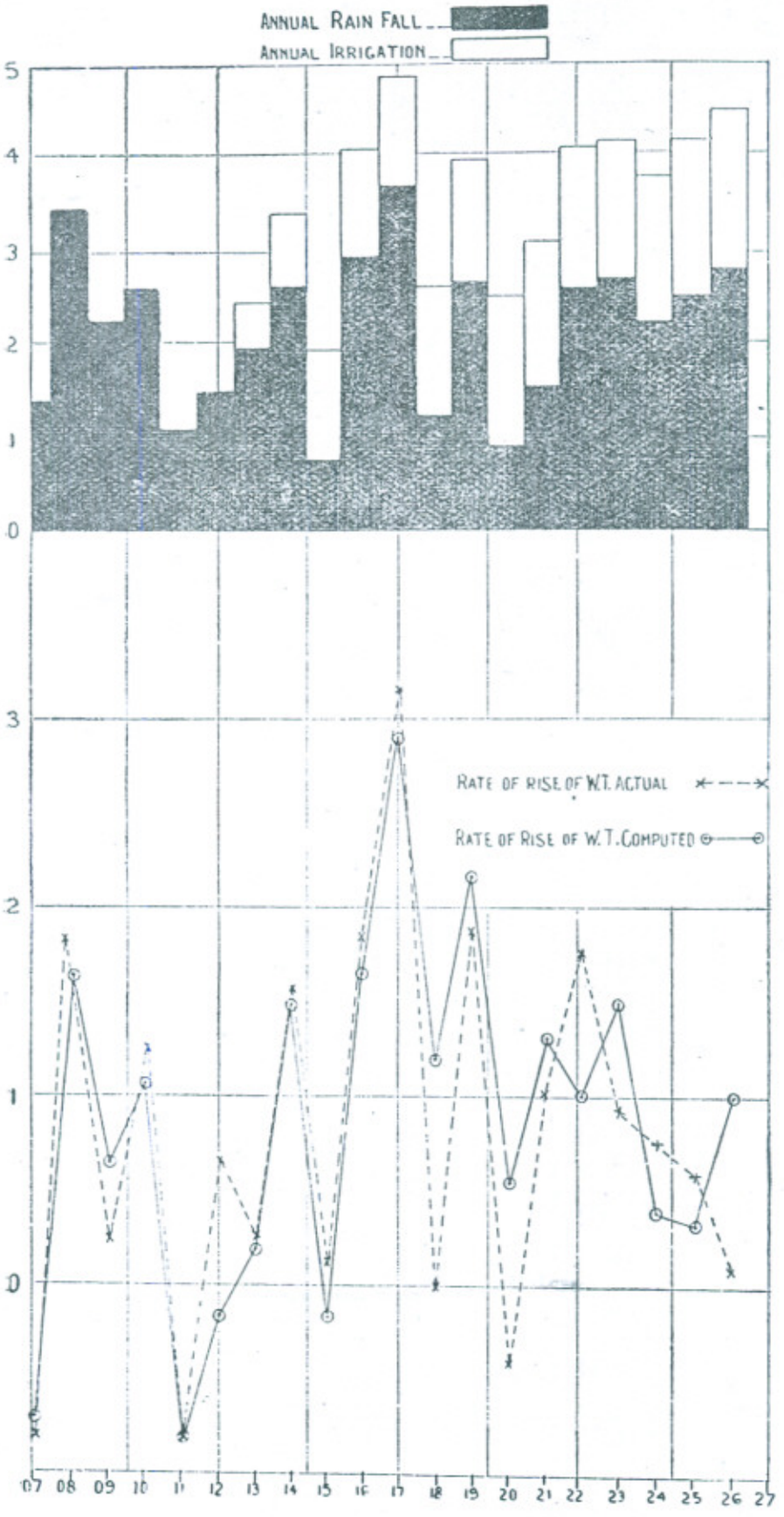


Fig. VI.

fortnight, and so on. For comparison the regression curves have been drawn in. One sees at once how remarkably the maxima on one curve fit in with the periods during which actual waste is in progress.

I will conclude by saying that we have clear evidence that economies are possible and will be effective in controlling the water-table. We need a detailed examination of the possibility of regulating closures of distributaries during the monsoon with due regard to rainfall. We need a positive policy of encouraging well irrigation by the zemindar, and we need actual demonstration that successful agriculture can be carried on with the restricted supplies given. The Chakanwali farm proves pretty conclusively what may be done in reasonably good land; we need similar demonstration farms in every area where restriction is necessary. In this the co-operation of the Agricultural Department will be essential. Reclamation of land badly affected with salt is another and more serious question and need not be discussed here. The immediate application of the principles of restriction outlined here is likely to obviate the heavier work of reclamation, and some major engineering works, if applied in time.

UPPER CHENAB CANAL
RISE OF WATER TABLE

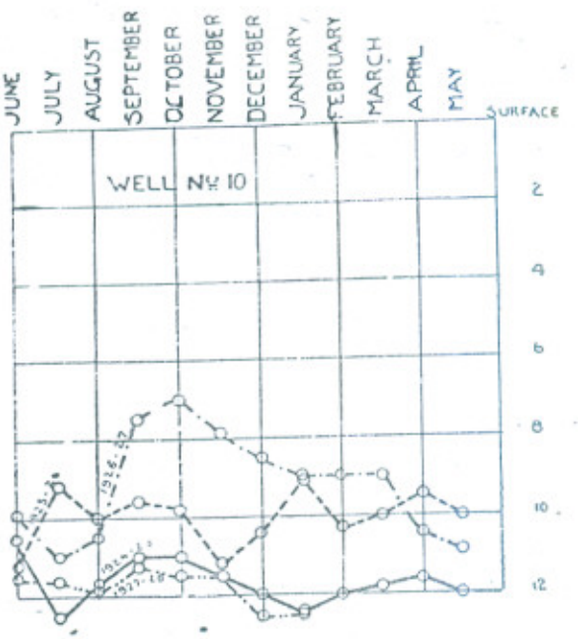


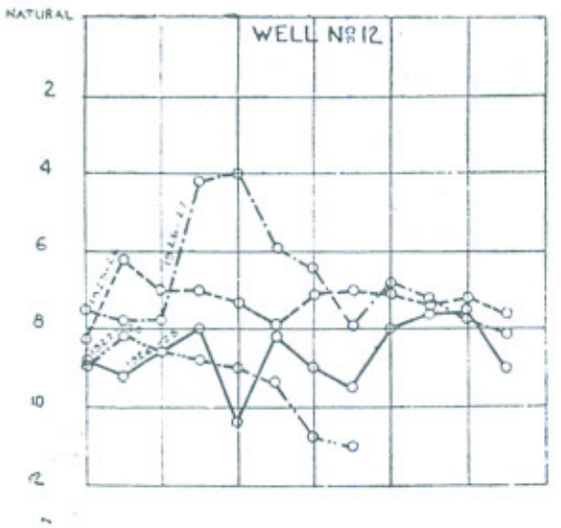
UPPER CHENAB CANAL CIRCLE

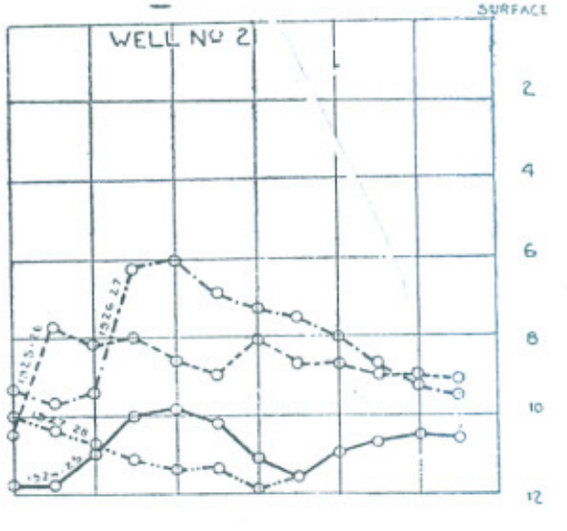
DIAGRAMS SHOWING WELL OBSERVATIONS

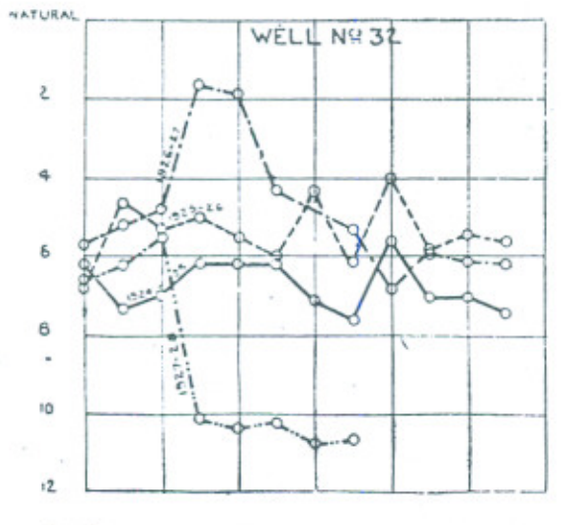
FOR 1924-25, 1925-26, 1926-27 AND 1927-28

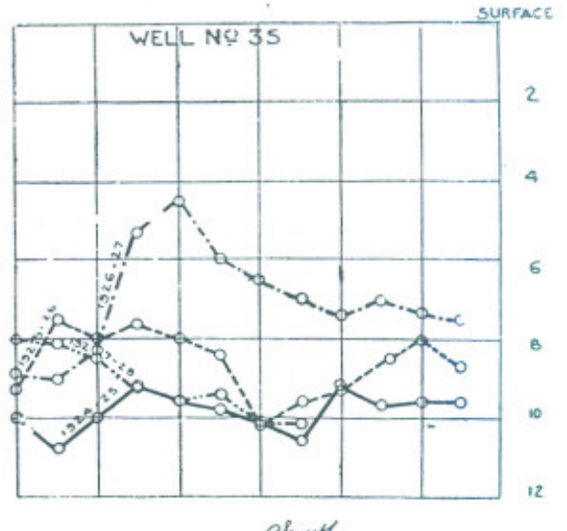






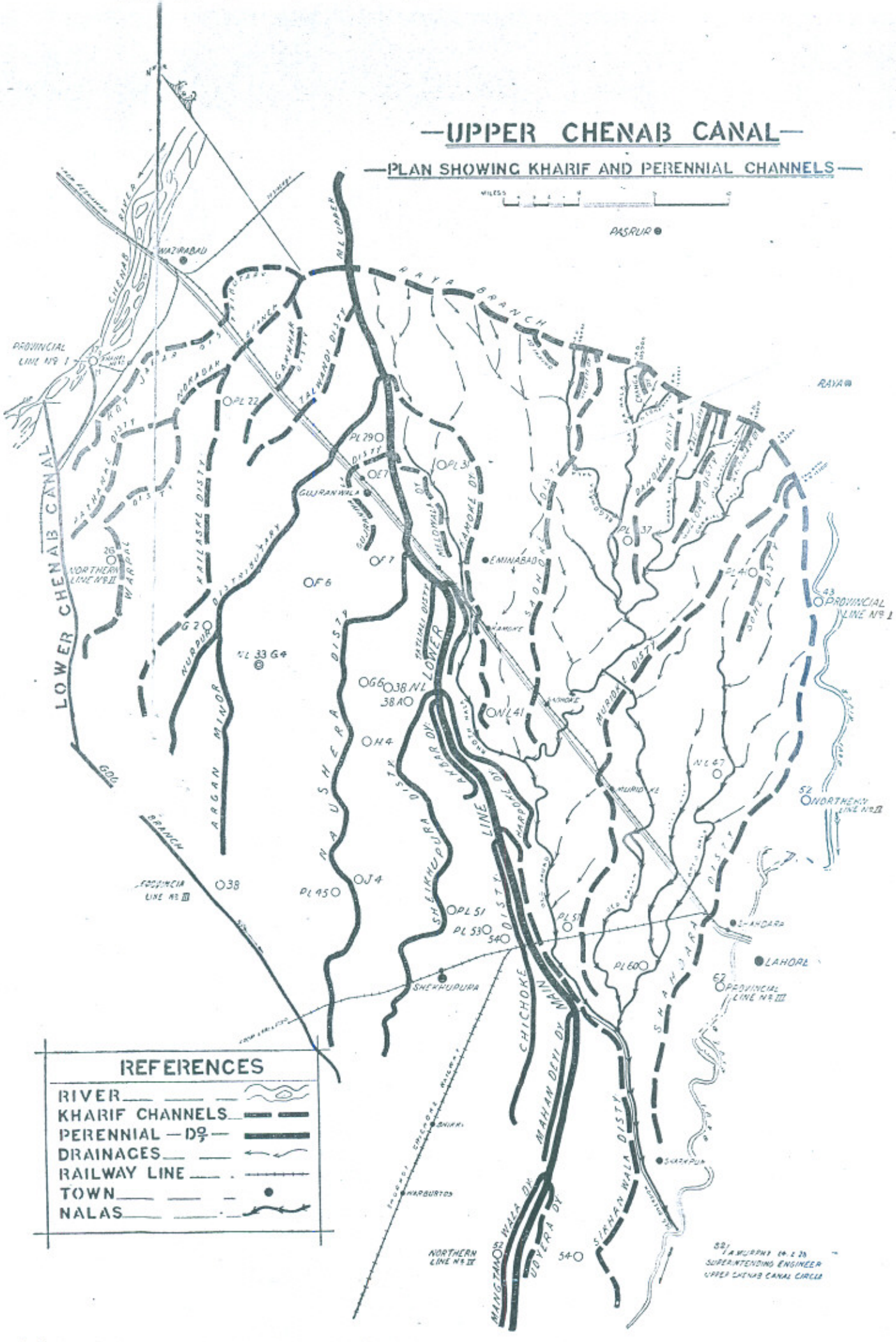






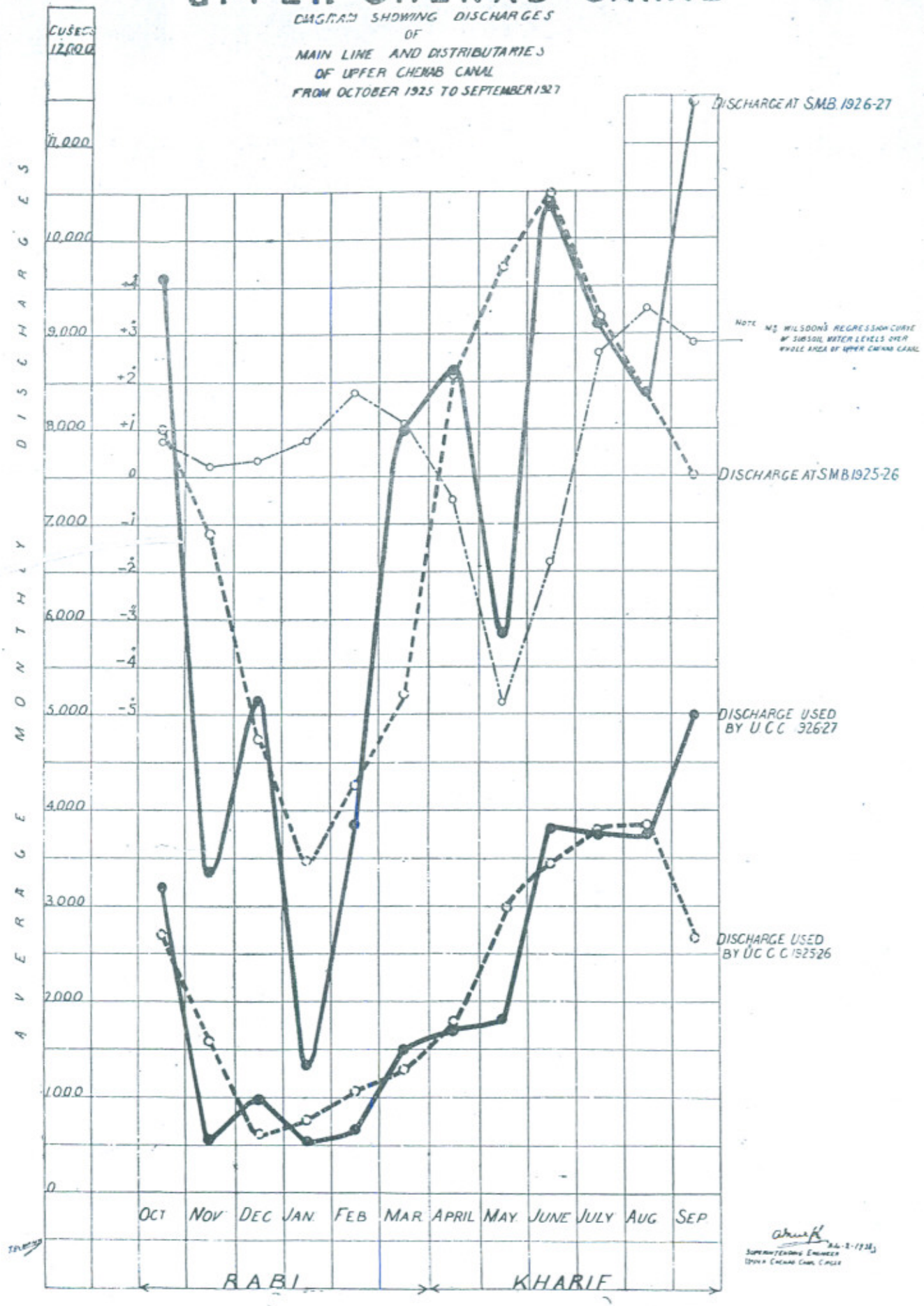
Traced by

SUPERINTENDING ENGINEER
UPPER CHENAB CANAL CIRCLE
LAHORE


—UPPER CHENAB CANAL—
—PLAN SHOWING KHARIF AND PERENNIAL CHANNELS—
MILES
PASRUR
WAZIRABAD
CHENAB RIVER
RAVI
RAYA BRANCH
RAYA
PROVINCIAL LINE No I
LOWER CHENAB CANAL
NORTHERN LINE No II
WARPAL
JHANG DISTY
KAILASKE DISTY
ARGAN MINOR
NAUSHERA DISTY
GUJRANWALA
EMINABAD
HAMOKE
MILLOWALI DY
PATHANI DISTY
LOWER
SHEIKHUPURA BRANCH
SHEIKHUPURA DY
SHEIKHUPURA LINE
CHICHOKE MALHIAN DISTY
MAHIAN DEVI DY MAIN
MANGTANOR WALA DY
DOVERA DY
SHAHKAN WALA DISTY
MURIDKE DISTY
SONE DISTY
SHAHDARA
LAHORE
PROVINCIAL LINE No III
NORTHERN LINE No III
SHAHKPUR
HARBURTON
SHIKKI
SHEIKHUPURA
REFERENCES
RIVER
KHARIF CHANNELS
PERENNIAL — D/S —
DRAINAGES
RAILWAY LINE
TOWN
NALAS
SD/ A.W. MURPHY M.V.O. I.S.O.
SUPERINTENDING ENGINEER
UPPER CHENAB CANAL CIRCLE

UPPER CHENAB CANAL

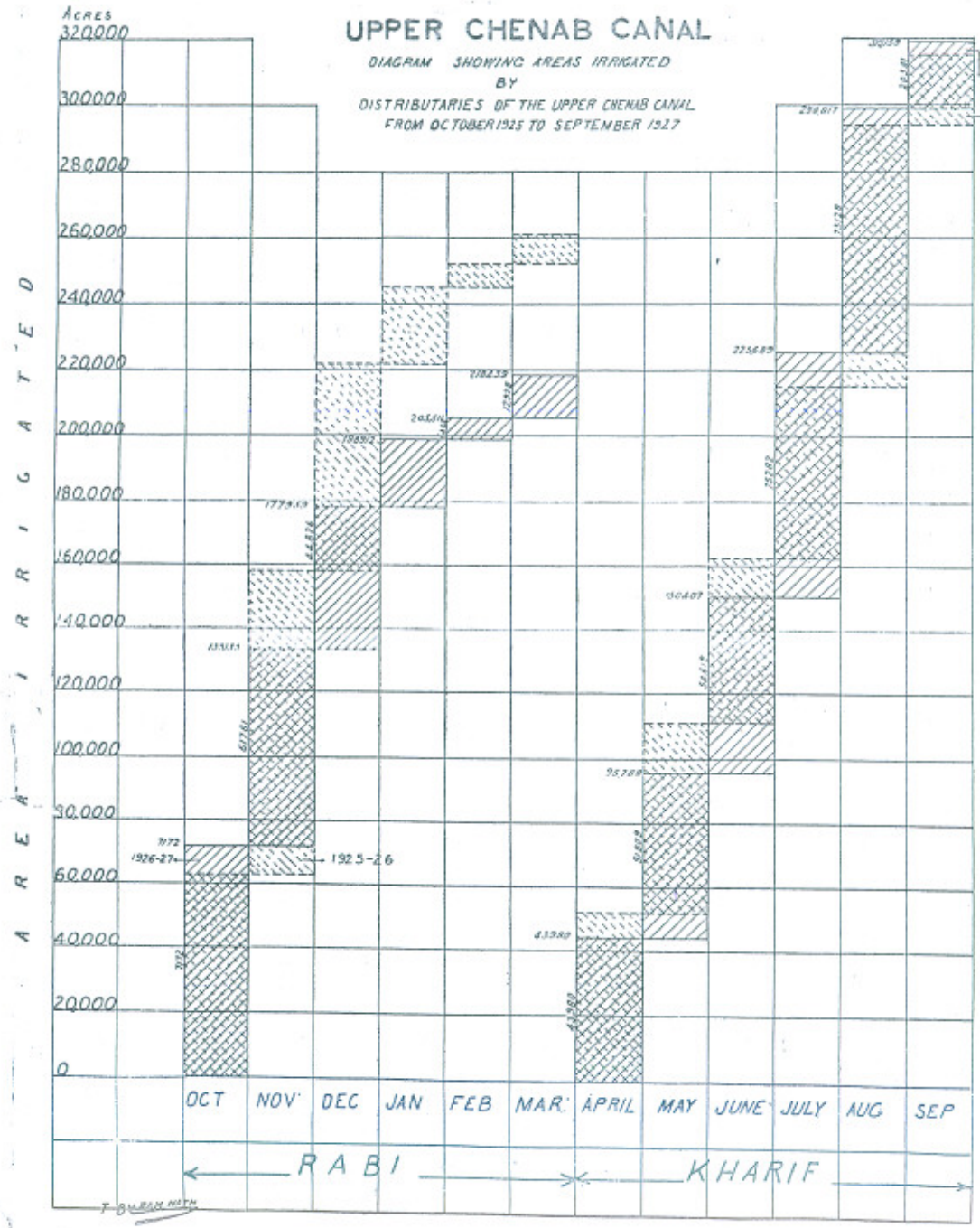
DIAGRAM SHOWING DISCHARGES
OF
MAIN LINE AND DISTRIBUTARIES
OF UPPER CHENAB CANAL
FROM OCTOBER 1925 TO SEPTEMBER 1927



SUPERINTENDING ENGINEER
UPPER CHENAB CANAL CIRCLE

UPPER CHENAB CANAL

DIAGRAM SHOWING AREAS IRRIGATED
BY
DISTRIBUTARIES OF THE UPPER CHENAB CANAL
FROM OCTOBER 1925 TO SEPTEMBER 1927



← IRRIGATED IN 1926-27

Do 1925-26

NOTE. FIRM LINES DENOTE AREA IRRIGATED IN 1926—27
DOTTED —— Do —— 1925-26

SUPERINTENDING ENGINEER
UPPER CHENAB CANAL CIRCLE

DISCUSSIONS.

Mr. Wilsdon in introducing the discussion of his paper, traversed its main points and illustrated the evidence for waste irrigation and its relation to the regression curves by means of a large number of lantern slides.

Mr. Robertson.—The rise in the sub-soil water-table throughout the Province has been a matter of great concern to the administration in recent years.

A special Waterlogging Enquiry Committee was appointed by H. E. the Governor to study the problem, and special efforts have been made by the Irrigation Branch of the P. W. D., and by the Rural Sanitary Board to check the spread of waterlogging.

The larger problem of the rise of the water-table cannot yet be said to be solved; but the scheme put before us to-day by Mr. Wildson promises to be a method which will help us to a solution without a large expenditure, and without hardship to the cultivators.

A study of the question since my appointment to the post of Superintending Engineer of the waterlogging Investigation Circle, in November 27th leads me to think that before we embark on large engineering schemes we should first try the effect of restriction of supplies and the economical distribution of water for irrigation. This feeling has been strengthened by the discussion I have had with Mr. Wilsdon, and other officers of the Department. It seems probable that we must resort to pumping and drainage on certain canals eventually; but we are in a position to try the methods of restriction first, as in the last year there has been no general further rise in the water-table. On the Chaj Doab the average levels in the wells for the period October, 1926-1927, show a fall of 63 on U. J. C. and 35 on L. J. C. and this is the area now being discussed.

This does not mean that any halt is suggested in the drainage works in hand or those which are at present under consideration.

An inspection of the drainage system in Egypt made in October by the order of Government while on my return from leave, has shown me that even with a high water-table it is possible to carry out intensive irrigation, and to avoid waterlogging by the employment of an elaborate system of surface drains, which parallel the irrigating channels, *i.e.*, for every watercourse there is a corresponding field drain, and for every distributary, a secondary drain, and for every main canal a main drain.

In that country the basis of the design aims at keeping the surface of the sub-soil water down to a level of 1·5 metres, *i.e.*, a little over 4 feet below the lowest point in the surface of the land served by the drainage system.

Under these conditions waterlogging cannot be said to exist in the Nile Delta between Cairo and the Sea, and similar crops to those grown in the Punjab are matured.

I do not suggest this as an ideal to follow, if we can deal with the water-table at lower levels; but it has shown that there is a method of dealing with the problem should the water-table continue to rise.

In a certain area in the Punjab we have constructed a series of drains in waterlogged areas ; but they do not work to their full efficiency as they are not connected with the land by a system of field drains and the attention of the irrigation officers-in-charge of such tracts has been drawn to this fact, and proposals are being made for a trial of such systems.

At Chakanwali experimental farm, near Hafizabad, Mr. Wilsdon has installed such drains, and their effects has been very marked in producing a general fall in the sub-soil water surface, and has enabled him to grow crops in areas where cultivation had been abandoned.

I would, therefore, suggest at this Congress that this extension of our drainage system by the addition of field drains should be tried out in such areas by the local officers-in-charge.

As many officers will doubtless wish to express their opinion to-day I will not discuss the subject in greater detail at present ; but hope to have more to say next year when our efforts to deal with the situation have developed further.

Mr. Murphy.—As Mr. Wilsdon's interesting paper deals to a large extent with conditions on the Upper Chenab Canal, I feel that it is necessary for me to make some remarks which may help to elucidate further information on the very complicated question of the causes which contribute to the rise in spring level, and the best means of counteracting the same.

The portion of the Rechna Doab which is contained within the Upper Chenab Canal Circle is so situated that the conditions are more favourable towards waterlogging than on any other of the main canals of the Punjab.

This plan of the Circle will make the conditions more clear.

It includes the area from the Head of the Main Line Lower to just short of the Tail at Balloki. The main canal and perennial distributaries are shown in full lines, while the *Kharif* channels are shown in broken lines.

The Raya Branch takes off on the left at Bombanwala and on the right is the Nokhar Branch, the distributaries of which extend close up to the Lower Chenab Canal, while the perennial distributaries of the Gujranwala Division reach as far as the irrigation boundary of the Gugera Branch.

The Raya Branch is crossed by several streams from the Deg Nallah which during the monsoon spread over the whole of the country between the Kamoki Distributary and the Shahdara Distributary, and reach the banks of the Main Canal below Kamoki, and consequently a good deal of water which would otherwise flow in south-westerly direction is stopped by the Main Line and its Distributaries.

On the right side of the Main Canal the main drainages run down to the Lower Chenab and Gugera Branch where they also are obstructed for want of proper outfalls.

There can be little doubt that any interference with the flow of the natural drainages has a very great effect on the rise of the sub-soil water, and consequently the conditions for this taking place are very favourable on both sides of the Main Canal.

Mr. Wilsdon's calculations show the effect of irrigation during the months of July, August and September, on the rise in the sub-soil water-level. This is very easy to understand, but I am afraid his method of prevention, namely, cutting off the water during these months, is not as far as the Upper Chenab Canal is concerned, an easy thing to do. On the Raya and Nokhar Branches and the *Kharif* Distributaries of Gujranwala Division over 90 per cent. of the total irrigation is rice, chiefly, because the country through which these channels run is mostly suitable for no other crop. Rice is a crop which cannot do without water during the hot summer months for more than 10 days, and if there were to be periodical ten-day closures, it will be possible for the channels at their present capacities to give the whole irrigated area a watering within the remaining period.

A further difficulty is the fact that the rainfall is unevenly distributed, and unfortunately where the spring-level is highest, namely, close to the Main Canal, is also the line along which the heavier rainfall generally occurs, so that if the channels were closed when there is good rain along the Main Canal, the tail portions might be very seriously affected.

The difference in the class of crops grown on perennial channels of the Gujranwala Division during the *Kharif* as compared with that on the purely *Kharif* channels is worthy of notice. On the former the rice area is about 30 per cent. of the total, and about the same as that under cotton. There is undoubtedly a considerable waste of water, or I might say an unnecessary amount of water is used in the cultivation of rice, and this is clearly shown in the difference in the deltas of the perennial and *Kharif* channels taking out of the Main Canal. Taking for instance the large Distributaries such as Nurpur with a Discharge of 403 cusecs, Nowshera 437 cusecs, Sheikhupura 215 cusecs, Chichoki 183 cusecs, the deltas for the year 1926 were :—

Nurpur	..	3·29	Nowshera	..	2·99
Sheikhupura	..	3·52	Chichoki	..	3·51

while on *Kharif* channels, such as :—

Talwandi	.. Discharge	109	Cusecs	Delta	5·29
Kamoki	.. ,,	220	,,	,,	5·54
Melowala	.. ,,	48	,,	,,	4·29
Sikhanwala	.. ,,	308	,,	,,	3·26

On the Nokhar Branch :—

Kot Jaffar	.. Discharge	143	Cusecs	Delta	5·6
Warpal	.. ,,	134	,,	,,	4·56
Pathanke	.. ,,	56	,,	,,	4·63
Kailaske	.. ,,	276	,,	,,	4·90

On Raya Branch :—

Sadhoki	Discharge	345	Cusecs	Delta	3·92
Muridki	.. ,,	686	,,	,,	3·66
Shahdara	.. ,,	443	,,	,,	3·42

The permissible discharge at the outlet head of Perennial Channels is 88 acres per cusec, and on *Kharif* Channels 66 acres per cusec, while the former channels do much nearer their permissible areas of irrigation in *Kharif* than the *Kharif* channels, and consequently it would seem that an unnecessarily large quantity of water is used on the latter. The total authorized discharge of the *Kharif* Channels is 3,517 cusecs and of the Perennial Channels 1,856 cusecs. The former is therefore nearly twice the latter, and consequently there is more scope for reduction of water during the summer, than during the *Rabi* season, when the actual supply received is only about 70 per cent. of the total authorized discharge, owing to the shortage of supply in the river ; or in other words a daily average of 1,250 cusecs is received in *Rabi*, against 3,250 cusecs in *Kharif*.

Mr. Wilsdon has come to the remarkable conclusion that rise in sub-soil water-level can be reduced by increasing the amount of water during the months of April, May and June. This is not easy to believe, and requires to be proved by monthly observations of a series of wells. Unfortunately our observations so far have been restricted to the months of June and October, except in the vicinity of Gujranwala, where a number of wells have been measured monthly for the past three years. Many of these are too close to the Main Line to indicate the changes taking place in the water-table over the country as a whole, but the following 10 wells which are furthest away from the canal, that is to say, 3 miles and so, have been selected as affording the best idea of the changes taking place.

Serial No.	Depths Below N. S.		Depths Below N. S.		Depths Below N. S.	
	June 1925.	October 1925.	June 1926.	October 1926.	June 1927.	October 1927.
6 ..	2·50	2·60	4·40	2·15	5·50	6·60
10 ..	11·20	9·80	9·90	7·00	11·50	11·50
18 ..	8·00	6·60	7·90	3·90	7·75	9·40
20 ..	10·00	9·40	9·90	7·00	10·00	13·00
21 ..	10·50	8·60	9·90	6·00	10·10	11·40
25 ..	5·60	4·00	6·70	3·85	7·50	9·60
31 ..	8·60	7·00	8·70	4·40	8·30	9·90
32 ..	6·80	5·50	5·70	1·85	6·60	10·40
36 ..	7·00	5·30	8·30	4·65	8·00	8·10
37 ..	7·50	6·20	8·30	3·35	7·30	10·10

At the beginning of last *Kharif* an effort was made to reduce the quantity used during the months of April and May and the results do seem to show that a good effort was obtained thereby. At the beginning of the season, enquiries were made by the Executive Engineers as to where the water which had been indented for was being used, and it was found that on the Kharif Channels practically none at all was being used for irrigation. It was either finding its way into the village tanks and depressions, or being allowed to run to waste over the fields. This water permits grass to be grown during the month of May, on which the cattle graze, and it is not until June that any serious efforts at cultivation are started.

There was a closure of 12 days of the Main Canal during the month of May and the *Kharif* Channels were kept closed for six days in April, and 13 days in May. Not only did this result in no reduction in the area irrigated, but in spite of a very dry summer, the total *Kharif* area was slightly in excess of that of the previous year, and the area on which remissions were given on account of shortage of water was less than the previous year, from which it may be concluded that for the cultivation of rice, it is not essential to open the channels before the end of May, and furthermore by doing this, the demand when the channels are opened is very much keener, and it is possible to run them with much bigger discharges than is the case during the months of April and May, and consequently the distributaries and outlets in the head reach have much better command than when supplies of about 60 per cent. only are being run and the distribution of water over the whole system is much more even.

This Diagram shows the average monthly discharges of the Main Canal at Sambrial for the years 1925-26 and 1926-27, and underneath are shown the discharges utilized in the Upper Chenab Canal Channels, as also the areas irrigated each month. The two minimum points in January and May represent the closures at the head. I have also marked in Mr. Wilsdon's Regression Curve for the Sub-soil Water, which he has given in para. 5 of his paper.

For the first time since its construction the Upper Chenab Canal was closed for a month during January 1927, and in addition to this long closure, there were two closures of 12 days in November and May, the former as part of the rotational working of the five linked canals.

It had been noticed that land close to the canal on which the water is standing after the monsoon in the areas which are waterlogged, continued to remain in this state all through October and November without any great sign of reduction in water-level, but as soon as even a 12 day closure starts, this water disappears, and the surface of the ground, at any rate, dries up and does not again become wet when the canal re-opens. The conclusion which may be drawn from this is that once the surface of the ground is dry, the evaporation from below can take place, and in these areas is able to keep pace with the percolation from the canal.

The effect of a month's closure in January is of course far greater still, and it is thought that these closures are one of the best methods that can be resorted to for reducing the rise in the spring-level.

It will be seen that between the 1st of November and the 1st of June, it is possible to close the canal for two periods of 12 days, and one of 31, or a total of 55 days in 7 months.

Not only does this save the loss by percolation which is probably between 400 and 500 cusecs for 55 days, but the canal when closed acts as a drain, and for the first 12 days carries not less than an average of 100 cusecs, drawn from the sub-soil water-table. These two factors added together must have a considerable effect on the sub-soil water reservoir.

If also the *Kharif* Channels are kept closed until the end of May a further saving of some 1,500 cusecs for 6 weeks will be obtained, and without adversely effecting the irrigated area. This will be much better than periodical closures in July, August and September, for during the early months of the season, when the water is lavishly used on the ground and there is no plant life to absorb it,—although evaporation is at its maximum, the balance must reach the sub-soil water-table, and it seems reasonable to argue, that until there is positive proof to the contrary, it does not matter much at what time of the year water is added to the sub-soil reservoir, the nett result will be the same, and if we can lower it still further before the rains begin, there is all the more space to be filled up before last year's level has again been reached.

It cannot be only a coincidence that the year in which these closures have taken place, and the quantity of water given in the months of April and May restricted, the water-level in the wells throughout the Circle not only fail to show the annual rise in June which has been steadily taking place ever since the canal was opened, but are actually lowered by some 2 feet in October than they were in the previous year, a reduction which has never once occurred before in a period of 25 years of observation.

On the plan I have shown a series of wells along the various Provincial lines which cross the Circle. The wells have been selected at intervals of about 5 miles along these lines.

I have also marked the wells referred to by Mr. Wilsdon in his Memoir on the "Statistical Examination of the Sensitivity of the water-table through rainfall and irrigation" to which he refers at the bottom of page 136 of his paper, and I might here give the water-levels in these wells :—

Name of Well.	Name of month and year.	Depth of water-level below measuring point.
E7	June 1926	10·9
	,, 1927 ..	11·8
	October 1926 ..	8·0
	,, 1927 ..	12·25
F6	June 1926 ..	11·6
	,, 1927 ..	11·6
	October 1926 ..	8·00
	,, 1927 ..	11·8
F7	June 1926 ..	9·00
	,, 1927 ..	9·75
	October 1926 ..	5·00
	,, 1927 ..	9·6
G2	June 1926 ..	14·1
	,, 1927 ..	11·0
	October 1926 ..	8·8
	,, 1927 ..	13·00
G4	June 1926 ..	6·30
	,, 1927 ..	5·75
	October 1926 ..	2·30
	,, 1927 ..	6·25
G6	June 1926 ..	9·3
	,, 1927 ..	10·1
	October 1926 ..	8·12
	,, 1927 ..	9·7
H4	June 1926 ..	10·8
	,, 1927 ..	11·25
	October 1926 ..	9·5
	,, 1927 ..	12·3
J4	June 1926 ..	10·4
	,, 1927 ..	10·5
	October 1926 ..	9·5
	,, 1927 ..	11·6

Of the above the only wells in which the level in June 1926 is higher than in June 1927 are G-2 and G-4, the former it will be seen, is sandwiched in between the Nurpur and Kailaski Distributaries, the latter a *Kharif* Channel, where there is a great waste of water, and this probably has effected this particular well. For G-4 I can offer no explanation.

Both of these wells are peculiar, for on page 37 of Mr. Wilsdon's Memoir referred to, it will be seen that G-2 showed falls of 2·72 feet in 1922 and 2·40 feet in 1926, and G-4 a drop of 3·80 feet in 1921, and the chances are that both wells suffer from inaccurate observation.

In spite of Mr. Wilsdon's mathematical calculations, the evidence does seem to prove that the restriction of water during the months of April and May has had a good effect on the sub-soil water-level, since the latter in the month of June has not shown its usual annual rise, and consequently rather than resort to increasing the supply given in these months, and reducing it during the months of July, August and September, as advocated by Mr. Wilsdon, it would seem to be the better policy to concentrate on restriction at the beginning of the season, combined with an efficient system of distribution in the Distributaries by means of careful remodelling of outlets.

It is extremely doubtful whether any more irrigation would be done by increasing the supply in April or May, but if this were to come about, we would be asking for trouble, if we cut down the supply later on when the crops are being matured, after having induced the people to cultivate a larger area than before.

As regards the help which may be expected from the use of wells, I have endeavoured to collect details of these showing the changes in conditions which have taken place since the opening of the Upper Chenab Canal. In the whole of the Gujranwala District and the Shahdara Tahsil of the Sheikhupura District, which comprise very nearly the whole area of the map, there were 10,660 wells before the advent of the canal, and to-day 9,432 or a falling off 1,228. These figures were collected a couple of years ago when the last settlements were in progress and since then the cultivators have begun to realise the danger of waterlogging and many new wells have been sunk, and old ones opened up, so that perhaps the total falling off is not now more than 1,000 in all.

On the other hand the average area matured is very nearly the same to-day as formerly, or approximately 26 acres per well, and the Settlement Report of Gujranwala District states that the percentage of area under the more valuable crops such as cotton and sugarcane is almost the same to-day as 15 years ago; showing that the advent of the canal has not caused any great change in class of agriculture done, and we cannot therefore expect to be able to force the general mass of the cultivators to alter their long-standing customs and give up the growing of rice for other crops like cotton, and even if they were to go largely

in for the cultivation of cotton, this would necessitate the opening of the *Kharif* Channels in April and running large supplies in April and May, thereby losing the advantage to be gained by keeping them closed during these months, as I have indicated. It is also worth noting that in the areas in which well irrigation is done on a large scale, the Distributaries running through them have the highest Deltas, such as those of the Nokhar Branch and the Nurpur and Talwandi, whereas the Deltas on the Raya Branch where wells are scarce compare favourably with the Perennial Channels.

As I started off by showing, the Upper Chenab Canal Circle is so situated as to be unnecessarily sensitive to the effects of rainfall and floods, and is almost a close drainage tract. Not only is there no proper outlet for the drainages on the right side when they reach the Lower Chenab Canal, but some idea of the quantity of water brought into the tract of the several streams of the Deg may be judged by taking the combined discharges passing the Raya Branch by the various super-passages and syphons, and the corresponding discharges at the tail of the Deg Diversion, which is the only outlet for them. Unfortunately the observations at the latter site have been spasmodic and unreliable, and only the figures for the past four years 1924 to 1927 inclusive are anyway complete.

The average daily discharges during these four years in the months of July and August was 2,730 cusecs at the Raya Branch and 432 cusecs at the tail of the Deg Diversion. Showing that the equivalent of 2,300 cusecs daily for two months remains inside the tract, and is nearly 70 per cent. of the total canal water utilized during the months April to October inclusive.

Looked at as whole therefore irrigation is not the most important factor in the rise of sub-soil in the Upper Chenab Canal Circle. In *Rabi*, the quantity of water used is so comparatively small as not to warrant serious interference with existing conditions, and the very great loss of Revenue which it would entail, although the cutting out of *Rabi*, irrigation in certain channels as relief to a local area is strongly advocated, as it is an old remedy which has been proved to be a success. The curtailing of supplies at the beginning of the *Kharif*, and as many days' closure of the Main Canal as is possible during the *Rabi* will have further good results, but since by far the greater portion of the water reaching the sub-soil reservoir is from local rainfall and floods from outside, the two measures which seem to promise the best results are thorough surface drainage, and the cutting off completely of the Deg floods before they cross the Raya Branch.

Mr. Roberts on Mr. Wilsdon's Paper.

I should like to say only a few words on the agricultural aspect of Mr. Wilsdon's Paper. It seems to me that the results arrived at by Mr. Wilsdon seem to call for restriction of water in the canal during

the wrong period of the year. Take for example the period May-June on the Lower Jhelum Canal. In May no crop except young cotton and young cane need water, and practically speaking there is no demand. During that time the zemindar uses water very inefficiently. This seems to be a rather serious objection to the general conclusions of this paper. The month of June on the Lower Bari Doab Canal would correspond more with the month of May on the Lower Jhelum Canal and every body knows well one could do with very much less water in that month. But if we are to go by Mr. Wilsdon's figures, May and June appear to be months when irrigation is efficient. The figures on the Board show very little wastage in June.

The point is if irrigation in May and June depresses the water-table, why cannot we verify this by records of the ordinary water-levels in the wells. If you go in for large scale restrictions and are going to reduce Government revenue by say 15 lakhs, you will reduce the zemindars' revenue by 80 lakhs. The figure, therefore, is big enough to justify records being taken on one canal to get direct evidence whether the facts are correct.

Lower Jhelum Canal is a canal which is particularly favourable as regards its *Rabi* supply. The *Rabi Kharif* ratios of supply, if we take *Kharif* as 10 on the Lower Jhelum Canal, Lower Bari Doab Canal and Lower Chenab Canal are proportional to 10 to 8, 10 to 4 and 10 to 7. Yet under Mr. Wilsdon's proposals we must restrict *Kharif* supply, which is a reversal of the generally accepted policy and would accentuate still further the unique *Rabi Kharif* supply proportions of the Lower Jhelum Canal. Before anything on a large scale is done, we should get some more definite information as to the actual depths of water in the wells in monthly periods.

Mr. D. Milne on Mr. Wilsdon's Paper.

I have listened with considerable interest to Mr. Wilsdon's Paper. It deals with a subject of very great importance to the Province and of special interest to the agricultural community. But I only got his paper this morning and have had no time to consider it carefully. It seems to me that it makes statements of very great importance, intimately connected with agriculture, but offers very little explanation as to how he got at his conclusions.

Mr. Roberts, in his remarks, has touched on some of the points in this connection. I think that until we are sure of the conclusions come to in Mr. Wilsdon's Paper, we should not interfere far with agricultural practice.

There was a proposal a number of years ago to start a Hydraulic Station in the Punjab which would be run by a committee and would be staffed by Agricultural and Irrigation Officers. This station was, among other things, to investigate the water requirements of crops, the methods of distribution of water, etc., and this discussion on Mr. Wilsdon's

Paper seems to emphasise the need of starting that station in order to get to the facts of the case as regards the amounts of water required by the crops. If such an institution were started it would be of great advantage to agriculture.

I do not know whether the experiments regarding distribution of water commenced by Mr. Woods still continue or not, but if they do not, it would, I think, be a sound thing to continue them in order to help to give Mr. Wilsdon the information that he wants, I also think that all officers in the Irrigation and Agricultural Departments who can possibly do so should try to collect information about the use made of water by zemindars. By this I mean that although we may have an Irrigation Station, it will be some years before we get results from it and if information is also collected by these officers if utilized it will help on the work at an earlier date.

There is one thing which appeals to me rather strongly and that is that our system of selling water in the Punjab is not conducive to the zemindar making the best use of it. I know that selling water by the volumetric system has its difficulties, very great difficulties, but we must endeavour to find some means or other to give some inducement to the zemindar to make the best use of his water.

There are two ways of maintaining a supply of water in the soil ; one is to reduce transpiration from the soil and the other is by adding water directly, and so long as the zemindar can go to the Irrigation Officer, ask for extra water and not have to pay for it, there will be no solution of the question of wasting water.

It seems to me essential that every endeavour should be made to investigate the possibility of giving a supply of water to the zamindar on such terms which will induce him to make the best use of it.

I am not ready to accept all the conclusions reached in Mr. Wilsdon's Paper, on the data given, but I have no doubt that the work he has done will place us one step further on.

Mr. Wilsdon in replying to the discussion stated that as he had already taken up too much time of the meeting he would discuss the point raised in a writtten communication.

Mr. Stewart on Mr. Wilsdon's Paper.

I do not wish to say much but I consider that Mr. Wilsdon's Paper is of very great importance from the point of view that he seems to be very decided that water must be reduced in certain canals from July to September. If that is to be done it must inevitably alter agricultural practice, and I cannot help feeling that before the statistics he has put forward are accepted they require further investigation and confirmation.

We are told here in the paper that the figures should be accepted with blind confidence. That may be all right from the point of view of the statistician but to the ordinary layman something more practical is necessary in order to give full confidence in them.

I think, therefore, that more investigation is required on the lines Mr. Roberts has suggested and that from actual observations a study if what is actually happening in practice must be made. The statistical results may be quite correct but I think they require confirmation from facts in actual practice.

Mr. M. S. Dhody writes—

I am afraid we are not facing the situation squarely but are merely in a timid way suggesting palliatives. Either waterlogging is a menace or it is not. If it is not then no fuss need be made, but if it is then, some radical cure is necessary. Land is being lost to cultivation and people are losing their habitations and are in difficulties about burying their dead. We know that of water sent down a canal system only 40 per cent. goes to actual irrigation and of this only a part goes to make plant life and the balance into the soil. Thus perhaps 80 per cent. goes into the soil one way or another no matter by what method, and all this helps water-logging. It is this which has to be reduced and the time of doing so is not of the importance suggested by Mr. Wilsdon. If it has been found that 3 or at most 4 waterings are enough for wheat then water should be given only to that amount and no more. Ordinarily a cultivator of unit area of 25 acres should get all his *Rabi* sowing in two turns and his later three waterings in six turns; thus each canal should get only 8 flow periods in *Rabi* and not 10 or more which it now gets. Water thus set free will go to develop new tracts and loss in revenue on any old canal would be made up in these areas. Loss is bound to occur whether it occurs by land getting waterlogged or by measures taken to reduce cultivation. There are three measures for combating waterlogging. (1) Scientific treatment as suggested by Mr. Wilsdon. (2) Engineering such as drains pumping schemes and (3) Administrative. I venture to say that it is the last that will be most effective. By this I mean the policy of restoration as suggested above according to which each of the five linked canals will run for 72 or at most 96 days in *Rabi* against about 120 or more at present.

If this can be done the cultivator will soon learn to economise water and where this is effected the loss in revenue will not be very great.

Closure of canals during the months July to September may be quite sound as brought out by Mr. Wilson, but it could be done only in the event of general slackness of demand which seldom occurs in practice.

The collation of his results and the rapidly changing diagrams on the screen are very elaborately worked out indeed but they do not help to solve the problem.

Mr. F. F. Haigh on Mr. Wildson's Paper.

Mr. Wilsdon has given us in this paper and in the work with which this paper deals an exceedingly valuable contribution to the efforts which are being made to remedy the waterlogging evil with which the Province is threatened.

During the discussion on the paper it has been suggested that before applying the methods advocated by Mr. Wilsdon we will require some confirmation of the work on which they are based. I would like to point out, however, that the confirmation we have already is very remarkable. The statistical analysis of well records and that of Woods' crop experiments were worked out independently and the way in which the periods during which water is wasted correspond with the peaks of Mr. Wilsdon's regression curves, is surely sufficient confirmation of the reliability of the work.

Mr. Wilsdon has shown in his reply to the discussion that the method of confirmation suggested, *i.e.*, the monthly observation of wells, is not practicable and we have at present no other suggestions as to methods from which confirmation can be obtained. Moreover, we cannot wait for an indefinite time for further confirmation as the waterlogging danger is advancing rapidly. Measures on a large scale to combat it are required in the near future.

I am entirely in agreement with Mr. Wilsdon that restrictions of supplies based on his statistical work should be put in force in the areas threatened with waterlogging and also in areas which may not at present be threatened but where restriction of supplies will have an effect on the waterlogged areas, *i.e.*, where such areas are dependent on supplies from feeder channels passing through the waterlogged areas. I would, however, institute such restrictions only to the extent required to eliminate wastage. Up to this point the effect of restrictions on the subsoil water is costing us nothing, but as soon as the restrictions on supplies results in restriction of area of crop matured, the method becomes an extremely expensive one.

Mr. Roberts has stated that the loss to the zamindar per acre of cultivation of which he is deprived is about 5·3 times the loss to Government. The loss to Government per cusec of water will be in the neighbourhood of Rs. 2,000/- per annum. In consequence the total loss works out to about Rs. 12,600/- per annum, representing a capitalised value of $2\frac{1}{2}$ lakhs per cusec, which would justify a very considerable expenditure in the way of pumping or Drainage scheme.

The following is suggested as the general considerations on which anti-waterlogging work should be based in the future.

From the study of the well records we can predict more or less accurately the future movement of the subsoil water level. Its rate of rise can be determined in any locality, allowance can be made for the reduction in the rise consequent on its approach to the surface, and we can predict at what future date the water surface will arrive at any given level. The calculations assume of course that past irrigation practice continues unmodified. Mr. Lindley working on these lines, has already prepared maps of the Rechna and Chaj Doab showing the time at which

the subsoil water will rise to the surface in each area. We do not, however, intend to let it rise to the surface and consequently we require to modify these maps to show the time at which the water will rise to the maximum level consistent with the safety of the land.

Having determined what restrictions of supplies are practicable consistent with no limitation of agriculture, the effect of these restrictions on the rate of rise can also be estimated and the future progress of the subsoil water level corrected accordingly.

The results of this work will show us the areas which will require attention in each year in the future, and by applying the rate of rise as estimated for that year, we can estimate the amount of water which will require to be removed from the subsoil to safeguard the land.

The rest is a matter of plain engineering. We will have to remove a definite amount of water per annum from the subsoil in a definite area and it is merely a matter of applying the most economical means selecting them from the various alternatives of drainage, pumping or lining.

Written Reply. By Mr. Wilsdon.

1. The discussion has mainly centered round a few points relating to the significance of the statistical results. I must profess myself somewhat disappointed as it was my hope to induce Agricultural experts to discuss the feasibility of restrictions of irrigation. As the objections raised are entirely based on a wrong interpretation of the results I will endeavour to answer them generally.

2. The main difficulty experienced is well illustrated by Mr. Roberts' remarks. He appears to be unwilling to accept the implications of the statistical results as he feels that irrigation water applied to the soil during May and June should exhibit a positive if not a maximum effect on the watertable when measured a year later. He suggests that it should be possible by means of detailed well observations to demonstrate the correctness of the results. Such an attitude appears to me to proceed from a complete misconception of the statistical method. It was of such possible arguments I was thinking when I stated that it is ' safer ' to accept the statistical result on the grounds of mathematical probability alone, rather than by its compatibility with preconceived physical theories. However if the implications of the regression curves are limited to the facts they express there can be no valid objection to their acceptance. Thus the regression curve makes no statement about the *amount* of irrigation water which percolates to the watertable in any month. For instance it merely asserts that extra water given in June is associated with a fall of the watertable *when measured a year later.* Such a relation must involve the whole subsequent treatment and cropping of the soil. It will, therefore, be impossible to obtain direct evidence of the correctness of the result by well observations which can measure quantitatively only one of the many factors concerned. Much as intensive study of all factors of this important problem is to be desired it is necessary to

retain a clear idea of the limitations of experimental methods. It is only by the statistical method that we can hope to gain a knowledge of the integrated effect of the many complex reactions which contribute to the result.

3. This brings me to Mr. Murphy's arguments on the subject of irrigation during the early *Kharif* months on the Upper Chenab Canal. He states that investigation shows that of the discharge in *Kharif* channels given during April or May little or none is utilized in actual irrigation. He naturally supposes that such waste water should be shown by positive regressions on the rise of the watertable. Secondly he has taken the change in the well levels for the year 1926-27 and attributes the marked decrease in the rate of rise to the restriction of irrigation during April and May and the complete closure during January. That there has been an exceptional change in the watertable not predicted by the regression equation can be seen from the diagram reproduced in Fig. 1. But it will be necessary to examine our facts much more closely before we can legitimately utilize this discrepancy between the predicted and observed effects as a disproof of the general equation. In the first place it must be noted that out of the 20 years record on which the statistics are based during six years there was no irrigation at all. Moreover, even now the ratio of canal to well-irrigated area is as 7 : 5. It is, therefore obvious that the features of the regression curve deduced from the record must be very largely determined by the influence of rainfall on well-irrigated agriculture. Again it must be borne in mind that the regression curve developed refers to the whole area irrigated. The regressions on individual wells given in the memoir (*e. g.*, Gujranwala Distributary, p. 14) as explained therein are not sufficiently reliable to warrant our drawing conclusions as to the behaviour of *Kharif* channels. When Mr. Murphy discusses complete closures until June it must be remembered that his arguments cannot apply to the whole area. Perennial and well irrigation must determine the greater proportion of the reaction of the watertable considered for the *doab* as a whole. Therefore, when we consider the general effect of irrigation during early *Kharif*, I do not find it difficult to imagine that increased rainfall or irrigation during these months may increase the area sown, or decrease the area which might otherwise fail, in such a manner that the final effect is a *fall* of the watertable. The water-course experiments for perennial channels do not show a marked amount of wasteful irrigation during these months. I feel that Mr. Murphy is over-emphasizing the obvious waste of irrigation water on *kharif* channels which may be regarded as already waterlogged. Our policy of restrictions must, however, be directed with the object of preventing areas threatened with waterlogging, but still capable of perennial irrigation, from becoming reduced to the same state. Therefore, while agreeing that wasteful irrigation should be prevented by complete closures during April and May on channels where there is no dry cropping, we should be making a very great mistake in adopting any measures which will tend to discourage dry cropping on perennial channels. I frankly admit that the truth of the hypothesis

which refers the negative period of the regression curve to well irrigation still remains to be proved, but I hope soon to be able to collect data which will enable an analysis to be made. For the time being I feel very strongly that on the grounds of probability we are not justified in neglecting this portion of the result.

4. As regards the relative effects of the April and May restrictions, and the January closure of 1926-27 we can only make surmises at present. It is necessary to point out however that the effect of the April and May restrictions cannot be as great as Mr. Murphy appears to believe. The following table shows the normal irrigation and rainfall (I_o and R_o) and that for 1926-27, during April and May :—

	April.	May.
I_o	1·07″	1·42″
R_o	·74″	1·15″
I_{27}	1·00″	0·81″
R_{27}	0·26″	1·25″

It will thus be seen that irrigation was practically normal during April but was 0·61″ in defect during May. The departure from the normal W (the total water added to the soil) during these months is thus about half an inch in defect. Even if we were to assume that the negative regressions were wrong and should be replaced by the maximum positive value of about 3. We should not expect a fall in the usual rate of rise of the watertable of more than about four inches for the two months. I am inclined to think that most of the variation should be attributed to the complete closure during January. During this period the observed regression is high, and is positive. The regression equation will not however take account of the unusual stopping of all percolation which effect, as explained in the paper, will appear in the slow changes. We cannot yet calculate this effect from the statistics, but I cannot agree with Mr. Dhody that the contribution of main canals and distributaries is likely to be unaffected by the time factor. He appears to have confused in his mind the observed sinkage of water as determined by Kennedy, with the *gain* of the watertable. These are by no means necessarily identical. Actually there is every reason to suppose that the evaporation from the soil of water absorbed from channels will follow a curve determined by the average humidity. This will mean that the proportion of the water which leaks through the bottom and sides of channels to swell the watertable will be greatest during the Monsoon and the winter

months December and January and at its minimum during April, May and June. For this reason I feel that the January closure is mainly responsible for the unpredicted effects observed in 1926-27. It is necessary however to observe considerable caution in the interpretation, in the light of the regression equation, of results obtained by entirely unusual variations of factors previously constant. A discussion of the relative responsibility of percolation from the main line of the Upper Chenab Canal for the rise of the watertable does not come within the scope of this paper. Since the majority of the variation in W (the water applied as rainfall or irrigation) which is the basis of the regression, will be due to rainfall and variation in the amount of irrigation water utilized which leave the percolation factor constant (except in so far as the latter is a function of the time of year) we cannot legitimately draw conclusions which refer a result observed when the previously constant factor is varied entirely to that factor. Thus we are not justified in saying that the large fall in the rate of rise observed when the canal was closed in January is due entirely or even largely to the stopping of percolation in the main line. The unusual variation must also affect the losses from other causes which will not be predicted by the regression curve.

5. In conclusion I may say that we have still much to learn from the proper analysis of available statistics, which, after all, only formalises our experience. Mr. Dhody might be reminded with profit to the clarity of his thinking that the mere statement of a problem is the first and essential step towards a solution. I feel that we have advanced for beyond mere statement and we have now quantitative estimates of the probable effect of measures we may take, as well as evidence of their feasibility in agricultural practice. As Mr. Haigh says, the rest is a matter of plain engineering; but this must be preceded by some efforts in the direction of clear thinking.