THE SUBSOIL WATER TABLE UNDER THE TRACT IRRIGATED BY THE LOWER CHENAB CANAL.

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Introduction.

The object of this paper is to discuss the conditions of the subsoil water-table and flow under the tract of country lying between the Chenab and Ravi rivers, under the influence of percolation inflow from channels of the Lower Chenab Canal system, and to draw such inferences as seem justifiable.

The material consists chiefly of data specially recorded from October 1916 to January 1917, but older records of spring levels have also been drawn upon. The enquiry was originally taken in hand, with the object of diagnosing, if possible, the causes of water logging in portions of the Gujranwala District, near Hafizabad, Pindi Bhattian, Thatha Raika, and elsewhere.

The following are the capacities of the more important channels traversing the tract in question :—

Main Canal,	discharge	11,000 cusecs.
Gugera Branch,	,,	5,000 ,,
Jhang Branch,	,,	3,000 ,,
Rakh Branch,	,,	1,100 ,,
Mian Ali Branch,	,,	574 ,,
Kot Nikka Branch,	,,	300 ,,

With the exception of the first fifteen miles of the main canal, which is in cutting, all these channels are more or less embanked.

The following five plates accompany this paper—

Plate 1, recording the reduced spring levels observed at various points during October 1916, with corresponding contour lines. Along any given contour line subsoil water stands at the same reduced level.

Plate 2, recording similar information for January 1917, and in addition the lines of subsoil water-table level minima, *i.e.*, troughs, lines of surface drainages, and also certain data relating to discharges of the Chenab observed during December 1916 and January 1917. It may be mentioned that the record of spring levels on these plans is not confined to the canal-irrigated tract, but extends to wells in the unirrigated tracts up to the banks of the rivers, and also includes observations of supply level in the rivers.

Plates 3, 4 and 5 are various longitudinal and cross sections, illustrating the relative position of the natural surface of the ground to the underlying water-table.

Sources of Subsoil Water Supply—

An examination of Plates 1 and 2 will show that the sources of water supply to the subsoil underlying the Lower Chenab Canal are :—

(*a*). *An underground inflow* from the subsoil of the tract lying between the head of the Lower Chenab Canal and the foot hills ; bounded by the Chenab and Ravi rivers, and partly irrigated by the Upper Chenab Canal. The subsoil of this tract appears, in turn, to be principally fed by water from the Jammu hills to the north-east.

(*b*). *An inflow from the River Chenab* in the reach lying between section lines viii and xv.

(*c*). *An inflow from the River Ravi* in the reach lying between section lines ix and xviii, which is most marked in the reach between sections xiv and xvii.

(*d*). *Percolation from the main canal, branches, distributaries, etc.*, of the Lower Chenab Canal, which is mostly in evidence in the tract lying between section lines i and vii, and traversed by the main canal and its branches.

(e). *Rainfall.*—The percolation inflow of rain water is not considered to be an important factor in the tract under discussion, as the average annual rainfall towards the head of the canal only amounts to fifteen inches, and elsewhere to less than ten inches. The soil is of a very close texture, and experience shows that before moisture can penetrate very far, it is again drawn up to the surface and evaporated.

(f). *Percolation from canal irrigated fields.*—This question has been frequently debated in the past, but it is believed that, as in the case of rain water, very little water from this source reaches the water-table, and in any case there is ample evidence on Plates 1 and 2 to show that in comparison with the percolation inflow from rivers, large canals and escape reservoirs, in which water flows or stands nearly throughout the year, all other sources of percolation influence the subsoil water-table to a quite insignificant extent.

Description of the Water-table.

The contour lines on Plates 1 and 2 illustrate the configuration of the water-table Generally speaking, these lines form salients, which point either seawards, or towards the hills; he former indicating ridges of high spring levels, and the latter troughs of low spring levels. The arrow marks along these lines on Plate 1 indicate the direction of the flow of the subsoil water.

It will be seen that the water-table is continuous and connected; that it is undulating and not level; and that the subsoil water is not at rest, but flows from points at which spring level is higher towards points at which it is lower.

Direction of Flow.

Plate 1 indicates that the general direction of subsoil water flow is the same as that of rivers and surface drainages, namely seawards. It may take a shorter and easier route and discharge into an adjoining river or stream, which is in itself flowing towards the sea, and such a condition exists under the tract lying to the right of the main canal; or it may follow a more prolonged course, as it does under the rest of the tract. As regards the direction of the flow of components, this is outward from the source of percolation, and forward toward the sea; the general resultant flow being at an angle of forty-five degrees to the line of the rivers, until a trough is reached, whence the flow is forward.

Drainage of the Subsoil.

Since water is flowing into the subsoil, it follows that there must be both an outflow and a drainage system. The drainage system under the Lower Chenab Canal may be divided into two parts (Plate 2) namely ; that lying to the right of a line along the main canal, to the Jhang branch as far as the Beranwala reservoir, and thence connecting well No. VII-50 with a point midway between wells Nos. VIII B. and IX B., and bounded on the north by the Chenab river. The water-table under this tract (A) (Plate 1) is fairly even, and inclines towards the River Chenab, and westward. The subsoil does not drain into the river at any particular point, but the inflow is more or less evenly distributed throughout the reach lying between point I A. and a point midway between VIII A. and IX A.

Below the rest of the tract (B) there are two branch troughs in the water-table ; one running between the main channel of the newly constructed Upper Chenab Canal and the main line and Gugera branch of the Lower Chenab Canal, which crosses the Gugera branch above the Buchiana reservoir. This is joined at well No. VIII-63 by another branch trough, which runs between the Rakh and Gugera branches and thereafter there is one clearly defined trough running approximately under the middle of the tract, and terminating on the banks of the Chenab near point XVIII A.

The cross sections on Plate 5 illustrate various trough formations, which may be concave or even have a flat bottom.

Inflow into the Rivers.

With a view to estimating the extent of inflow of water from the subsoil into the two rivers, and of locating, if possible, the points of inflow, a series of discharges were observed at various points of the Chenab during December 1916 and January 1917 ; the results obtained have been detailed on Plate 2, and may be summarised as follows :—

The discharge below the offtake of the canal at Khanki was 30 cusecs, and at Partraki ferry (the tail end of tract A.) 379 cusecs, so that the inflow amounted to 349 cusecs, while the increase in the reach extending from the Chiniot ferry to just above the junction of the Chenab and Jhelum amounted to 940 – 370 = 570 cusecs.

The discharge of the Jhelum, immediately above its confluence with the Chenab, was 639 cusecs, while the discharge of the

Chenab above the junction was 942 cusecs. The discharge of the Chenab above its junction with the Ravi was 2,494 cusecs ; that is to say its discharge had increased by 2,424 – (942 + 639) or 913 cusecs between the two junctions, and by 2,494 – (30 + 639) or 1,825 cusecs between Khanki and the Chenab—Ravi junction.

No discharges were observed of the Ravi, because the levels on Plate I clearly showed that there was nowhere an outflow of subsoil water into this river.

Unfortunately, these discharge observations do not lead to any definite conclusions as to the net outflow of subsoil water from the tract. An examination of the levels of supply in the Chenab and of the spring levels in adjoining wells (Plates I and 2) show that conditions vary from point to point, and that while in some reaches there is an inflow of subsoil water from the land towards the river, in others the conditions are reversed. Arguing from analogy, it may be assumed that similar inflow and outflow is taking place on the opposite bank of the river, and isolated tests have established the correctness of this assumption. The position therefore is that somewhere there is an inflow to and somewhere an outflow from the river, from and to the adjoining subsoil, and from and to either bank. In short, where the water-table of the adjoining tract stands at a higher level than the supply level in the river, subsoil water flows towards the river, and *vice versa*. Clearly, therefore, the only information that can be gleaned from these discharges is the extent of the net increase from point to point, while it is not possible to account in detail for that net increase.

As regards outflows into the river, it may be definitely stated with reference to the Lower Chenab canal tract, that subsoil waters do not unite at troughs, and then flow into the river, at the outfalls of surface drainages only ; or that at every surface drainage outfall an inflow of subsoil water may be expected. There is ample evidence on Plates I and 2 to show that there is no concentration of subsoil water in its approach to the river, but that on the contrary the inflow is diffused, and the subsoil may in turn both feed and be fed by a river.

Water-table Ridges.

An inspection of Plates I and 2 shows the existence of ridges of high spring levels in certain portions of the water-table ; for instance, under parts of the Upper Chenab Canal, on the head reach, near Gujranwala, and opposite Lahore ; but by far the most important one is that underlying the main line of the

Lower Chenab Canal, continuing under the Rakh branch down as far as Sangla, and under the Jhang branch as far as the Beranwala reservoir, and this ridge with its right flank underlies the water logged area. It is now proposed to make a detailed study of this ridge in all its aspects, with a view to extracting all the information possible on the water logging problem.

Plate 4, and Fig. 3 of Plate 5, illustrate two cross sections of the ridge, and Figs. 2, 3 and 4 of Plate 3 illustrate longitudinal sections originating on the ridge, and running in the direction of the flow.

The progressive rise of spring levels that took place between the years 1886 and 1916 in the wells of section line No. II, which crosses the main line at the head of the Kot Nikka branch, is illustrated on Plate 4. There is no record of what the level of the water in the river was in 1886 at its intersection by cross section line No. II, but assuming that it was not very different to what it is now, it is clear that, whereas in 1886 the river supply was four feet higher than the spring level in well No. II. 9 (which is close to the main line of he Lower Chenab Canal) the conditions were reversed long before October 1916, and the water in this well is now 23·80 feet higher than that in the river, having risen 27·80 feet; and the subsoil water is now within 2·20 feet of the natural surface, having been 30 feet distant in 1886.

In the year 1886, therefore, there was an inflow through the subsoil from the Chenab, towards the main line; or in other words the conditions of the water-table under tract A, were at that time similar to those still obtaining under tract B, which may be assumed to be the normal conditions.

The sudden and marked rise of spring levels that took place in the interval between the years 1897 and 1905 is noteworthy, for this rise will be found to synchronise with the running of increased discharges in the main line, consequent on the development of irrigation. Since 1905 the spring level near the canal has been practically stationary, and so has the level of supply in the main line.

In view of all these facts it seems safe to conclude, that not only does this ridge owe its existence to the heavy percolation from the main line, and, to a lesser extent, from the Rakh and Jhang branches; but that the rise of spring levels in the tract between these canals and the Chenab is due to the same cause. Subsoil water from the ridge has selected the Chenab

as one of its outfalls ; it has gradually permeated the surrounding subsoil, and has raised the water-table, until now the water slope from the summit of the ridge to the outfall is represented by a line which is nearly straight. It may be assumed that this slope is just sufficient to produce a flow which balances the inflow and outflow through the subsoil.

Conditions leading to Water Logging.

Plate 3, Fig. 4 illustrates the relative position of the subsoil water to the natural ground surface in a particular case. A study of this diagram will make it clear that because water logging has taken place in one spot it does not necessarily follow that it will extend to adjacent tracts ; for instance, this section shows that, while in the vicinity of well No. VI-39 (farther from the canal) a state of water logging is imminent, the area round well No. V-28 (nearer the canal) will probably never be so troubled. In short it may be said that water logging will be confined to depressions of the ground which are low enough to intersect the subsoil water-table.

Form of Ridge.

As indicated by contour lines on Plate I, the form of the ridge is peculiar. The comparatively obtuse salients near the head of the Lower Chenab Canal get gradually more and more acute as they approach Nanuana (well No: IV-21), where a maximum is reached ; thereafter they again grow gradually more and more obtuse and extend across both the Jhang and Rakh branches, until at well No IX-70, and contour line 550 they cease to exist ; an indication of the dissipation of the ridge. These features are striking because the off-takes from the Jhang branch above the Beranwala reservoir are quite unimportant, and not such as to reduce the capacity of, or percolation from the branch, to any appreciable extent. Had the ridge been to any considerable extent dependent on percolation from the Jhang branch clearly it would not have dissipated so early.

The potent source of percolation that causes this ridge, and maintains it, appears to be the main canal. The contours on Plate I indicate that while a certain portion of the percolation from the main canal disperses laterally to the right and left, the remainder is moving forward under the main line and then continuing under the Jhang and Rakh branches till it is finally dissipated. No doubt these two branches add their quota of percolation water to the water-table, but it is believed

that were it not for the forward flow of percolation from the main canal the ridge under the two branches would not be so formidable.

The gradual sharpening of the contour salients, referred to above, appears to be due to the same cause, for the subsoil in the vicinity of wells No. IV-21, V-30 and 31, has not only to dispose of local percolation, but also of the body of water which is coming forward from higher up the main line.

Absence of Ridge under the Gugera Branch.

The absence of a ridge under the Gugera branch with a capacity of five thousand cusecs, while there is one both under the Jhang branch, with a capacity of three thousand cusecs, and under the Rakh branch with a capacity of eleven hundred cusecs, calls for some comment. The explanation of this pecularity seems to be that while the main canal and the Rakh and Jhang branches flow in the same direction as the subsoil water, namely seaward, the Gugera branch flows athwart the direction of subsoil flow. Consequently, percolation from the branch flows off to the right as it takes place, and none of it travels forward under the channel to add itself to the percolation from the lower reaches and cause the formation of high ridges. It should be noted that no sooner does the branch curve round (well No. V-36) and take a seaward direction, than a ridge is formed.

Here there are two distinct conditions, and it seems safe to draw the general conclusion that the prevention of leakage from the main line would have the effect of not only lowering the spring level on both sides, but also under the Jhang and Rakh branches ; and with these improved conditions it would probably never be necessary to line any of the branches.

Controlling the rise of the Water-table.

Any action which has for its object the lowering of the subsoil water-table, or arresting its further rise, must be designed to act effectively in one or more of the following directions :—

1. Lowering the level of the outfall of the subsoil water.
2. Reducing the resistance of the subsoil to the passage of water.
3. Removing any local obstruction which may be tending to produce a hump in the subsoil water slope, and to raise the water table behind it.
4. Reducing percolation from canals.

In order to simplify the statement of the case, it is proposed to explain the four points mentioned above, by discussing the specific question of percolation from the main line.

Lowering the level of the outfall.—A lowering of the outfall would have the effect of lowering the entire water-table from outfall to source; but the subsoil water outfall of the tract to the right of the main line is the Chenab, and as this cannot be lowered, no help can be looked for in this direction.

Reducing the resistance offered by the subsoil.—It may be taken for granted that it is not within the range of practical engineering to increase the porosity of the subsoil; this factor may therefore be neglected.

Removal of obstructions which interfere with the subsoil flow.—It is necessary to make it quite clear that the class of obstruction referred to here is not soil obstruction, but obstructions caused by local high water-tables which lie across the path of a more important subsoil current. Such a case is typified in Plate I. It will be seen that the symmetry of the contours has been disturbed in the vicinity of well No. VIII-66 by heavy percolation from the Buchiana reservoir. The effect will be more readily realised by a reference to Fig. 1, Plate 3; the high spring level at well No. VIII-66 will be seen to obstruct the free forward flow of the subsoil water coming from the direction of well No. IV-26. In this particular case there is no immediate danger, but it can be readily realised that if the water-table were relatively higher, certain tracts lying between well No. IV-26 and the reservoir would be water-logged and the obvious remedy then would be to prohibit any escape of water into the reservoir. In other cases it might be possible and necessary to divert a channel that proved troublesome.

The reduction of percolation.—This course is obviously by far the most important, since percolation is the source of the whole evil, and the more it can be reduced, the less will be the troubles to be contended with; efforts in the past have therefore been in this direction.

Remedial Measures.

Lining of Channels.—Certain lengths of large, medium and small channels of the Lower Chenab Canal have been lined or water proofed, and if this measure were carried far enough, it would give successful results, but one of the objections to it is the excessive cost, and another, that it is not always possible to

arrange for sufficiently long closures of the canal to allow of the work being carried out.

In any case the methods of selection of lengths to be lined has not been systematised. More often than not it has been assumed that the canal nearest to the water-logged area is the one calling for treatment. Subsoil water-table surveys, such as those on Plates 1 and 2, make it possible to review the whole situation, and to trace back the flow from the water-logged area to the source, and if the general plan is not sufficiently detailed, a more complete survey can be prepared for the particular tract, when action with a definite end in view can be taken. The indication is that the main canal should be dealt with in the first instance, and when this has been done the effect should be studied, and other channels dealt with if necessary.

Withdrawal of canal irrigation—This is a course that has been followed in certain cases, when distributaries have been entirely closed with the object of cutting off the body of water percolating from irrigated fields to the water-table, as well as the percolation from the channel itself, but as regards the first of these objects, it has been already mentioned that the quantity of water that reaches the water-table from irrigated fields is believed to be negligible. As regards percolation from channels, it depends on the size of the channel whether the inflow is material or not. Taking the case of the Jagganwala distributary, which used to irrigate the tract lying around wells Nos. II-9 and 10. This was a small channel with a discharge of only five cusecs, and was nowhere more than three miles distant from the main canal, while a reference to Plate 4 will show that the preponderating cause of the high water-table under this tract is percolation from the main line with its discharge of eleven thousand cusecs, and it may be concluded that the percolation from the Jagganwala distributary was never of any consequence.

So far as the tract irrigated by this distributary is concerned, the water-table is so close to the ground surface that there is no need for canal irrigation, but in future cases, where action of this kind is contemplated, it would perhaps be as well to roughly estimate, to see whether the withdrawal will be worth while.

Restriction of Irrigation to the Kharif Season.

This is another method, which has been introduced of late years both as a curative and preventive measure. There can be little doubt but that during the six months that the kharif branches

and distributaries are closed, percolation entirely ceases. The subsoil has the opportunity to drain away water received during the summer months, and if this happens the water-table will revert to its normal low level, but it should not be assumed that this will happen as a matter of course in every case, for if the water-table of the tract surrounding the kharif tract is high, the subsoil of the latter will certainly not drain.

There is one other drawback to this system of irrigation, and that is that kharif channels have a capacity of about treble that of perennial channels for corresponding areas, and as this means greater percolation, it is possible to do more harm than good with this system if areas are selected promiscuously and without regard to water-table conditions.

Surface Drainage of water-logged Areas.

On the Lower Chenab Canal, depressions, which have been converted into swamps by the rise of the water-table, have been successfully drained by means of surface drains. Some of these drains have proved expensive to excavate, while all will be troublesome and expensive to maintain. There will be an annually recurring expenditure on maintenance, and it remains to be seen whether this method will really prove economical in the end. In any case the effect of a surface drain is purely local ; it only lowers the water-table in its immediate vicinity, so that a system of surface drainage cannot be expected to lower the water-table generally, or even to arrest its rise.

It has been stated that permanent beneficial results have been attained by the introduction of a system of surface drains in the Delhi branch tract of the Western Jumna Canal, but before this statement can be finally accepted, it will be necessary to closely examine the data on which it is based, with a view to seeing whether all other conditions obtaining prior to the excavation of these drains are unchanged. One material change at least has been made ; namely that owing to the extension of irrigation to the Sirsa branch and other tracts, the Delhi branch is run for shorter and closed for longer periods during the winter season, and this is a very potent factor tending to lower the water-table, and it is not, therefore, possible to attribute the beneficial results to the action of surface drains alone.

DISCUSSION.

MR. C. G. MAY, in introducing his paper, said that he had been working on the subject for about eighteen months, and that the paper represented some of the results of his labours. He was ready to admit that it was little more than an elementary introduction to a difficult subject, but he hoped that it would arouse interest and draw others into the field of enquiry. He, however, warned both critics and enquirers against drawing general conclusions, where only specific ones were justifiable.

MAJOR SOPWITH said that as he had been engaged during 1912 in a detailed examination of the subsoil conditions around Delhi, it might be of interest to hear some of his conclusions, as bearing on certain aspects of the questions which formed the subject of Mr. May's paper. There were three points which should be kept in mind, as of practical importance in any consideration of the state and condition of the subsoil table. First, it was desirable to have a practical definition of water-logging, and he suggested that it might be taken for granted that a water-logged condition had not been reached, from a purely agricultural point of view, so long as the subsoil water was more than ten feet from the ground surface. From a sanitary point of view, however, this depth below ground surface was not sufficient, and, as on this depth depended, to a large extent, the intensity of malaria prevalent, and consequently the health of the people and their capacity for work, this consideration was indirectly important from an agricultural point of view. After discussion of the question with expert sanitary authorities he suggested that a figure of fifteen feet below ground surface should be considered as the limit of water-logging conditions on this account.

Secondly, as Mr. May had gone into the question of the influence of rainfall on the subsoil table, the following note on this subject might be of interest :—"The raising of the water table by rain alone cannot be very great in the Punjab. From the memoranda of the Department of Agriculture in India, published in 1912,* it is shown that evaporation and transpiration account for from 16 inches to 24 inches of rainfall ; the evaporation being practically constant, and independent of the total amount of rainfall. Consequently, in the Punjab, where the

* Records of Drainage in India by Dr. J. Walter Leather, Ph.D. F.I.C., &c.

total annual rainfall is not very great, the amount that goes to swell the subsoil lake, by percolation, can be but a small quantity."

These experiments, carried out at Cawnpore, and in the Bombay Presidency, had extended over a period of seven years ; they related to the effect of local rainfall on a flat surface, and consequently did not cover completely the case of a large underground flow due to heavy rainfall in neighbouring hills, the flow from which would certainly, in part, be underground, and would tend to affect the subsoil water condition.

Thirdly, in his list of sources of subsoil water supply, Mr. May had not included a very interesting theory advanced by the late Mr. Barnes. This theory applied, strictly speaking, not to the source of supply, but to the prevention of escape of subsoil water to the outer air by the action of soil gases, and it was, therefore, of practical importance in considering the whole question of water-logging. Mr. Barnes thought that, quite apart from percolation from the canals, water-logging conditions would be established, if the movements of the soil gases were interfered with by filling up the air spaces between the soil particles by irrigation, and he therefore concluded that " water-proofing the canals does not provide a cure for the water-logging of the soil of the Colony (he was writing of the particular tract, with which Mr. May's paper deals) but can, at best, only put off the evil day." The arguments were based on enormous assumptions (which are obvious) and Mr. Barnes modified his views largely at a date subsequent to the writing of his note, but the action of soil gases was sufficiently important to be considered in any physical examination of water-logging conditions.

Mr. May considered that percolation from irrigated fields had little effect in raising the water-table, and while this effect was probably small, when high efficiency in the distribution of irrigation water by zeminders was reached, yet, when such efficiency had not been reached, it appeared certain that the effect could be very great, and the following note which he had made on the conditions in the Durbar area at Delhi in 1911 and 1912, appeared to bear out this contention.

"The first area to be examined was that on which the Durbar camps were situated in 1911. During some 5½ months, the distributary which supplied this area ran continuously, and no

rotational turns were in force. Consequently, something between two and three times the normal quantity of canal water passed down this distributary. The total area of the camp was 900 acres, of which 265 acres were irrigated. The water supplied was equivalent to a depth of about five feet over the whole area, and about seventeen feet over the actual irrigated area. The camp sites, previous to the Durbar, had been ordinary agricultural land subject to ordinary irrigation. The actual level of the subsoil table, before this excessive flow of water commenced, was unfortunately not on record, but it was an ascertained fact that the level at the close of the Durbar was very much greater than it was at the beginning. In one place, where actual well measurements had taken place, it was ascertained to have risen seventeen feet, but it must be remembered that the influence of percolation from the Delhi branch of the Western Jumna Canal also affected the area, and consquently the rise would be affected by this inflow, as well as by the inflow from the distributary, which ran through the area. During the period, 19·8 inches of rain fell, of which 3·6 inches fell in one day, and 11·6 inches in three consecutive days. A vast flow of surface water occurred on each occasion from the area in question, and the amount going into the subsoil must have been very small. As the method of treating the surface of the ground, while the Durbar gardens were being prepared, differed but little from the method employed over the same irrigated area before the Durbar, there is not much reason to suppose that evaporation losses were decreased during the Durbar operations. A lengthy investigation of the conditions of the subsoil table was undertaken during 1912, and the interesting fact was brought out that the water table sank one-and-a-half to three-and-a-half feet between the end of January and the begining of April, a period of just over two months. This coincided with a resumption of normal irrigation conditions, with periodical closures of the Delhi branch of the canal, and since the ground surface was some twenty-five to forty feet above the Najafgarh Jhil drain and the Jumna river, which were the main drainage lines, the run off of the subsoil water might have been expected to have been at a greater rate than that indicated, but the soil in this area appeared to be somewhat difficult for water to pass through, since a cross section revealed the slope of the water table towards the Najafgarh Jhil drain to be about 1 in 1,100 ; tts depth below surface at its head being about seven feet,

while another cross section to the Jumna river showed a water-table practically level and three feet below ground surface for 6,500 feet, and then a fall of about 1 in 500 from that point to the river. The curious hump of water revealed at the top of this cross section was clearly due to the heavy irrigation of the gardens, situated at this point, being carried on during this period, and an excessive watering having been effected just before the measurements were taken for the cross section. All this tends to prove the great effect that percolation from canals and percolation from excessively watered areas has on the level of the subsoil water, and its consequent tendency to cause water-logging."

Another most interesting example investigated was that of an area some ten miles north of Delhi, near Siraspur. A careful examination of statistics, from 1891 to 1911, shewed that the number of cusec-days decreased on the average by thirty-two per cent. after 1896, when the Sirsa branch was fully developed. The villagers, finding themselves with less water, took more trouble, and ceased from very excessive watering, with the result that the area of irrigated land in the rabi increased by two to three hundred per cent., and consequently much less water percolated into the subsoil and the subsoil table automatically lowered itself by ten to fifteen feet* and has never subsequently risen to anything approaching its former level. The extra area irrigated would tend to decrease evaporation, by filling up the space between soil particles over a greater area, and therefore the fall in the table could only be attributed to the decrease of percolation of canal water from the channels and from the fields. In other words, the percolation of canal water from channels and fields was solely responsible for the water-logged condition of the soil previous to 1896. The subsoil level appeared to have been very slightly affected by rainfall ; only in one year, 1900, did the curve follow the rainfall curve, when the subsoil table rose some five feet gradually, and that year was distinguished by a wet June, July, August and September, with soaking rain, and an absence of heavy and intense storms, so that the rain-water had exceptional opportunities to soak downwards into the subsoil.

Mr. May doubted whether the introduction of a system of surface drains in the Delhi branch tract of the Western Jumna

* Before 1896 the spring level was five to ten feet below the surface ; after 1896 it was twenty to twenty-five feet.

Canal had alone produced the beneficial results observed in the subsoil conditions, and the above note bore out his supposition that the decrease in the quantity of water, due to the opening of the Sirsa branch, had had a great effect on the lowering of the subsoil table.

He had, further, examined investigations that had been made as to the effect of natural drainages from the canal area into the Jumna, in 1906, 1907, and 1913. A series of discharges, at intervals of about ten miles, were taken in the Jumna bed in January 1913, a time when practically the whole river supply was drawn off by the canals, and the visible flow was due only to such water as might spring up in the bed, or percolate back from the land bordering the river. It was found that the discharge was practically constant from Begi Ghat to the junction of Main Drain No. II ; it then began to rise till fifteen miles downstream, an increase of about 160 cusecs had taken place. This increased discharge remained more or less constant for another thirty-five miles, and then began to increase again steadily as far as Delhi, this increase coinciding with the junction of Main Drain No. VI. As these drainages were actually dry at the time, the increase in discharges could only have been due to an underground flow, so that the drainages would appear to have been fulfilling their function, though a subsoil survey would have been necessary to confirm this in detail. A full examination of the question led to the conclusion that no river water came to the surface in the bed, and that all visible flow in the Jumna, when the whole supply above Tajawala had been taken by the canals, was due to percolation back into the river from irrigated areas, and from rainwater, flowing underground. As the rate of increase in the discharge below the head of the Delhi branch was much less than that above, where much more water flowed in the canal, the conclusion seemed obvious that the great factor was canal water and not rain water, while water springing up, after reaching the river bed, would seem to have been due to the high level of the subsoil table, and its consequently high head. It was worthy of note that, as ascertained in the investigations of 1906 and 1907, above the head of the Delhi branch there was always, even in the driest years, an inflow into the Jumna, while below that point, which coincided with a greatly decreased canal flow (two branches having taken away water—one above and the other at that point), the river, in the very dry years, flowed into the subsoil, as was proved by the gradually decreasing discharges, in those years, between Panipat and Delhi.

This appeared to show conclusively the great quantity of water that percolated into the subsoil from canals which carried large quantities of water—a quantity out of all proportion to the percolation of rain water. The former factor also showed that there was a subsoil flow more or less parallel to the river, at least part of which found a line of least resistance back to the river-bed by underground flow beneath the lines of natural drainages.

His conclusion was, therefore, that dangerous water-logging could not occur only from rain, or from any such treatment of the ground as was done in dry farming, which would prevent evaporation except in the most low lying ground ; on the other hand the effect of the percolation of canal water at a great rate was liable to cause such water logging, if the soil were such that the flow off could not equal the inflow, except by very great heading up, a condition that usually obtained in the Punjab. Complete waterproofing of the canals would go far towards preventing all dangerous water logging, but this would involve the waterproofing of all the channels, which was probably impossible for financial reasons, unless the water itself could be made to waterproof the channels through which it passed, by automatically depositing an even and sufficient layer of argillaceous matter.

By determining the head available, when the critical point of dangerous water-logging was reached, and the rate of flow off from the lake due to that head (which depended on the nature of the soil) it would be possible to ascertain the rate of percolation that could be allowed to take place without creating such conditions, and this would be important knowledge, as complete prevention of percolation was probably impossible in a practical way. The more efficient the cultivator became, in other words, the more economical he was in the use of canal water, the less became the risk of water-logging from extravagant depths of waterings on the land, as was proved by the results of the Siraspur investigation, but this efficiency could only be obtained by decreasing the supply to cultivators using it extravagantly.

Everything pointed to the necessity of an expert physicist working on this problem of the causes and cures of water-logging, in close connection with engineer officers experienced in the needs, possibilities, and impossibilities, of irrigation. Measurements of wells in great numbers, examination of results obtained from drain gauges, careful observations of discharges in rivers and below their junctions, would all tend to increase the knowledge of what was involved ; but it was only by adding an examination of

the soil, the flow of water through it, and the evaporation losses from it, by an expert physicist, that this knowledge could be made sufficiently complete to enable the problem to be tackled boldly.

MR. QUINN-YOUNG had never seen any proof or theory for the frequently made assertion that there was a subsoil water table under the earth's surface, or that there was any inflow riverwards, or outflow canalwards. The commonly accepted idea was that there was below the surface a sheet of water of a certain depth formed by rainfall, infiltration of canal water, and, possibly, gravitation from saturated soils : this he thought a false conception. Mr. May, however, went further, and represented this water-table as actually flowing. If such a water-table existed, it would be possible to reach it when sinking borings, and although he had seen borings sunk to seven hundred feet, he had never yet come across a sheet of water at any depth. He had also sunk deep shafts at the toe of the banks of channels in flow, and had failed to obtain any water by infiltration, even though the shafts went below spring level. He attributed these results to the geological formation of the subsoil, a question which did not enter into Mr. May's paper.

A well or shaft became full of water because the boring caused a break in the continuity of the saturated strata and consequently the water oozed out into the cavity. But this water came from a saturated stratum and not from any water table, and when water was contained in a state of saturation, it was not evident how it could flow in any direction. Subsoil water flowed into rivers on account of a break in continuity, in the same way that it flowed into a well, or as it flowed out from the end of a glacier, or from a saturated sponge. If more water were poured into a saturated lamina, it was not possible to say whether more would flow into the rivers ; it was possible that the saturation would become more intense, or the saturated strata of greater depth.

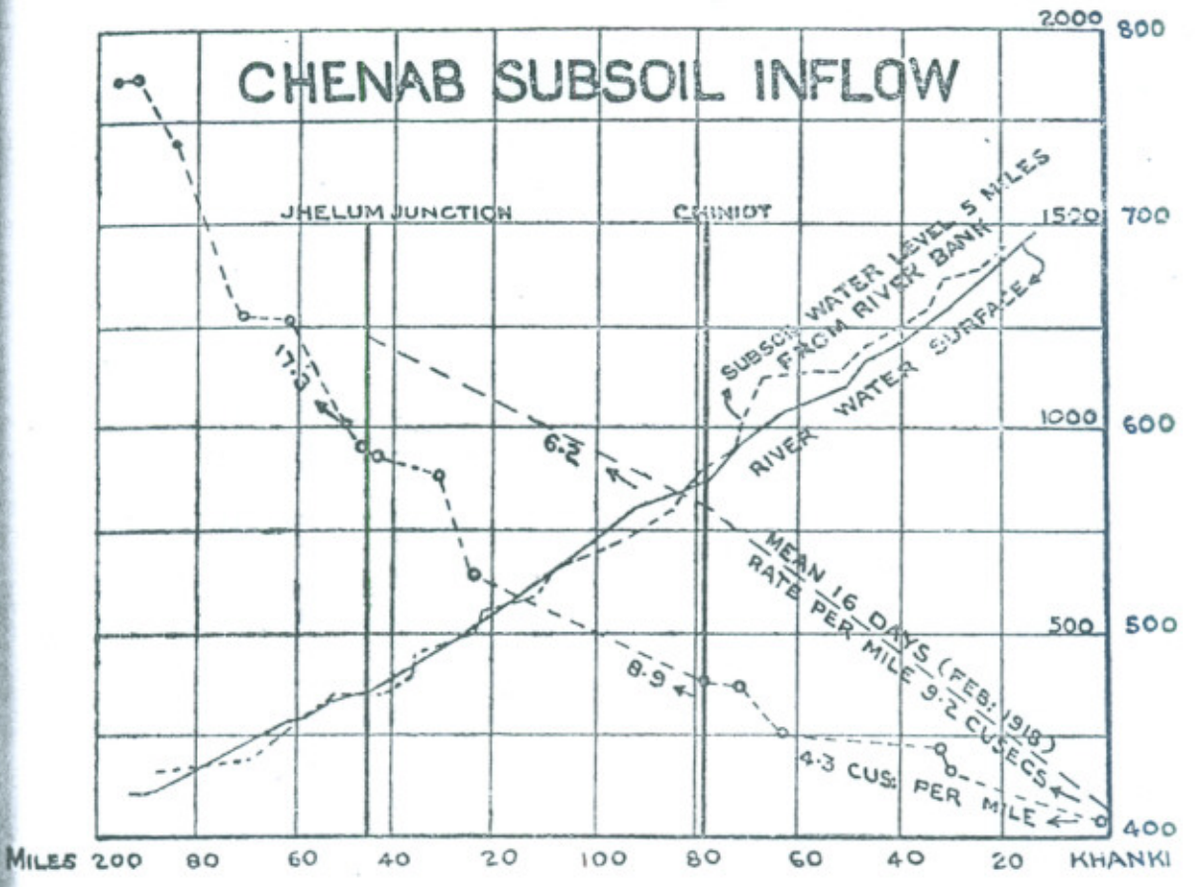
He did not see any reason for Mr. May's flow deductions ; the character of the contours must be influenced by the proximity of the sources of supply and by the nature of the subsoils, which latter had not been investigated. An impervious layer in the subsoil must have some influence in raising or depressing the saturation level, and, unless such were taken into account, false contour lines would be drawn, and false deductions made.

Without complete knowledge, and the aid of the physicist and geologist, it was not possible to draw any definite conclusions as regards the flow of subsoil water. The only satisfactory remedy for restoring water-logged areas was to raise the level of the swamped country by placing over it a good layer of productive earth. This had been done on a large scale in Italy and in the United States ; and in the Punjab it was possible to do the same by raising the areas with the silt borne in the canals. Digging surface drains was only a partial palliative ; it was not restorative.

MR. F. W. CARNE remarked that there was no indication in the paper that the author had considered whether the consistency of the soil had anything to do with water-logging, but surely the existence of a more or less impermiable stratum, comparatively near the natural surface, must have considerable effect. In the case of the main line of the Lower Chenab Canal, where water-logging was so much in evidence, from Bucha to below Sagar, the existence of a stratum of clay was realised as far back as 1906, when some cultivators near Khanki, finding that it hindered the upflow of water into their well, borrowed boring tools to make a hole through the clay. In sinking wells for the lengthening of bridges between Khanki and Chenawan this layer was again encountered, and in an attempt in 1907 to sink a small tube well in the Sagar rest-house compound, the point could only be persuaded to go down a little over twelve feet with great difficulty, for the same reason. The country along this reach of the canal appeared to be like a saturated sponge lying on a plate, and water might be seen oozing back from the land on the far side of the left bank seepage drain into the drain, the upper layer of the soil having become supersaturated. Such an effect would not have been in evidence but for the existence of this impervious stratum some distance below the natural surface.

MR. NICHOLSON thought that all the arguments in the paper were based on the assumption that the whole of the subsoil of the tract was uniform. Doubtless the soil was all alluvial to a great depth, but the Punjab was not formed from the deposit of one flood, but by separate floods which carried various grades of material, and this was noticed in deep borings for tube wells. In any case, it was known that the Kirana, Chiniot, and Sangla hills were only high peaks of a subterranean mountain range, and the existence of this rocky bar might account for holding up

the subsoil water contours, and forming the ridge which in Plate 2 was shewn coming into the Chenab just above Chiniot.



The diagram showed the inflow discharges recorded in the paper, together with the free water surface level in the river, and that of the subsoil water five miles away from the bank, and it would be noticed that the tendency to inflow into the river was much greater above Chiniot than below, though the discharges recorded showed an opposite result. The effect of evaporation had been considered, but did not explain the anomaly. From the Jhelum junction to the Ravi junction the rate of inflow was highest, yet the conditions of subsoil level in that reach on the side of the Lower Chenab Canal pointed to an outflow from the river, and there was no canal irrigation on the other side of the river which could cause such a high rate of inflow. Data of other discharges had been obtained for the Chenab reach and plotted on the diagram ; the results of these pointed to a directly opposite condition to that shewn by Mr. May's discharges and more in accordance with what would have been expected from the subsoil water conditions.

MR. B. H. WILSDON agreed with previous speakers in holding that the character of the subsoil of the doab was a factor which

must not be lost sight of in attempting to interpret the data. There was evidence in the contour maps themselves showing that differences in the rate of accumulation of water in the subsoil could only be interpreted by attributing them to variation in the transmissive capacity of the subsoils. Thus, comparing cross lines II and III in Plate I, which cut the upper Gugera branch and the main line of the Upper Chenab Canal, it was seen that a pronounced salient was produced over the latter, while, as pointed out by Mr. May, no salient was produced over the Gugera branch, although the canals crossed what was assumed to be the normal direction of the subsoil flow in the doab, at approximately the same angle. The fact that the Upper Chenab Canal had produced more effect in the few years it had been running than the Gugera branch, could only be attributed to a difference in the subsoil conditions, and it was noteworthy that this sharp salient corresponded with the Deg Nala. Before any definite conclusions could be drawn from the data provided, further knowledge was necessary of the various factors controlling the question. These were the transmissive constant of the subsoils, which could only be obtained by a thorough subsoil survey, and a more reliable estimate of the amount of water reaching the subsoil from water courses and irrigated fields. Recent experiments at Lyallpur had tended to show that evaporation through the soil, as a factor controlling the accumulation of subsoil water, was negligible.

The collection and expression of accurate data in the form of contour maps was undoubtedly valuable, but it was unfortunate that the data for adjacent doabs were not made available, as any arguments based on the discharge of the rivers was useless unless the form of the contours on both sides was known.

The object of a contour map must be to shew the stream lines, indicating the direction and intensity of flow. At present it was impossible to do this on any reasonable assumption of proportionality between rate of flow and gradient. Thus, it was impossible to crowd the stream lines which passed, for instance, crossline VII, together with those entering from beneath the river on both sides of the doab into the flat gradient onwards to the junction of the Chenab and Ravi. The obvious conclusion was that all the factors had not yet been taken into account. One already mentioned was the transmission capacity of subsoils, and the other was that of time, since it was not justifiable to assume that the contours yet represented a state of steady flow.

MR. WOODS thought Mr. May was mistaken in supposing that the percolation inflow of rain water to the subsoil water-

table was not an important factor as a source of supply to the underground rèservoir of the Rechna Doab, as such a supposition would not be in accordance with the results of experimental observation at Rothampstead in England, at Pusa in India, and elsewhere. The Pusa experiments showed that out of an annual rainfall of twenty eight inches, about fifty per cent percolated through a layer of soil five feet thick, and that the volume percolating did not vary appreciably, whether the thickness of the soil was twenty, fifty, or sixty inches ; so that it might reasonably be inferred that what went through sixty inches would go through any greater depth of soil, down to the subsoil water table. It was true that the annual rainfall of the Lyallpur district averaged only about twelve inches, but the canal irrigation must be regarded as a reinforcement to the rainfall, increasing it to an equivalent of at least thirty inches per annum. Besides this, agricultural operations such as ploughing, hoeing, harrowing, construction of field embankments, and so forth, in an extensively cultivated tract, must have the effect of helping the rainfall to percolate into the soil rather than to be evaporated from the surface. From these and other general reasons the ordinary rough assunption that about one-third of the rainfall percolated down to the subsoil water-table held good in the case of Lyallpur.

The levels of the subsoil water-table were regularly recorded every year, in the months of June and October ; and the fact that the spring level was usually higher in October, after the monsoon rains, than in April, before the rainy season, seemed to prove that the rainfall did percolate to the subsoil water-table of the Rechna Doab. Statistical data indicated that about forty per cent of the rise in the general level of the subsoil water-table of the Rechna Doab was attributable to percolation of rainfall into the soil.

Percolation from canals and water channels generally owed its importance, in relation to water-logging problems, to the fact that this form of percolation was concentrated on the vertical sections of the soil which lay immediately along the alignments of those channels, and thus produced local elevations in the surface of the subsoil water-table which might bring the latter dangerously close to the ground surface in the immediate vicinity of the channels. The intensity of percolation flow from important water channels might also, under certain conditions, serve to obstruct the normal movements of the ground-water, and pond it up to stagnation in particular localities. The acute salient of the ground-water contour at Nanuana, which was

pointed out by Mr. May, was evidently due to the fact that well No IV-21 was located in the angle between the main canal and the upper Gugera branch. In this angle there was no lateral outfall for the flow of the ground-water stream, so that it was ponded up, and water-logging resulted at the ground surface. The ground water contours across the upper Gugera branch did not form sharp salients pointing downstream, along the canal, evidently because the ground-water level was higher on its left side than on its right. On the left, the ground-water stream, flowing down the doab from the Upper Chenab Canal and from the sub-Himalayan tracts, was obstructed by the percolation stream from the upper Gugera branch of the Lower Chenab Canal, and ponded up on the left side of the latter.

Whether the effect of a surface drain on the level of the subsoil water table was purely local, and whether a system of surface drainage could not be expected to lower the water table generally, or even to arrest its rise, depended on what was meant by the term surface drain. If the drain were dug to a depth appreciably below the level of the subsoil water-table, it must have effect in lowering that level, or preventing it from rising, and the extent of its influence would depend on its depth, on the nature of the soil, and on its having effective hydraulic gradients. It was usually practicable, by means of surface drains, to prevent subsoil water from water-logging the ground surface, and that was all that was necessary. The drainage of the Western Jumna Canal tracts had been greatly improved by surface drains, and by remodelling the alignments long before the Sirsa branch canal was dug, though undoubtedly a further immense improvement had been effected by the extension of the irrigable area.

MR. W. B. HARVEY mentioned a method of stopping percolation from canals by pumping air into the soil below the canal bed, and claimed that, in an experiment, he had reduced the percolation of water through sand from 2·55 to 1·03 gallons per hour, by pumping air into the sand for ten minutes, at a pressure of ten pounds per square inch. After twenty-four hours the percolation was only 0·45 gallon per hour, and even after seventy-two hours only 0·64 gallon per hour although no more compressed air had been added.

LALA WAZIR CHAND CHOPRA thought that it would be interesting to see how the levels at five year intervals, from the time that the Lower Chenab Canal was opened, compared with the present levels, and this would be a help in studying the process by which the troughs and ridges were formed. As regards the presence or absence of water-table ridges, he noted

from the plan that under certain conditions ridges were formed under channels which were themselves on natural surface ridges, whilst they were absent when the channels ran on sidelong ground. Thus there were ridges under the main line of the Lower Chenab Canal after it emerged from the river-bed, and also under the Jhang and Rakh branches until they got too close to the present trough. Similarly a ridge was forming under the main line of the newly opened Upper Chenab Canal, but there was no ridge under the upper reaches of the Gugera or Mianwali branches, or under the Raya branch of the Upper Chenab Canal, all of which ran on sidelong ground. Mr. May had suggested that rainfall and irrigation had little effect in raising the water table, but he had noticed in the Sialkot district, before the introduction of irrigation, how a very appreciable rise or fall was visible in the spring level in years of heavy or slight rainfall. Had Mr. May any knowledge of the geological conditions of the water-logged tracts, especially near the canal, and at what depth of sand there was over the clay, supposing that clay were present ?

MR. E. R. FOY said that the conversion of perennial into kharif channels had arrested water-logging on the Upper Bari Doab Canal in the Gurdaspur District. Not only did the subsoil water drain away when percolation ceased, but it was artificially removed by wells which had to be worked when canal water was not available. The same thing had happened on the upper reaches of the Abohar branch of the Sirhind Canal, where, in 1902, some perennial distributaries were converted into kharif ones, and the water table since then had been either stationary or fallen slightly. Considering the question of the effect of rainfall, it would be difficult to substantiate the claim that it was negligible. There was a tract between the Bhatinda and Kotla branches of the Sirhind Canal which had never had canal water. The water-table formed a saucer about fifteen feet below the natural surface as compared with a high water-table averaging five feet or less. In the monsoon of 1917 this saucer filled up to within five feet of the natural surface, almost entirely with rain water, as the canals surrounding the tract were closed except for a very few days from the end of July till the end of November. This excessive rise was, therefore, not due to percolation from the canal. The exceptionally heavy rainfall of forty-five inches was responsible, and its effect was serious, not only in the saucer mentioned, but all over the upper reaches of the canal, where spring level was high.

Another important point was that a rising water-table never fell to its original level unless remedial measures were adopted. The rise after a heavy monsoon was very marked ; the next year there might be a drought, but the spring level would not fall to the same extent as it rose the year before, and this was progressive ; there being fluctuations, but an ultimate rise. When plotted, the fluctuations looked like an enteric fever chart up to the crisis, there being rises and falls, but the rise getting higher and higher as the malady, enteric fever or water-logging increased.

MR. R. P. HADOW agreed with Mr. May's introductory remarks, namely, that the paper only touched the fringe of a very large question and that it would be unwise to generalize from this one example, and it was perhaps this that had prevented Mr. May from feeling justified in bringing out more than a few inferences, such as he had promised at the commencement of his paper. He also supported Mr. Wilsdon's remarks that it was impossible to consider the subsoil conditions of any one doab without taking into consideration the conditions in the surrounding doabs. One inference drawn was that the direction of flow was at right angles to the contour lines, but this was only true as long as the shape of the contour lines were absolutely accurate, and he did not think that the data before Mr. May entitled him to draw the contour lines as he had done, and that this had led him into the apparent inconsistency of saying that the lower half of the doab was fed by an inflow from the Chenab, whilst the discharge observations showed that the river supply was increasing throughout, and not decreasing as it should have done if the supply were percolating into the doab. It was, of course, open to Mr. May to say that the river discharge was increased by a supply from the Jech Doab ; but there was nothing in the paper to support this. If this were the case, the subsoil levels in the Jech Doab would have to be radically different from those in the Rechna Doab, by being convex to the natural surface everywhere. It was quite impossible to consider the tract by itself simply because it was bounded by two rivers ; a knowledge of the conditions of the subsoil levels in the surrounding tracts was very necessary.

He was surprised that no one had referred to what, for want of a better name, he would call Mr. Gibb's theory on water-logging. This had been put forward at a conference on water-logging held in April 1917, and from the papers relating to this conference it was evident that it raised considerable

interest. Mr. Gibb's theory was, apparently, that "the junction of the rivers at the south-western angle of a doab closed the outlet for subsoil drainage at that point, and so hindered the natural course of such drainage as to threaten a gradual approach throughout the Punjab proper to conditions of water-logging." The evidence on which this theory was based had not been given, but the levels in Plate 2 did not fully bear out Mr. Gibb's theory, and in January 1917, at least, there was nothing in the river levels to prevent the subsoil water following the natural drainage, but until the shape and position of these contours could be accurately fixed it was scarcely possible to say whether the subsoil drainage from the doab had a clear outflow into the rivers at the angle of the doab or not: it had also to be proved that what was true for the Rechna Doab was true for other doabs.

Mr. Gibb had pointed out that the junction of rivers at the angle of a doab fixed the level of the outflow of the subsoil drainage to that of the rivers, but did this necessarily "threaten a gradual approach throughout the Punjab proper to conditions of water-logging?" That appeared to be a hasty generalization for which no evidence was yet forthcoming, and as long as it was possible to obtain such a subsoil gradient from the fixed point at the angle of the doab as would be sufficient to cause an outflow equal to the inflow, and would, at the same time, not approach too near the surface, a stable condition would be attained which would only lead to water-logging in low places where the subsoil gradient approached too near the surface. It was to be hoped that the Congress would not have long to wait for a complete subsoil water contour maps of the Jech and Bari doabs which would enable members to consider the question as a whole.

MR. E. S. LINDLEY considered that the system of well measurements, on which Mr. May had based his paper, was lamentably defective for the purpose. For convenience, the selected wells had been originally chosen on cross section lines, and although these lines may have been suitable in the past, in many cases they were no longer in the best position to determine accurately the shape of the contours, which were continually changing. The observations took no account of closures in the canals or of the level of the river water, both of which had a great effect in extreme cases. Moreover the levels only represented the conditions at the beginning and end of one winter and, as already pointed out, did not take into consideration the levels of the adjacent doabs, which were necessary for a consideration of the problem of this one doab. The most valuable contribution to the subject

lay in the discharge observations of the Chenab, taken when both the Khanki and Rasul weirs had been staunched so long that the rivers had had a unique opportunity of settling down into stable conditions, but Mr. May had not discussed these data as fully as he might have done, and the few conclusions that had been presented appeared to be the reverse of what the data really showed. A statement showing the discharges in tabular form had been prepared, and he proposed to analyse the figures to see what information could be extracted from them.

Site.	Discharge. (Cusecs.)	Distance. (miles.)	Gain by percolation. (Cusecs.)	Length. (miles)	Gain per mile (Cusecs.)	Gain per mile of reach. (Cusecs.)
Khanki	30	0	...	..	...	
Qadrabad	156	23	126	23	5·5	
Pirkot	218	28	62	5	12·4	4·7
Baharwala	253	58	35	30	1·2	
Patraki	377	68	124	10	12·4	
Chiniot	379	74	2	6	0·3	
Alipur	640	120	261	46	5·7	
Jhang	898	129	258	9	28·8	
Jhelum Junction	942	140	44	11	4·0	
(Jhelum River)	(639)	...	...	...	...	4·5
Trimmu	1,595	142	14	2	7·0	
Haveli	1,651	146	56	4	14·0	
Alayar	1,896	159	245	13	18·8	11·8
Kharanwala	1,927	171	31	11	2·8	
Kacha Kabira	2,340	180	413	10	41·3	28·3
Fazil Shah	2,494	190	154	10	15·4	
(Ravi river)	(*nil*)					
Toawala	2,507	194	13	4	3·2	
Totals ...	...	...	1,838	194	9·5	

Mr. May claimed that from the water-logged reach percolation to the river was more or less uniform. The details were a low rate in the first reach in which canal and river were running away from each other, and the river was almost at right-angles to the subsoil contours; a sudden gain where the Budh Nala came straight out of the water-logged tract nearly to the river; an exceedingly low rate where the river came slightly in across the contours and would consequently gain more than in the first reach; a high rate of gain in a reach that included part of a reach of the river cutting in sharply across the contours, and also nearly approaching the Budh Nala; and a negligible rate of gain in a reach in which the river was parallel to the ridge of the water-table. It was a pity that the two large inflows were not more exactly located in a year that gave a unique opportunity for such observation; the circumstances leading to the low rate in the second reach were also undetermined.

In the next reach, from Chiniot to Alipur, the inclination of contours to the course of the river indicated a fair rate of loss in the whole length, yet there was a higher rate of gain than from Khanki to Chiniot, but, on the data presented, it was impossible to say whether this were accounted for by drainage from a strip along the river filled by monsoon river-levels, or by an excess of percolation from the Jech Doab over that into the Rechna Doab: judging by the conditions of the corresponding part of the Rechna Doab lower down, the latter was quite possible.

In the next, a very short reach, there was a very large gain for which the data showed no cause whatever. The reach down to the Jhelum junction showed a very low rate, though it included the tail of the Jech Doab, which should give a good supply, and a sharp turn in of the river, that also should collect some percolation from the Rechna Doab. From the junction down to Kharanwala, there was a fairly high rate of gain; the right bank was now no longer an irrigated doab, and the gain did not seem to be sufficiently accounted for by a local turn out of the contours, though this was more marked than the plan showed, when contours were corrected for the printed level of well XV—131. The last part of that reach, having shewn a very low local rate of percolation, in below Kharanwala, nearly a quarter of the whole percolation into the river appeared in a ten mile reach, and a fairly high rate in the last reach, which could only be the concentrated drainage from the trough of the whole

water-table. It was a pity that this had not been more exactly located ; both the Kharanwala and Kacha Kabira observations having been probably too much up-stream.

Light could have been thrown on some of the above points if similar plans had been prepared of the Jech Doab. Other points must probably and unfortunately remain undecided, until another rare opportunity for such observation found someone in a position to investigate more thoroughly.

The marked flow into the doab from the Ravi which was indicated by the contours also called for comment. This was perhaps due to the fact that the areas of probably more concentrated percolation loss from the canal system were on the Chenab side of the trough, and that it was only a few years since the Upper Chenab Canal had brought water into the upper part of that side of the doab, and since the Balloki barrage lowered the winter supplies of the river.

Mr. May's paper failed to recognise the fact that the water-table was only a certain phase in the progress from one regime to another. Originally there must have been percolation from both rivers into the doab, down to a point at which the total flow had again to find its way into the rivers above their junction. The Lower Chenab Canal had imposed a load of percolation over the whole irrigable area, less at the tails of channels and greater nearer the heads, where the supply carried was not merely that for local irrigation, but the whole, and it was obvious that the water-table in the upper part of the load would rise more quickly towards its final levels, and as the uppermost areas nearly attained the new regime they would be bounded by a zone of steeper gradients, in which there was a strong flow onwards. This zone was clearly marked, approximately from Marh down to the Sarfattu reservoir. This also accounted for the flat-bottomed trough shown in one of the sections, but it had to be remembered that these sections were neither along a contour nor a line of flow.

Mr. May correctly observed that a channel running across the sub-soil contours at a slant forms no ridge, while one which ran down them formed a ridge which got more acute downstream ; this was the obvious result of flow accumulating on a narrower width, but it was unsafe to conclude from the blunting and eventual disappearance of the ridge below Nanuana, that there was less total percolation from the separate channel, than from the single main line. There might be equal percola-

tion loss, but the distance between the channels spread it over a wider front.

The water-table showed a most marked trough near Lyallpur, widening at first as if about to disappear and turn into a ridge from which flow would take place into the rivers, while the tail of the doab again showed a most marked trough and concentration of flow down the centre. It was a pity that the form of these contours depended on a small number of wells, of which probably a good many were working wells, while the annual variation due to river levels might extend across the whole tract at this point.

It was to be hoped that the discussion on the paper would result in an improvement of the system of well measurements, so that it would become possible to draw more definite conclusions from them.

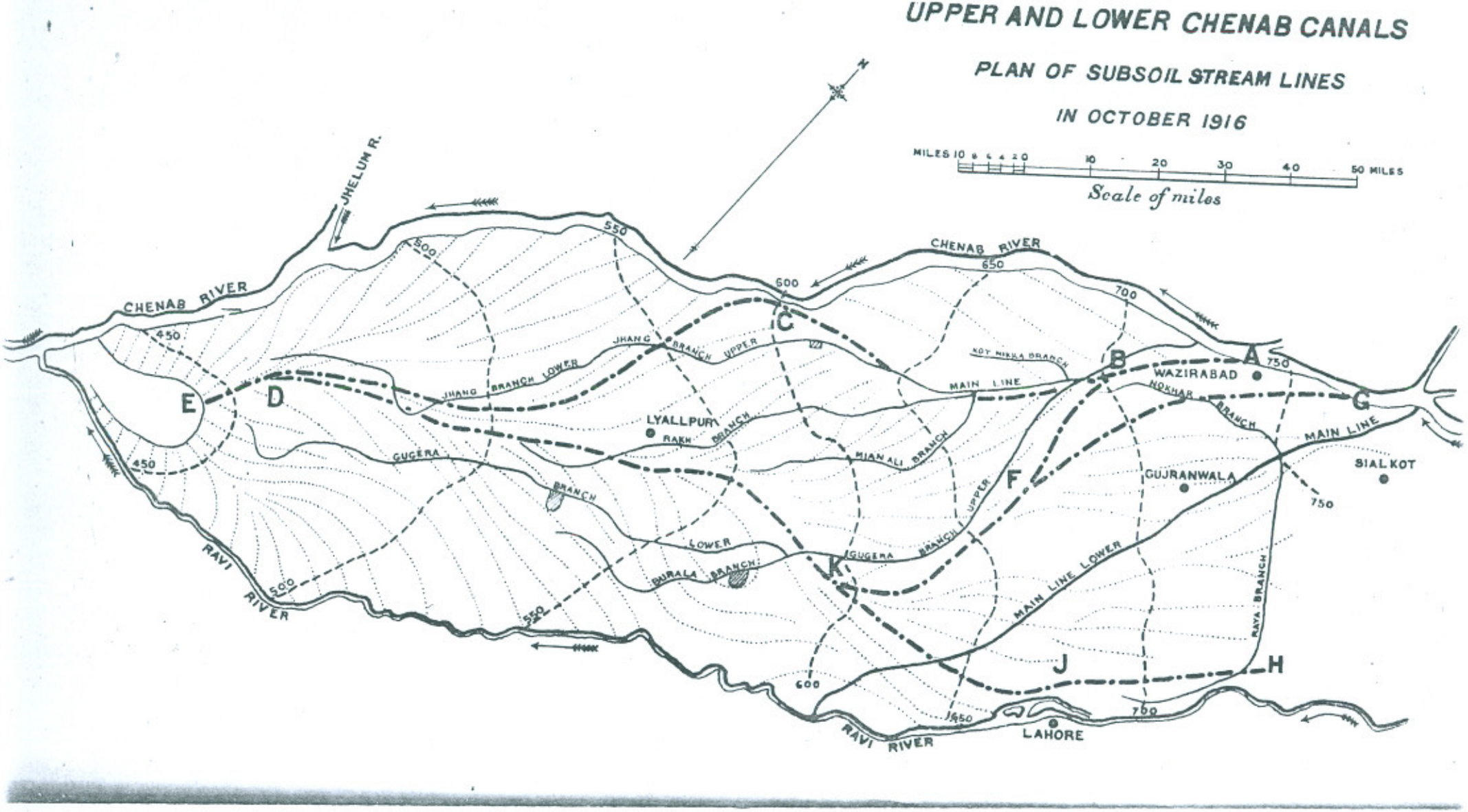
MR. C. A. COLYER enquired if Mr. May could supplement his suggested methods of curing the evil of water-logging. At present the methods seemed too drastic to be of wide application on account of the expense involved. Cases of very local humps in the water-table might be successfully attacked by surface drains. In the deltaic or plains area of a submontane district, the water-table was largely affected by the discharge from drainages spreading over the country, and, being unable to run off, soaking through the ground to augment the subsoil infiltration from the hills. This was further aggravated by the cultivation of the channel, and the erection of dams for mills, etc. The subsoil water trouble might be alleviated by the more frequent occupation of natural drainages under the Canal Act, by better supervision of such drainages, and by more catch water and surface drains.

MR. W. P. SANGSTER thought that Mr. May had rightly stated that water-logging would be confined to depressions which were low enough to intersect the subsoil water-table. There was nothing to fear from water-logging except in a very few depressed tracts, and it was possible to prevent the water-table intersecting even these areas by the simple remedy of drainage. The great importance of surface drainage had not been realised in the past. There was nothing to fear from water-logging, provided that there was a proper system of surface drainage. Some speakers suggested that water-logging commenced when the water-table rose to within ten or fifteen feet of the surface. In his opinion, it was possible to prevent

water-logging even if the water-table rose to within three or four feet of the surface; it could still be kept healthy for the people and fertile for the crops. Where the crops flourished, the people too would thrive; and to make the crops flourish the soil had to be ventilated and ærated. This could be done by means of surface drains, as explained in Bulletin No. 53 of the Agricultural Research Institute, Pusa, which all members of the Congress should study.

The United Provinces suffered from too low a subsoil water-level. In the Agricultural Journal of India, Volume XII, Part I, January 1917, an article by Mr E. A. Molony entitled "Rainfall, Irrigation, and the Subsoil Water Reservoirs of the United Provinces" assumed the following axiom. "The level of the subsoil water is highest at a distance from, and lowest close to, the great rivers which act as main drains carrying water from the subsoil." This was precisely the opposite to the case of the Punjab doabs. The chief aim should be to dig and maintain a proper system of surface drains; they need not be seepage drains, as it was not necessary that they should be deeper than would ensure ventilation and æration of the soil; their chief function should be to prevent the accumulation of standing water after heavy rain. It was a significant fact that the Act under which irrigation operations were carried out was entitled the Canal and Drainage Act. As an example of how successful such drains might be, he invited attention to an article by Mr. C. H. Hutton in the Agricultural Journal for April, 1918, Volume XIII, Part II, which described the extensive drainage measures undertaken in the Gangetic plain to remove the accumulation of water in wide depressions within the catchment areas of natural drainages.

MR. E. S. CRUMP, in a written communication, pointed out that Plate I indicated, by means of small arrows, the fact that subsoil flow was normal to the subsoil contours, *i. e.*, in the direction of the steepest gradient, and it was clear that a continuous line, intersecting the contours at right angles, represented a streamline. In the attached plan, stream lines *A C E*, *B K D*, *G F K* and *G J K*, were drawn so as to form the boundaries of a number of characteristic main streams, each of which admitted of separate study. Within these boundaries, portions of other stream lines were shown in fine dotted lines to indicate the general behaviour of each stream, but for the sake of clearness, with the exception of the pot-hole contour R. L. 440, only the dotted fifty feet contours of Mr. May's Plate I were shown.


UPPER AND LOWER CHENAB CANALS
PLAN OF SUBSOIL STREAM LINES
IN OCTOBER 1916
MILES 10 8 6 4 2 0 10 20 30 40 50 MILES
Scale of miles
JHELUM R.
CHENAB RIVER
CHENAB RIVER
RAVI RIVER
RAVI RIVER
450
500
550
600
650
700
750
A
B
C
D
E
F
G
H
J
K
JHANG BRANCH UPPER
JHANG BRANCH LOWER
KOT NIKKA BRANCH
MAIN LINE
NOKHAR BRANCH
MAIN LINE
LYALLPUR
RAKH BRANCH
GUGERA BRANCH
MIANALI BRANCH
UPPER GUGERA BRANCH
LOWER GUGERA BRANCH
BURALA BRANCH
MAIN LINE LOWER
RAYA BRANCH
WAZIRABAD
GUJRANWALA
SIALKOT
LAHORE

Following Mr. May in disregarding, as relatively unimportant, the effect of the last two sources enumerated by him, there remained the following :—

(*a*). The original subsoil stream coming from the Jammu hills,

(*b*). Percolation from the Chenab.

(*c*). Percolation from the Ravi.

(*d*). Percolation from canal channels.

Of these sources, only the last admitted of direct quantitative measurement. Existing data had recently been co-ordinated and presented by Mr. Woods in a general form in his formula, $Q = c\,a\,d$ and he had also, in a recent pamphlet, applied the formula to calculate in detail the percolation losses from all the important canal systems of the Punjab. With regard to sinks or outfalls, only two were specified in clear terms by Mr. May:—

(*a*) Surface drains.

(*b*). Subsoil outflow to the rivers.

The discharges of the former were not stated, but it was believed that they were relatively small, and represented only a fraction of the combined discharge of any of the main streams.

The five main subsoil streams shown in the plan were conveniently named and their features analysed, in terms of the above sources and sinks, as follows :—

No. I. The Lower Chenab Canal Escape Stream.

Boundaries : *A B C* and the Chenab. Source : percolation from the Lower Chenab Canal system. Sinks : the Chenab and surface drains.

No. II. The Lower Chenab Canal Main Stream.

Boundaries : *B C D* and *B F K D*. Source : same as above. Sinks : none other than surface drains.

No. III. The Upper Chenab Canal Main Stream.

Boundaries : *G F K* and *H J K*. Sources : the original subsoil stream (*a*) and percolation from the Upper Chenab Canal system. Sinks : none.

No. IV. The Chenab Riverain Stream.

Boundaries : *C D E* and the Chenab. Sources: the Chenab supplemented by percolation from minor channels of the Lower Chenab Canal. Sinks : the pot-hole contour R. L. 440.

No. V. The Ravi Riverain Stream.

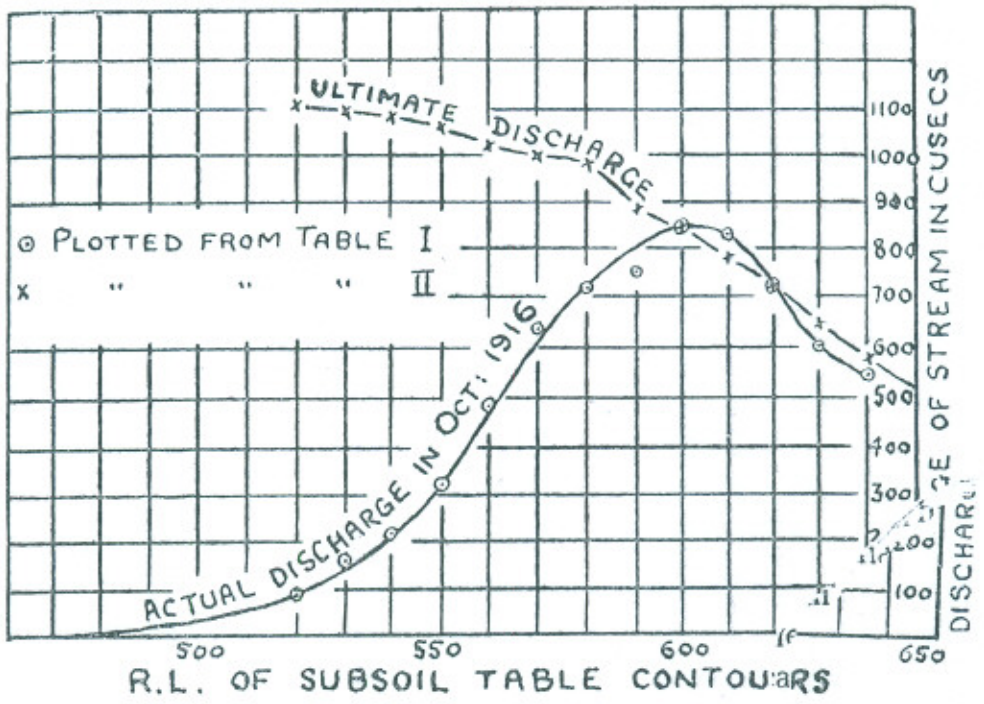
Boundaries : $JKDE$ and the Ravi. Sources : the Ravi supplemented by percolation from minor channels of both canals. Sinks : same as above.

Of the above, No. I was unique in exhibiting, throughout its course, approximate uniformity and steadiness of flow, as evidenced by the general equality of spacing and parallelism of the contours, and, as a consequence, of the streamlines. Nos. I and II had their sole and common source—of comparatively modern origin—in percolation from the larger channels of the Lower Chenab Canal. Nos. II and III were alike in having no outlet other than surface drains : both apparently disappeared, at the points D and K respectively, within the doab. No. III embraced the whole of the original subsoil stream—a source of great antiquity. Nos. IV and V were identical in general character, both being mainly riverain in origin. In both these streams the direction of subsoil flow along the river margins was everywhere inwards from the river to the doab, and their final disappearance in the peculiar pot-hole of contour R.L. 440 was not associated with any direct riverain outfall.

From a consideration of the above facts, it would seem that the two sinks hypothecated by Mr. May were apparently inadequate to explain the disappearance of streams Nos. II, III, IV and V. While in view of the extreme slowness of subsoil flow, and the comparatively recent origin of the important source (d), it was conceivable that the effect of this source might not yet have extended to the lower reaches of these four streams. In other words, their disappearance might be only apparent, and due to their not having yet attained to steady and permanent conditions of flow. This conception might suffice to explain the behaviour of stream No. II ; but failed—in view of the great age of the contributary sources (a), (b), and (c)—to explain the disappearance of streams Nos. III, IV and V.

In considering the time-effect, attention must be confined streams wholly modern in origin. Only Nos. I and II fulfilled this condition, and of these No. I had evidently become steady, and the time-effect had, in its case, ceased to operate. The method adopted was to compare the ultimate flow (represented by the accumulated percolation losses) with the actual flow (as evidenced by the present configuration of the subsoil table). A difficulty arose in apportioning percolation losses from the Lower Chenab Canal channels between streams Nos. I and II. The

distribution assumed was indicated by the footnote of Table II, and was derived from the assumption that the average nature of the subsoil, and the effective depth of the subsoil stream, were the same for the two streams. With this distribution, column 6 of Table II shewed the ultimate flow across various contours of stream No. II, as calculated from Mr. Woods's figures for percolation losses. The results were shown by the broken line in the following diagram :—



This also shewed the actual discharge, as calculated in Table I by the method outlined by Mr. Lindley in speaking at the Congress ; thus :—Experiments showed that the velocity (v) and the gradient (s) obeyed the law.

$$v = ks \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where (k) was a constant depending on the nature of the subsoil and on the temperature. In a soil having a water-saturation content (p) the discharge per foot width of a subsoil stream of depth (D) feet was

$$q - pDv = pDks \quad \ldots\ldots\ldots \quad (2)$$

From this it followed that the total discharge, through the mean contour, of a strip of (A) square miles area and with (L) miles, measured along the mean contour, bounded by two adjacent ten feet contours and by two streamline boundaries, was given by

$$Q = (10pDk) \times \frac{L^2}{A} \text{ cusecs} \quad \ldots \quad (5)$$

By taking streams Nos. I and II together and equating their combined discharge (as calculated from (3) above) to the sum of percolation losses (taken from Mr. Woods's figures), it was found that the value of $10pDk$ was 55·8, which was the value taken in column 7 of Table I, and might be applied, in the absence of more exact knowledge, throughout the doab.

To obtain an approximate idea of the actual velocity of flow, it was necessary to assign roughly assumed values to p and D of equation (4). Taking p as 0·25 and D as 25 feet

$$k = 55\ 8/\ 62{\cdot}5 = 0{\cdot}89$$

a value which was, beyond all doubt, on the big side. With a gradient of 1 in 2000, from equation (1) above

$$v = 0{\cdot}000445 \text{ feet per second}$$

$$= 2{\cdot}7 \text{ miles per annum.}$$

It might, then, be safely assumed that the velocities prevalent in the doab were of the order of *a mile a year.* With this figure in mind, the facts presented in the diagram were not surprising. The diagram clearly indicated that stream No. II, although upwards of thirty years old, had not yet become steady. The full effect of percolation had in 1916 only extended to the vicinity of contour R.L. 600, which was a little less than half the distance from Khanki to the confluence of the two rivers. The obvious inference was that important developments were to be expected during the next three or four decades.

Table III needed little explanation. It was derived from Tables I and II, and showed the rate of rise or fall of the subsoil surface in feet per annum. It might be noted that the rate of rise, as calculated, took no account of the rate of widening of the stream. This could only be ascertained by comparing contour and streamline plans for two different periods. Clearly, if the width were increasing, the rate of rise was correspondingly reduced.

With regard to the river discharges observed by Mr. May, a riverward flow along the whole margin of the Chenab was implied. For the reach between the point C and the confluence, this result was at variance with the facts indicated by the streamlines of the plan. The explanation appeared to be that the streamlines show the prevailing *inward* flow due to the *average* river level, whereas Mr. May's observations were taken with the river at its lowest. The effect was analogous to the seepage during a closure, into an irrigation channel which normally

acted in an opposite manner. In the case of the river, the reversal of flow would probably not extend farther than a mile, or less, into the doab, so that the influence on the contours would escape detection by ordinary well measurements.

It remained to furnish an explanation of the disappearance of streams of ancient origin. The two riverain streams had not been greatly modified by the introduction of the two canal systems, their present configuration was, indeed, typical of the conditions which obtained in an unirrigated doab. A careful study of these two streams would show that, apart from the reinforcing effect of canal percolation, the arrangement of their streamlines pointed to a *continuous* reduction of their discharge, and suggested the existence of a sink, or sinks, which operated uniformly over the whole track. Two such sinks seemed possible :—

(*c*). Evaporation from the subsoil water surface.

(*a*). Escapage into an underlying subsoil stream.

The former was postulated and investigated by the late Professor Barnes. From certain remarks made by Mr. Wilsdon in the discussion, it appeared that such experiments as had been carried out at Lyallpur had led to the conclusion that the magnitude of this effect was too small to provide an adequate explanation of the facts presented. The latter was, therefore, now put forward as a solution of the problem. It appeared that the streams hitherto considered formed a complex system of relatively shallow surface currents, which disturbed, to only a limited depth, the main subsoil stream which underlay them all, and flowed steadily seawards, forming a capacious drain into which they were continuously absorbed. The deflection seawards of all streamlines throughout the doab offered strong confirmation of the truth of this conception, and could not, indeed, be explained upon any other hypothesis.

TABLE I.

Showing the actual discharge of stream No. II as calculated from direct measurements of the contoured plan.

1	2	3	4	5	6	7	8	9
R. L. of contours.	L—Width of stream between boundaries (measured along mean contour).	A—Area of strip in sq. miles.	L^2/A.	Mean area.	Mean values of col. 4.	$Q = 10 \cdot pDk \cdot L^2/A$ 55·8 = col. (6) = Discharge of stream in cusecs.	Difference. Outflow.	Difference. Inflow.
650-40	2·96	93·4	9·4					
				103·2	9·80	547		
640-30	34·0	113·0	10·2				53	...
				126·0	10·75	600		
630-20	39·6	139·0	11·3				122	...
				137·5	12·95	723		
620-10	44·6	136·0	14·6				117	...
				137·0	15·05	839		
610-00	46·2	138·0	15·5				12	...
				136·0	15·25	851		
600-590	44·8	134·0	15·0				...	95
				135·0	13·55	756		
590-80	40·6	136·0	12·1				...	39
				115·6	12·85	717		
580-70	36·0	95·3	13·6				...	77
				97·2	11·65	640		
570-60	31·0	99·2	9·7				...	155
				93·4	8·70	485		
550-40	21·	87·6	7·7				...	159
				99·3	5·85	326		
540-30	17·2	111·0	4·0				...	108
				94·2	3·90	218		
530-20	12·6	77·4	3·8				...	59
				81·2	2·85	159		
520-10	7·6	85·1	1·9				...	57
				62·5	1·65	92		
		40·0	1·4					

TABLE II.

Showing the ultimate discharge of stream No. II, this being the sum of percolation losses from the Lower Chenab Canal system. (Losses are calculated from Mr. Woods's tables).

Contour.	Total percolation up to the contours of col. (1) from:				Ultimate discharge = Total of cols. (2) to (5) *plus* 174 cusecs.	Difference of col. (6) = percolation from channels intercepted between contours.
	Jhang	Rakh	Mian Ali	Gugera		
1	2	3	4	5	6	7
650	83	35	19	199	510	
						65
640	105	40	25	230	575	
						71
630	127	54	31	260	545	
						76
620	166	67	38	277	722	
						61
610	181	74	43	311	783	
						55
600	207	85	47	336	849	
						35
590	223	72	50	345	885	
						99
580	248	96	50	416	984	
						16
570	258	102	50	416	1,000	
						25
560	278	108	50	416	1,026	
						37
550	306	117	50	416	1,063	
						22
540	314	131	50	416	1,085	
						14
530	314	145	50	416	1,099	
						4
520	314	149	50	416	1,103	

NOTE.—The figure of 174 cusecs added in col. (6) is derived as follows :—

(*a*).	Total loss from R. D. O.—2,00,000 Main Line L. C. C.	=560	cusecs.
(*b*).	,, ,, ,, ,, — 34,000 Jhang Branch	45	,,
(*c*)	,, ,, ,, ,, — 30,000 Rakh Branch	19	,,
(*d*)	,, ,, ,, Kot Nikka Branch	26	,,
	Total ...	650	,,
	Deduct assumed share of Stream No. I	412	,,
	Balance entering Stream No. II	238	,,
	Deduct items (*b*) and (*c*) already included in cols. 2 and 3.	64	,,
	Balance to be added to totals of cols. (2) to (5)	174	,,

Losses (*a*), (*b*) and (*c*) above are shared by Streams I and II.

TABLE III.

Showing the rate of rise or fall of the subsoil table, of stream II, disregarding the rate at which the stream is widening.

R. L. of contours.	A.—Area of strip (col. 3 of Table I).	Percolation into strip (col. 7 of Table II).	Deduct outflow of stream (col. 8 of Table I).	Add inflow of the stream (col. 9 of Table I).	Resultant inflow.	Resultant outflow.	Rate of rise or fall in feet per annum.	
							Rise.	Fall.
1	2	3	4	5	6	7	8	9
640 30	113·0	71	53	...	18	...	0·7	...
630-20	139·0	75	122	...	...	45	..	1·5
620-10	136·0	51	117	...	...	55	...	1·9
610-00	138·0	55	12	...	54	...	1·7	...
600-590	134·0	35	...	95	131	...	4·4	...
590-80	136·0	99	...	39	138	...	4·5	...
580-70	95·3	16	...	77	93	...	4·4	...
570 60	99·2	25	...	155	181	...	8·2	...
560-50	87·6	37	...	159	195	...	10·0	...
550-40	111·0	22	..	108	130	...	5·2	...
540-30	77·4	14	...	59	73	...	4·2	...
530-20	85·1	4	..	57	71	...	3·7	...

NOTE.— $\text{Col. } 8 = 4{\cdot}53 \times \frac{\text{Col. } 6}{\text{Col. } 2}$

$\text{Col. } 9 = 4{\cdot}53 \times \frac{\text{Col. } 7}{\text{Col. } 2}$

MR. MAY said that, before replying in detail to the various criticisms, he wished to emphasise his former remark that the paper never purported to be an exhaustive treatise, but only an elementary introduction to a very complex subject. He agreed that the geological and physical aspects of the case could not be ignored, and that the accuracy of the contours could be improved, both by bringing a larger number of wells under observation, and by improving the method of selection, but it seemed to him that these were matters for a specialised rather than a general paper.

While Mr. Quinn-Young denied the existence of a subsoil water-table he admitted that the subsoil was saturated with water at some point below the naturul surface, but it was this point at which saturation obtained which was generally known as the water-table, and the author had never previously heard of the theory that there was below the surface a sheet of water of a certain depth. On the subject of subsoil water flow, Mr. Quinn-Young's remarks appeared to be contradictory; he denied the existence of flow and yet spoke of water oozing (a particular form of flow) into wells and flowing into rivers. Any one seriously maintaining that subsoil water did not flow must explain how wells were replenished, as water was drawn from them. Again, he said that false contour lines would be drawn, if the possible influence of impervious layers in the subsoil in raising or depressing the saturation level were not taken into account. The author was unable to follow this line of reasoning, because the form and position of water-level contours depend on the record of observed levels, not on an appreciation of geological conditions.

Mr. Nicholson criticised the author for assuming that the subsoil of the tract was uniform, (actually this independent variable was not discussed at all) and then put forward a diagram comparing the inflow discharges with the inflow tendency; but curiously enough the measure of inflow tendency was assumed to be the difference between the free surface water level in the river and the subsoil water-level five miles away, no account whatever having been taken of the varying densities of the intervening subsoil. This illustrated the difficulties with which the author was also faced.

Mr. Woods doubted the author's belief that the percolation inflow of rain water was not an important source of supply to the underground reservoirs of the Rechna Doab, and mentioned the results of experiments at Rothampstead and elsewhere; but the author had not said that his view was of general application,

or even that it applied to any part of the Rechna Doab other than that irrigated by the Lower Chenab Canal. Since the paper was written, however, the author had had to modify his views. The summer season of 1917 had been one of heavy rainfall, and, either owing to increased percolation inflow, or reduced evaporation, or both, the subsoil reservoirs received such additions as to bring the water-table to within a distance of five feet and less of the natural suface of the ground, under an area of 640 square miles in October 1917, as against 320 square miles in 1916, and 130 square miles in 1915. Mr. Woods was mistaken in stating that well No. IV-21 was located between the Rakh branch and the large Gugera branch ; it was actually between the Rakh and the Mian Ali branches ; and subsequent investigation controverted his theory that the lateral flow of water streams was hindered in the forks between the branches, as in this case the flow was not forward at all. This condition existed from January to April 1918, and if it were not permanent, it obtained for long periods.

The author had already endeavoured to trace the gradual rise of spring level, as suggested by Lala Wazir Chand Chopra, but the quest had proved futile ; the early method of well selection was defective, there were too many observation points close to the larger canals, and not enough at a distance ; the unirrigated tract was ignored altogether ; and this latter defect was perpetuated even when Mr. Reid's system was introduced in 1905. There was thus no record whatever of subsoil water conditions as they existed prior to the advent of the canal, and it was to be hoped that no time would be lost in opening a record of the Sind Sagar Doab. The author agreed with Mr. Hadow that the record put forward did not support Mr. Gibb's theory, and that not only was there nothing to prevent the inflow of subsoil water into the Chenab in January 1917, but the record for June 1917 showed that when the Chenab rose the subsoil water changed its course, and flowed into the Ravi below the dam at Sidhnai.

In his diagram Mr. Crump had placed too much stress on the depression in the water-table at the tail end of the doab ; this was a purely temporary condition.

ERRATUM.

Plate 2. Well No. XV. 131, the R. L. of spring level is correctly shown as 473·79 ; the 470 feet contour should be corrected.