PAPER No. 98.

THE SUB-SOIL WATER-TABLE, AND METHODS FOR ITS INVESTIGATION.

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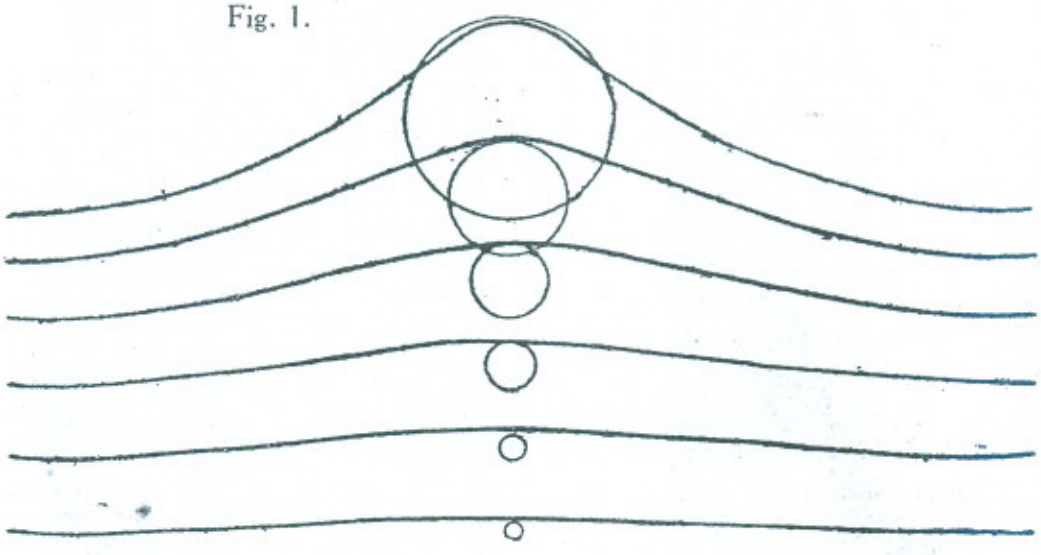
Scientific Research Officer.

It is now generally recognised that knowledge of the conditions of the sub-soil water-table is very desirable, if not essential, in the design of an irrigation system. At the present moment the inadequacy of our knowledge in this respect is strongly impressed on us, both in attempting to foresee the probable course of events in new irrigated tracts, and in understanding the causes which have caused, and are causing, changes in the water-table. These changes may have serious economic consequences either through water-logging or the inverse process of depletion, such as is to be witnessed in Jullundur. Only on a complete understanding of the causes are we likely to be able satisfactorily to base remedial measures. The action of Government in providing funds for an independent committee for the purpose of investigating problems of this nature will I think be generally welcomed, as it affords an opportunity for a comprehensive and scientific attack which would be impossible by sporadic individual effort. On this account I have felt that a more or less general discussion of the methods of investigation which may be adopted should prove useful at this juncture, and may invoke the interest of those with detailed local knowledge in the attempts which must be made to study all aspects of the question.

2. The interpretation of the contoured water-table map.

I will first consider the interpretation of records of well levels. Here we may have only the changes with time in the depths to water to guide us. This was the case in an investigation, I have recently completed, of the water-table of the districts of Jullundur, Hoshiarpur and Ambala for which no ground surface levels exist ; usually depths can be referred to reduced levels as in the water-table contours maintained by the Irrigation Department. In either case, without a knowledge of the depth and variability of the sub-soil itself we can draw no definite conclusions as to the quantitative movement of the ground water. This point will be clear from the following considerations :—

Fig. 1.



Consider the simplified case of the motion of an infinitely deep stream whose surface has the wave form shown in Fig. I. The usual hypothesis made in attempting to determine the motion of the fluid, as in Darcy's well discharge formula, is that the flow across any vertical section is proportional to the pressure gradient, the transmission constant of the soil, and the depth. This hypothesis is obviously inadmissible, as with an infinitely deep soil the flow would become infinite. If however we consider the section as part of a train of waves in harmonic motion we can obtain a solution by a general hydrodynamical method. This, it is true, applies strictly only to the flow of a perfect fluid, but as under these conditions we find that the motion becomes inappreciable at some depth below the surface, *a fortiori* we must expect the flow of water in the soil, which approximates to that of a very viscous fluid, to penetrate only to a limited depth.

The velocity potential in such a case may be written

$$\phi = A\ e^{my}\ cos\ (mx - nt) \qquad (1)$$

The velocities with respect to x (horizontal) and y (vertical) will then be given by

$$u = -\ \frac{\partial\phi}{\partial x}\ ;\ v = -\ \frac{\partial\phi}{\partial y}$$

If in place of x and y we use co-ordinates $\xi = x - x_0$, *and* $\eta = y - y_0$ the solution of (1) becomes

$$\xi^2 + \eta^2 = \frac{A^2 m^2}{n^2}\ e^{2my} \qquad (2)$$

This means that each particle describes a circle about its mean position with radius $r = \frac{Am}{n}\ e^{my}$. At the surface ($y=0$) the radius is determined by the constants $\frac{A\,m}{n}$; since y is negative as we proceed downwards the radius diminishes exponentially. It can be shown that at a depth equal to two wave lengths the radius is reduced to $\frac{A\,m}{n}\ e^{-4\pi}$ so that the velocity becomes quite imperceptible.

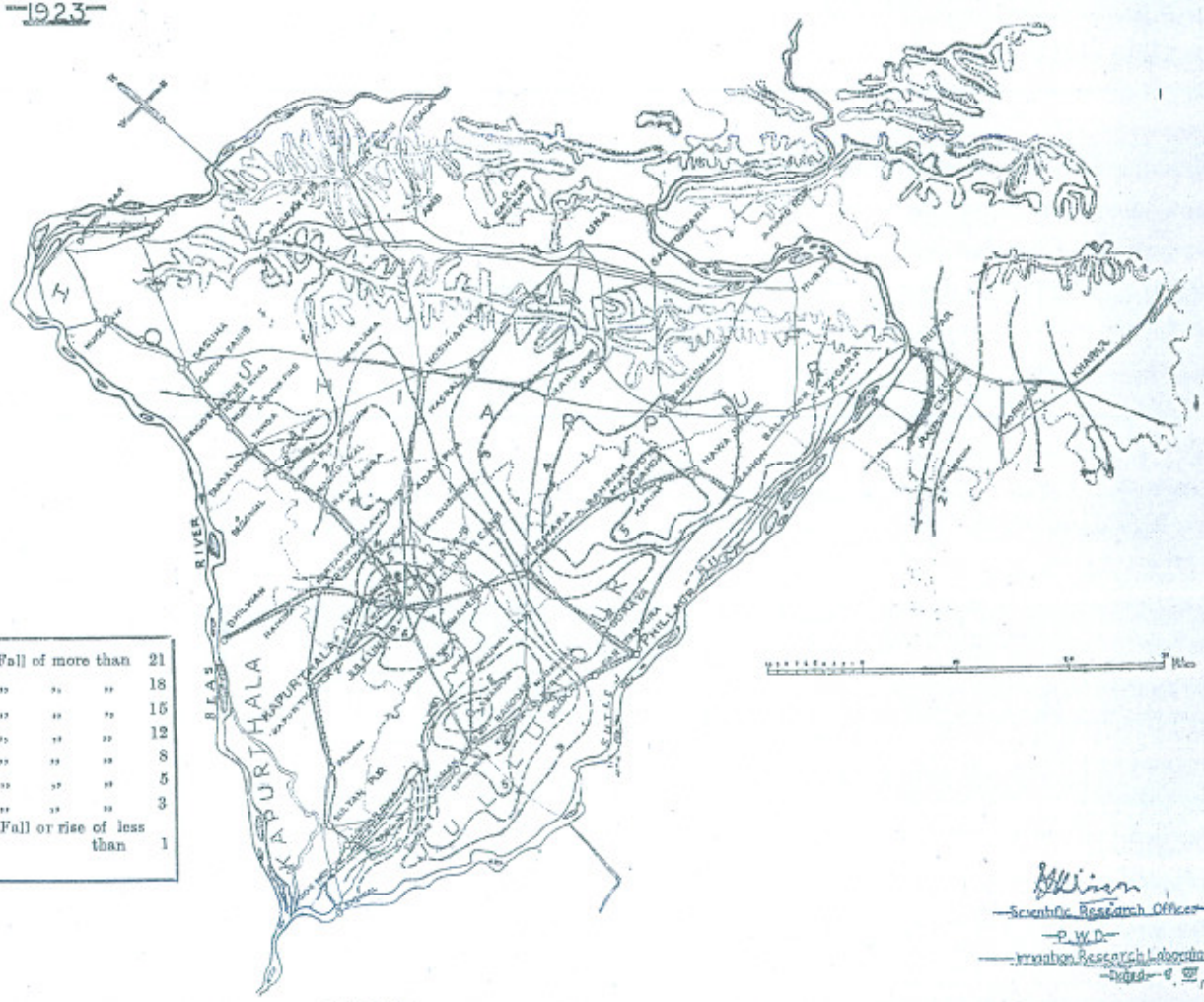
The conditions of flow in a soil, for a case similar to this, cannot at present be determined mathematically. The only hope is in experimental measurements. It is possible that the time rate of subsidence of depressions or elevations in a uniform deep soil may afford data which can be treated mathematically with the object of arriving at a formula by means of which we can calculate the total flow associated with an observed hydraulic gradient.

Another illustration of our powerlessness to form any idea of the flow in the sub-soil without further knowledge of the sub-soil itself is afforded by the remarkable 'pot-hole' distribution of contours shown at the tail of some doabs. The only explanation which can be put forward is that

PLATE I.

WATER TABLE DEPLETION

1923



Contour	No.	7	a Fall of more than			21
,,	,,	6	,,	,,	,,	18
,,	,,	5	,,	,,	,,	15
,,	,,	4	,,	,,	,,	12
,,	,,	3	,,	,,	,,	8
,,	,,	2	,,	,,	,,	5
,,	,,	1	,,	,,	,,	3
,,	,,	0	a Fall or rise of less than			1

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Dated 8. VII. 25

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there are large variations in the soil texture at these points and that there must be an underflow in a more permeable stratum beneath the V.

3. Statistical Investigations.

Instead of expecting the water-table contours to tell us everything about the movement of the water-table, we can adopt frankly empirical methods of correlating the changes with other external factors. In the case of a canal irrigated tract it is obvious to the eye that there is a relation between the humps in the water-table and the presence of channels. However, the total change at all points in the doab may not be explained by flow from the regions in which we have humps. Because the humps are the most salient features of a contour map, there has been a tendency to attribute to them all changes in the water-table, and at the same time to forget the general rise in the table which may be taking place. The true connexion can only be discovered by statistical examination of the rate of rise of each area separately and correlation with other variables such as rainfall, intensity of irrigation and so on. Work along these lines is at present in progress ; the kind of result which can be expected by the method may be best illustrated by an account of the Jullundur investigation where the statistical data are much less reliable or complete than in irrigated tracts.

Persistent complaints of the fall of the spring level in the districts of Jullundur, Hoshiarpur, and Amballa, led to the statistical investigation of existing records. These consist of measurements of well depths taken at settlements, and records of recent *jamabandis*. The records are thus extremely rough and ready, since they depend on the local *patwari*, a brick and a length of string. No levelled survey has been made in these districts so that depths to water cannot be referred to reduced levels. To add to the difficulties of the investigation there have been frequent changes of the wells under observation. The only thing to be done was to make the best of what data existed, and by statistical examination, to attempt to eliminate the errors.

For Jullundur there were measurements for the years, 1848, 1882, 1908 and 1923. For Hoshiarpur, 1852, 1884, 1911-12 and 1924. For Amballa only 1887-88 and 1917-18. An abstract of the chief data is given in Table I. For each village the mean depletion was calculated, *i. e.*, the change in the depth of spring level. It was found that when plotted on the map the depletions contoured. Plate I shows such depletions contoured for the period 1882-87 to 1923. The standard deviation of depletions included within the contours has been calculated. In the case of the Jullundur measurements it is small, and even in Hoshiarpur where proximity to the Pabbi hills and " chos " renders the sub-soil conditions much more variable, the standard deviation is not more than 10 per cent. It will be seen that in some localities the depletion has been over 20 feet. If the depletions are plotted for the intermediate periods the same shaped surface is developed. During the earliest period it was found that a *rise* in the spring level had taken place in areas which have since suffered the most serious depletions.

This indicates that during this period the water-table was in equilibrium; since the 1880's however there has been a progressive depletion. It is of importance to form some opinion as to the reason for this and to be able, if possible, to decide if there is any likelihood of equilibrium being again attained. The factors which we may attempt to correlate with the depletions are the intensity of well irrigation, the rainfall, and changes in drainage conditions such as might result from the construction of canals drawing off water from the Beas or Sutlej.

A notable feature is the increase of well irrigation in Jullundur since the first settlement. In some localities the number of working wells has doubled or trebled. The intensity of well irrigation (number of working wells per square mile) is plotted in Plate 2. This refers to the year 1917. In Jullundur a contoured surface is developed which shows an obvious correlation with the depletion surface. For Amballa and Hoshiarpur, soil conditions are so variable that the intensities will not contour. Correlation co-efficients have been worked out which indicate significant relations between the depletions and the intensity of irrigation at the times considered; the correlation is negligible in the case of Amballa and Hoshiarpur, except in a limited area in the former district (Dasuya Tahsil). There can be no doubt however that the water-table in Jullundur and Hoshiarpur forms a continuous system, and it would seem probable that it is the excessive draft of the irrigation wells which is responsible for the trouble.

Since irrigation is not the only factor which may have been operative the correlation was extended to the depth and the rainfall. The depth of the water may be expected to increase the demand for wells since with bullock power the rate of lifting water will be smaller. Secondly a lower water-table means less water available for crops suspended in the soil by capillarity; the amount available will vary inversely as the log of the depth to water. Correlation of these factors ($\triangle$ I : log D) gave a co-efficient of 0·4 which supports our hypothesis.

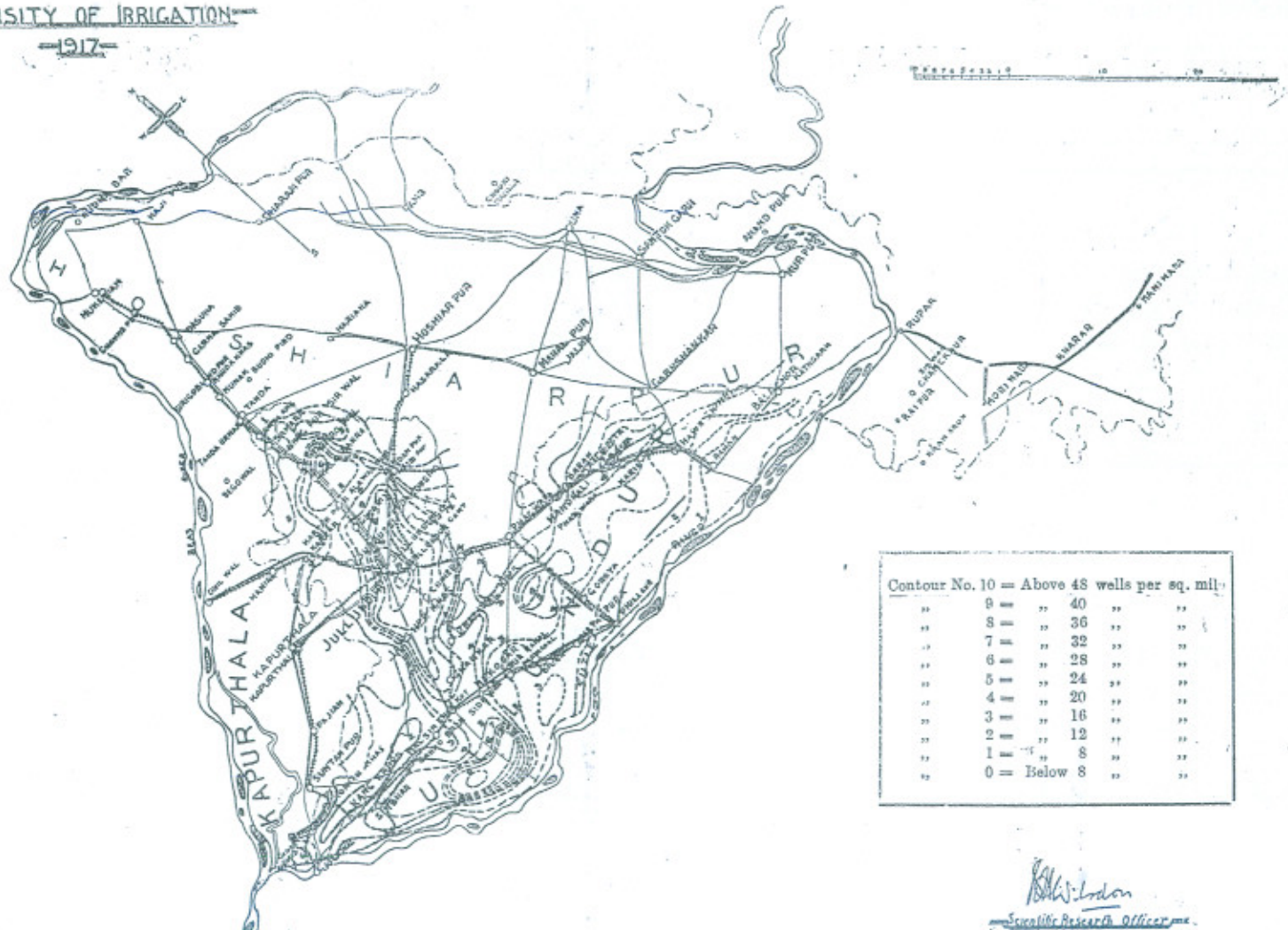
If we now take into account the rainfall we can obtain the regression equation

$$\triangle = I\,[\,0{\cdot}4 \log_{10} D + 4{\cdot}26 - (3{\cdot}47 \pm 0{\cdot}86)\,]$$

The factor $\pm$ 0·86 expresses the probable variation of the rainfall. It will be seen that no improvement in the conditions is to be expected by any probable change in the rainfall. We must therefore conclude that while the intensity of irrigation is at its present pitch the depletion is likely to continue. This equation refers to conditions in the Jullundur Tahsil; in riverain tracts the equation is somewhat modified, and the relation between the rainfall factor and the others shows a marked change about the year 1880. This coincides with the opening of the Sirhind Canal, and it seems reasonable to suppose that the decrease in average supplies in the river due to the draw off into the canal might affect areas in "Bet" assessment circles, mainly as a consequence of the drying up of drainages through silting as a result of reduced velocities.

PLATE II.

INTENSITY OF IRRIGATION
1917.


KAPURTHALA
JUKH
HOSHIAR PUR
JALLANDHAR
RUPAR
KHARAR
KHANNA
RAIPUR
MODI NALA
BALACHAUR
NAWANSHAHR
PHAGWARA
KAPURTHALA
SULTANPUR
KALA SANGHIAN
BEGOWAL
TANDA
MUKERIAN
DASUYA
MIANI
GARHSHANKAR
RAHON
NAWANPIND
KHAIRA
KHAIRA KALAN
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6. Physical Methods.

It remains to be considered what possible physical measurements can help us in estimating the amount and direction of flow in the sub-soil. In the first place there is the well known method of pumping tests. Under favourable conditions by measurement of the discharge of the well, and the resulting depression of the natural water-table at known distances from the well, by application of the Darcy theoretical formula, the intensity and direction of the sub-soil stream can be estimated (See Prinz, Hydrologie; Berlin 1923, 181). The applicability of the method depends on the presence of an impervious layer and on assumptions as to the uniformity and parallel character of the flow. All these conditions are absent in the sort of soils we have to investigate.

It is obvious therefore that we must have some sort of knowledge of the sub-soil in order to form an approximate estimate of the flow. Indiscriminate boring experiments are expensive and may not give all the information required. A knowledge of the depth of the water-table may, under certain conditions, give us some information as to the variability of the soil. Thus in a series of borings taken parallel and near to a large channel, quite remarkable variations are to be noticed in the height of equilibrium water level in the borings. The measurement of actual velocities of the water in different layers of the soil is, however, a difficult problem. The rate of diffusion of salt placed in an observation well has been used under certain conditions, but cannot be employed in all. If the soil is a clean sand the method may work, but if any appreciable amount of colloidal matter is present, great errors may be produced by absorption of the salt. If a supply of radium were available, a method could be devised in which the emanation, which being a rare gas is not absorbed, and being radioactive could be detected with extreme precision, is used as the indicator.

7. The Eötvös Torsion Balance.

In order to gain a more detailed knowledge of the sub-soil we should have to rely on extremely expensive borings were it not for the invention of the Eötvös Torsion Balance. This remarkably sensitive instrument has been used largely in prospecting for oil and in finding water, salt, and mineral lodes. There seems little doubt that its employment on our own problem could be used to gain definite information of use in the problem of water-logging. In the first place by its means we could settle the question of the existence of rock barriers which might act as submerged weirs and hold up the ground water. Evidence of such a barrier is present along a line between Sangla Hill and Chiniot. Isolated observations of the force of gravity made by the Geodetic Survey also point to regions of excess density at certain places in the north Punjab, which are probably connected with sub-merged ranges, such as the Burrard range which lies beneath the soil parallel to the Himalayas further east. The instrument might be used not only to detect rock masses, but to distinguish between regions of sandy pervious soil and impervious clay.

The principle on which the instrument is constructed is the following. Gold or platinum weights are fixed to a beam as shown. By varying h the length of the suspended weight, and measuring the couples on the suspended system the variation in intensity and direction of gravity can be calculated. With this instrument mean values, probably correct to one part in $10,^{10}$ can be obtained. From the calculated variations in gravity it is then possible to find the form of the submerged masses which produce the deflexions. I think it will be agreed that it is only by the use of this instrument that we can expect to obtain a survey of our sub-soil conditions in a reasonable space of time.

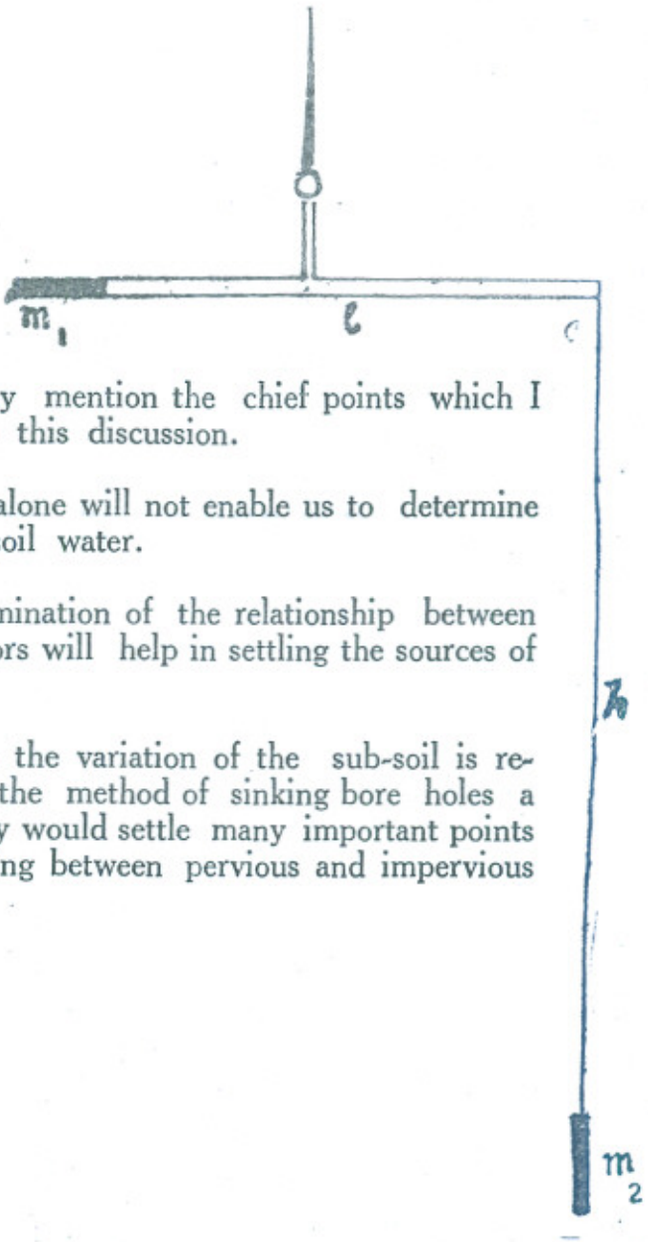

Fig. 2.

8. Conclusion.

In conclusion I may mention the chief points which I wished to emphasize in this discussion.

1. Contour maps alone will not enable us to determine the movement of sub-soil water.

2. Statistical examination of the relationship between changes and local factors will help in settling the sources of the sub-soil streams.

3. Information on the variation of the sub-soil is required. In addition to the method of sinking bore holes a Torsion Balance survey would settle many important points and assist in distinguishing between pervious and impervious sub-soils.

TABLE.

Depletion, Well Irrigation and Rainfall Statistics for Jullundur and Hoshiarpur Districts.

District.	Jullundur.												Hoshiarpur.					
Tahsil.	Jullundur.			Nakodar.			Phillaur.			Nawashahr.			Hoshiarpur.		Garhshankar.		Dasuya.	
Year ..	'80.	'08.	'17.	'80.	'08.	'17.	'80.	'08.	'17.	'80.	'08.	'17.	'11.	'24.	'11.	'24.	'11.	'24.
Δ ..	−0·593	8·19	6·18	−2·48	3·37	12·71	1·925	7·78	7·63	−2·57	4·98	4·02	−0·335	3·684	3·11	6·43	0·827	1·98
I ..	11·86	15·91	24·05	14·58	21·92	26·21	14·16	16·38	19·77	11·95	15·56	18·29	..	15·87	..	19·33	..	18·69
R .. (average to date).	30·89	25·57	26·62	24·74	21·78	20·32	22·60	24·75	24·99	23·57	29·42	28·81	..	..	..	..	..	..
R average ..	..	27·15±6·68		..	22·14±6·32		..	24·28±6·04		..	27·76±6·85		35·41±6·79		33·09±7·97		34·21±8·32	

Δ—Depletion (a negative sign indicates a rise in the spring level).
I—Intensity of irrigation (number of working wells per square mile).
R—Rainfall in inches.

DISCUSSION.

MR. WILSDON, in introducing his paper, said that his main object had been to summarise the methods which could be adopted in attacking the problems of the movement of sub-soil water. The main lines of attack were theoretical, statistical and experimental. Our theoretical knowledge did not take us far. The viscosity terms were the all-important factors in determining the flow of water under given forces in a porous medium. Pure theory had succeeded in finding solutions only in the simplest cases and we were reduced to adopting empirical investigations with models under proper conditions, as in other applied hydrodynamical work such as aeronautics and ship design.

In the statistical method we were limited by the existing records. An example of what could be done with very inadequate material was to be seen in the description given in the paper on the investigation of the Beas-Sutlej Doab. In the irrigated tracts the records of rainfall were unfortunately so widely scattered that this factor largely determined the fineness to which the investigation could be pushed.

The nearest approach we could get to the conditions beneath the soil was by considering the flowing water to be a very viscous fluid such as pitch or treacle. We could then come to a solution by hydrodynamic methods. It could be proved that each article performed a circle about its mean position. As we proceeded downwards the radius decreased exponentially, and a point was reached where there was no velocity at all. But the difficulty remained that with a viscous liquid no simple solution could be obtained. Therefore we had to adopt empirical methods, say by examining the history of the water-table. Unfortunately existing data were not very reliable. It was, nevertheless, possible to extract certain very definite information by an examination of the records, as in the case of Jullundur and Hoshiarpur Districts. In Jullundur we had only three periods of time and in Hoshiarpur two, but by working out the correlation for each village of the whole district and taking the aver. ge of the whole, very definite relations could be established. The writer had shown here that the depletions in the water table which were taking place, varied with the increase of well irrigation. There was close correlation between the changes of the rainfall plus irrigation and the sub-soil water level. It was due to well irrigation that the water-table was going down, but we could not be sure that by stopping well irrigation depletion would not occur. At present we had to make the best of the existing data, but it was obviously very important that in future we should have more extensive data for rainfall.

Physical investigation held out some prospect of determining the actual velocities of moving sub-soil water.

Of the actual physical methods by which we could try and extend our knowledge the most obvious method was by boring-experiments, but this would give only limited information and indiscriminate boring experiments were expensive. Another method was by pumping water

from wells. It was by detailed examination in such cases that we were likely to get information, as the sub-soil was not of a uniform character.

Yet another method was the rate of diffusion of salt in a well. This was very unreliable and he had not very great hopes of its success, but other methods were feasible, and deserved trial.

In order to gain knowledge of the actual constitution of the sub-soil apart from an elaborate survey by sinking bores, the only method available was that afforded by the Eotvos Torsion balance which was described in the text.

He was of opinion that beneath our soil we had sometimes a submerged rock, instancing the cases of Sangla and Sargodha. This was not beyond possibility as isolated observation of the force of gravity made by the Geodetic Survey of the Geological Department showed. Such masses might form a sort of weir for the sub-soil water. The Eotvos balance was a very delicate instrument and he size, shape and the density of the submerged soil could actually be calculated.

MR. COLYER said it was particularly gratifying to him to see the proposal which he had put forward in a paper before the Congress when in its infancy, *viz.*, the establishment of a Research and Investigation Section to deal with such problems as water-logging, now an accomplished fact ; and it must be gratifying to this Congress to know that it had materially influenced the scientific advance of the Punjab.

While it was unnecessary to labour the importance of the subject so ably dealt with by Mr. Wilsdon, it might be as well to mention, for the enlightenment of those who were not in close touch with this problem, the increasing interest which it is attracting b th outside and within the sphere of pure Engineering, and to mention a few of the agencies now at work upon the prevention, cure, or investigation of water-logging. This interest was expressed in various ways, amongst which are—

Questions in the Legislative Council.

Claims for compensation.

Discussions in the Canal Standing Committees.

Conferences between the Revenue and the Irrigation authorities.

The establishment by the Local Government with the active interest of H. E. the Governor, of a special committee to investigate water-logging ; the Physicist member being the Scientific Research Officer of the Irrigation Branch, and the Technical Member an Engineer from the Irrigation Branch. The extension of the operations of the Drainage Board, whose Superintending and Executive Engineers were both Irrigation Branch Engineers.

The investigation by Executive Engineer, Discharge Division, of the inter-provincial question of the discharges of the Indus, and its tributaries, a problem which was closely connected with percolation and the flow of sub soil water. Special Divisions and Sub-Divisions had been formed in the Irrigation Branch for dealing with marked cases of seepage directly attributable to the existence of Canals, while large sums were being

spent upon the reclamation and improvement of water-logged areas by the installation of pumps driven by steam, oil or electric power. And it was understood that there was a scheme afoot for a practical experiment, on a large scale, of the efficacy of the Mole Drainage system. The continued extension of surface drainage systems, the progressive gazetting of natural drainages with power to remove obstructions and the excavation of cunettes, were all evidence of a realization of the importance of this problem.

Coming to the detailed points mentioned in Mr. Wilsdon's paper, it was refreshing to find that he had frankly stated that investigation was hampered by the irregularity of the soil, and had proposed to combat it with a very scientific and up-to-date "diviner's rod," with an unpronounceable name, which could not only detect the existence and form of rock masses, but could also distinguish between pervious and impervious soil, without the use of expensive borings.

The effect of such impervious strata underlying pervious soil was strikingly illustrated in the N.-W. F. P. where in one case, on the Upper Swat Canal, both rain-water and canal-water stored in fissures in the rock, outcropped in the form of springs ; and, in another case near the Kabul River, where large areas of sub-soil water-would outcrop in the winter season, although there were (then) concurrent complaints of poor supplies at the tail of the canal which runs parallel to the low hills on the one side and to the river on the other. This showed that the water-logging was not due to the canal, but to outcropping of the rainfall absorbed in the surrounding ranges of low hills, after travelling underground, and *incidentally under the canal*, until it found a "vent" in the sandy top-soil near the river.

Another seasonal wave of sub-soil water which was worth mentioning, was one experienced on the low bank of the Ravi at Balloki, where in the winter (late January) they had been swamped out of borrow-pits by a sudden rise of sub soil water, to the extent of one foot or perhaps 2 feet, not accompanied by any appreciable rise in the river, and which subsequently subsided and permitted work to proceed.

Another important aspect of Mr. Wilsdon's paper, was the bearing of this investigation upon the problem of percolation from above weirs and similar work on rivers and canals, and the probability of the full, or only a part of the "visible head" becoming effective as "hydrostatic" or blowing-up pressure.

MIAN IQBAL HUSSAIN said that guided by Mr. C. G. May who in 1918 had introduced the subject of sub-soil flow to the Congress, he had written a paper for this body in 1919 on water-logging and particularly brought out the point that it was Hydro-geological problem. He had also made proposals for remedial measures but unfortunately they had not been given a trial.

Since then we had been trying to find a theory to solve the whole problem, but so far had not succeeded. If all these lands which had

got water-logged, had been reclaimed at that time, they could have been made fit for cultivation. But now possibly they had become too rotten and their agricultural and manural value was probably lost.

We should take practical measures as is being done on the Gang Canal and also by the Rural Sanitary Board.

Going back to the question of theory, he would suggest to Mr. Wilsdon that his viscous fluid theory could hardly be applied to the flow of perfect fluids. Flow of water in the sub-soil is analogous to the flow of electricity round conductors and we should try to deduce a theory from that source.

Resistance caused by the sub-soil will be directly proportional to the distance and inversely proportional to the area of voids. Determination of the area of the voids is a practicable thing, while measuring the diameter of particles of sand, etc., too imaginary and too intricate.

He regretted that he could not agree with the author that conditions of flow in a soil could not be determined mathematically.

Depletion in Bis Doab.—The main cause actually lies in denuding the Sewalik hills round Hoshiarpur, where no trees are left. Part of this range was even devoid of verdure. Two hours after rain the whole of the range is dry, there is no reservoiring and no ponding. In the plains below the hills all low places which were jheels before are filled up with sand and the water finds its way rapidly to the river. He was glad the Government had now taken up the work of re-afforestation and reclamation of " chas " lands and it would be through that, that the depletion would be stopped.

Increase in the number of wells cannot be taken as a cause for depletion. The number of wells had to increase because they were not supplying the discharge needed for irrigation. The real cause was that the feed to the sub-soil water was cut off from the main source round hill ranges. In Dasuya Tehsil, below Mukerian the intensity of well irrigation was not low and there was no depletion because a sufficiently large water-logged tract existed just to the north of it.

About the conclusions at which the author had arrived he did not think he was right that surface contours did not determine the direction of subterranean flow in general. Where we have not super-imposed hydraulic pressure, subterranean flow follows the lie of the land. He also doubted the practical advantage of a Torsion Balance survey but as scientists we should support such investigations.

MR. NICHOLSON said that he would not consider the paper in all its respects. Referring to the bottom of the s cond page he said that he thought some explanation could be put forward for the large variation. His opinion was that if the question was approached with the idea of subterranean flow one would be liable to go wrong from the very start. H s reading was that possibly the rainfall was extremely low and evaporation extremely high. He considered sub-soil water to be more like an ocean which did not flow. He further remarked that it was unfortunate

that he did not meet Mr. Wilsdon before. He had the whole of the records and he could have put Mr. Wilsdon on to them. It took him, with 3 subordinates, 3 months to get these records copied out. Then in addition to the figures taken there were canal records.

Another point to which Mr. Nicholson raised objection was the statement that depletion was due to increase in Irrigation.

MR. INGLIS said the conditions in Bombay were very different, but there we could see that there were sub-soil streams. In certain cases these sub-soil springs as one might call them, penetrated as far as the river, but where the water was held up by black soil it had to get out. He considered it highly probable that some similar conditions existed even in the Punjab. In Bombay 2,000 acres had been reclaimed by sinking two bore-holes 6 inches diameter connecting the sub-soil water with the permeable soil.

MR. FOY said that at the bottom of page 4, the author said "This coincides with the opening of the Sirhind Canal, and it seems reasonable to suppose that the decrease in average supplies in the river due to the draw-off into the canal might effect areas in 'Bet' assessment circles, mainly as a consequence of the drying up of drainages through silting as a result of reduced velocities." He would like the author to explain this point. He did not see the connection between the drawing of water by the Sirhind from the Sutlej river and the drainages in that part of the country as the drainages cross it.

Another point was that the Sirhind Canal took off below the Sewaliks, and if any supply in the river is likely to affect the sub-soil table, it was when the river was full and so the little draw-off compared to the enormous volume in the Sutlej was not likely to be affected in the winter months, whether the canal was flowing or not. There was only a small difference between the levels which would hardly effect the question at all.

He did not know what the author meant by the variations in supply during closures, in the water levels of the wells on each side. In 1916 and 1917 which were two extraordinary years of rainfall, the canal was running full the whole year. During 1916, in spite of the canal running the whole time, there was no appreciable difference between the observations of the spring levels. In 1917 there was a 3 months' closure owing to heavy rains and yet that year water-levels in the swamps and wells were much higher. He thought this was a clear indication that the canal supply did not affect the drainage in any way.

MR. WILSDON'S REPLY.—Taking the various points which had arisen, he had grounds for hoping that the Eotvos Torsion Balance would distinguish between pervious and impervious soil. It would certainly determine the location and depth of rock masses, and was very largely employed for this purpose all over the world by applied Geologists.

Mian Iqbal Hussain's confidence that such hydrodynamical problems as had been propounded could be solved by mathematical methods probably proceeded rather from optimism in other people's abilities, than

in any appreciation of the extreme difficulties to be encountered. If such questions were to be solved mathematically so easily it could scarcely be necessary for practical research in such subjects as ærodynamics to be conducted almost entirely by the method of models.

Mr. Nicholson had referred to the question of evaporation in determining variations in the sub-soil water level. In the case of Jullundur there was no evidence of any such changes in the climate as would bring about the **loca ised** effects brought to light. As regards the question of the sub-soil streams, even oceans had marked currents, which were responsible for most of the movement. In the soil he had no doubt similar local variations in flow due to difference in soil texture, were the rule. He hoped to be able to utilize the data collected by Mr. Nicholson, which, if providing a sufficiently long period, would be very valuable.

As regards Mr. Foy's objections to his attribution of changes in the water-table of areas near the Sutlej, to the opening of the Sirhind Canal, he wished to make it clear that it was not the alteration in the **volume** of flow caused by withdrawals which he had in mind as a possible hypothesis explaining the marked changes, evident from the statistics as taking place about 1850, but the cold weather levels downstream of the weir, which would markedly affect the **area** of canal bed covered with water. Drainages running parallel with the river might thus become silted up and would then no longer carry water spilled from the river during the monsoon. No effect of variations in the volume of water taken by the canal in later years when such changes in the river bed had established themselves, would therefore be expected.