A NEW PHENOMENON IN THE MOVEMENT OF THE FREE WATER-LEVEL IN A SOIL AND ITS BEARING ON THE MEASUREMENT OF WATER-TABLE

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Introduction

During certain experiments which were carried out in the Irrigation Research Institute and reported in these *Proceedings*,[1] it was observed that the level of water in a pipe embedded in a soil rises very considerably when a very small quantity of water was added to the surface of the soil. As an example while the quantity of water added, if it actually percolated to the subsoil, could raise the water-level in it by only ·04 cm., the actual rise observed in the pipe was about 8 cm. It was concluded therefore that the fluctuation of the level in a pipe is only an indication of the change in pressure deficiency at the soil surface and not an indication of the actual contribution of water to the water-table.

The reason for this abnormal rise was explained as being due to the flattening of the concave menisci at the soil surface on the addition of water and the consequent decrease in pressure deficiency. This rise therefore, is related not directly to the quantity of water added to the subsoil, but to the decrease in pressure deficiency at the micro-interfaces of the soil-air-water. If this is the case, evaporation from saturated soil surface must bring about an abnormal fall in water-level in a pipe embedded in a soil because a small quantity of water removed by evaporation can cause a considerable change in the curvature of the menisci and this also depends on the grain size of the soil. A finer soil should show a greater depression than a coarser one, for the same loss of water by evaporation. If the view expressed above is correct, then in the case of a stratified soil, having for example a fine stratum at the top and a coarse one below, the water-level in a pipe must initially fall due to evaporation; but, when the soil-air-water interface has reached the coarser stratum, a decrease in pressure deficiency must result and the falling water-level in the pipe must begin to rise.

From what has been said above, it appears that a magnified and complicated effect on the movement of water-level in a pipe or well is produced by evaporation, rainfall or irrigation. These effects are most pronounced when the level of water is at a distance from the soil surface less than the capillary height of the soil. The magnitude of the effect when the water-level in the pipe is beyond capillary height is under investigation.

The existence of such a magnified and complicated effect brings us to the difficulty, as to how to interpret the fluctuation of water-level in a pipe or well in their true relation to the quantity of water removed by processes such as evaporation and drainage or added by rainfall, irrigation and seepage. If the movement of the water-level in a pipe is brought about by a decrease or increase in the curvature of the water menisci at the micro-interfaces, the mechanical composition and the moisture content of the soil lying above the indicated water-level must be known before a correct correlation can be made. The problem therefore of connecting the fluctuations of water-level in pipes and wells obtained in the usual surveys with irrigation, rainfall, seepage and evaporation does not appear to be as simple as has been thought in the past.

In order to test the views expressed in the foregoing paragraphs, a series of experiments have been carried out.

Experiment

The experimental tube L consists of a galvanised iron pipe closed at the bottom shown in the inset in Fig. 1 about 200 cm. long and 8 cm. in diameter fitted with a number of side tubes S_1, S_2, S_3, S_4 and S_5. The tube is packed under water with the soil to be investigated. Great care in packing is essential for faithful reproduction of the results. Water, free from air bubbles and suspended matter, is allowed to flow down the sand column continuously for about three weeks to quicken its settling. The pressure gradient, as given by the pressure pipes S_1, S_2 and S_3, indicates the uniformity of packing along the length of the tube. The value of the transmission constant is determined at intervals, and when it becomes constant it shows that the sand column has been stabilised. The inflow of water is now stopped. S_1, S_2, S_3 and S_4 are closed while S_5, which connects the main tube with the glass tube M, is opened. The level of water in M now rises to the level of free water in L. Evaporation is allowed to take place from the sand surface under atmospheric conditions. So long as there is any free water present above the sand surface, the level of water in M falls very slowly and remains the same as that in L. But as soon as the water-level in the pipe touches the sand surface the level in M begins to fall vary rapidly. The level in M corresponding to the commencement of the rapid rate of fall is taken as the zero datum level. A pipe embedded in the body of the sand also gave the level as a check, but since the readings always tallied with those of M, and as the latter were easier to observe, the former readings were discontinued after some time and only the level in M was subsequently read. In the first set of experiments three specimens of sand, namely coarse, fine and very fine, were investigated. The experimental cylinder was packed with each specimen in turn and the readings of the side tubes were observed. This series gave the readings for homogeneous stratum. It may be pointed out here that the sizes of particles are not uniform, but the stratum consists of the same type of material and is hence homogeneous. In the second series of observations, the coarse sand mentioned above was packed in the cylinder, but a few centimetres at the top were left for filling either with fine or very fine sand referred to above. This produced the required heterogeneity in the strata. Different thicknesses of the top layers were investigated. The results obtained are given in the following figures and are described with reference to them.

Results

Referring to Fig. 1, it will be seen that there are four curves in it, *viz.*, *a*, *b*, *c* and *d*. The curve *a* represents the rate of evaporation from the

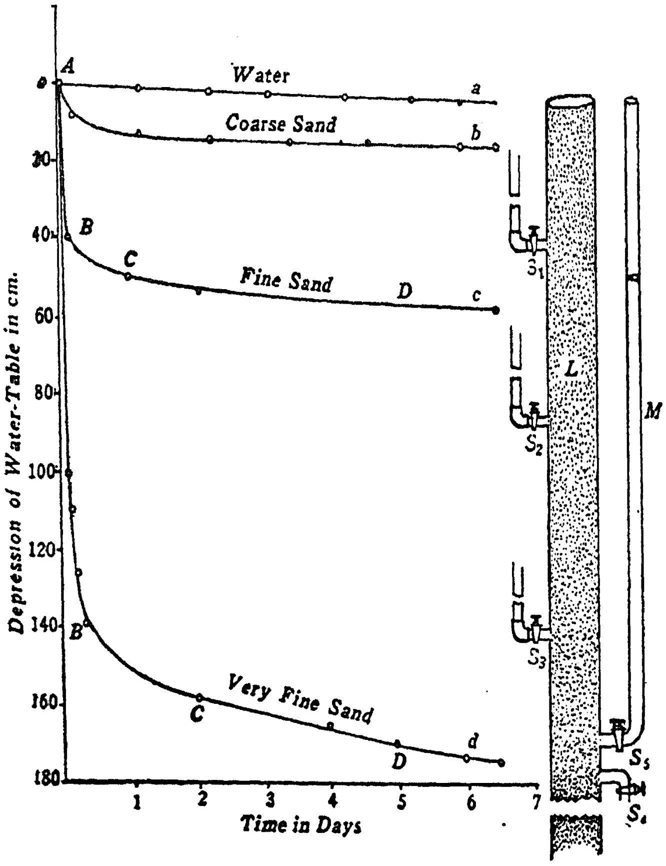

FIG. 1. Depression of water-table in sand without stratification

surface of water. This rate of evaporation is also equal to that occurring over a sand surface as it is well known that, when sand is saturated or nearly so, the rate of evaporation from it does not differ from that over a plane water surface, other conditions being similar.

Curve *b* shows the rate of depression of water-level in the pipe with respect to time for very coarse sand. There is a rapid initial fall of about 5 cm. and subsequently the rate of fall becomes very slow. The sand particles in this experiment had a grade between 2·5 and 3·0 mm., and were too coarse to be analysed in a siltometer.

Curve *c* shows the rate of depression of water-level in the pipe* for fine sand as indicated by the level in M. In this case the rapid initial fall continues up to about 45 cm. and subsequently the rate becomes very slow. The curve is composed of three distinct parts AB, BC and CD. The fall along AB is very rapid but the rate of fall decreases in the region of BC. From C, the curve becomes almost asymptotic to the time axis showing that the rate of drepression is now very slow. The fine sand referred to here, was mechanically analysed in the optical lever siltometer[2] and its size distribution curve is shown in Fig. 2.

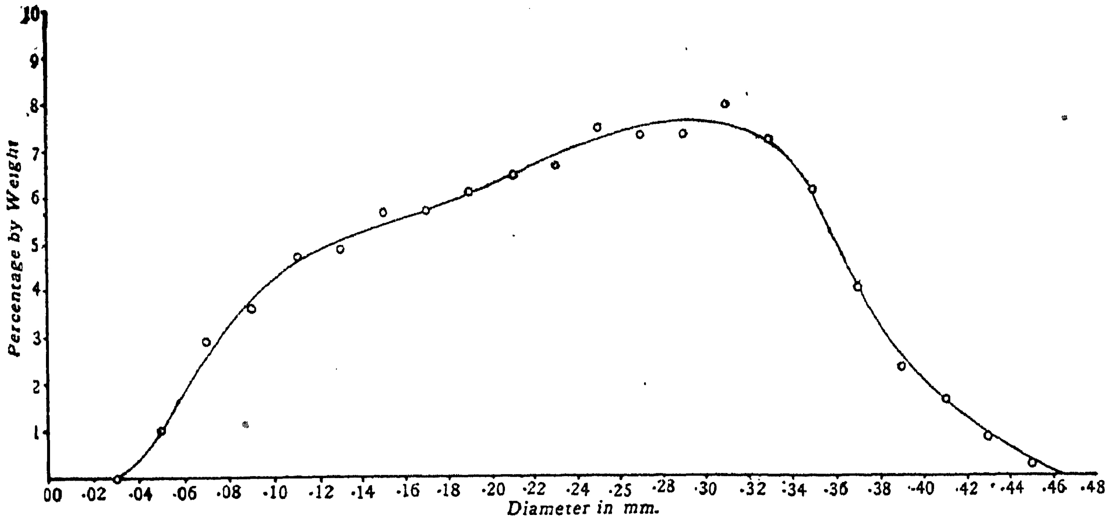

FIG. 2. Size distribution curve of fine sand

Curve *d* in Fig. 1 shows the rate of depression of water-level in the pipe for very fine sand. The nature of the curve resembles that for fine sand, though the numerical values are of course different. The initial rapid fall continues up to 150 cm. and then the rate decreases. The analysis of this sample is given in Fig. 3.

The results of the movements of water-level when stratification exists, *i.e.*, when there are two strata in the tube will now be described.

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* This was usually called water-table.

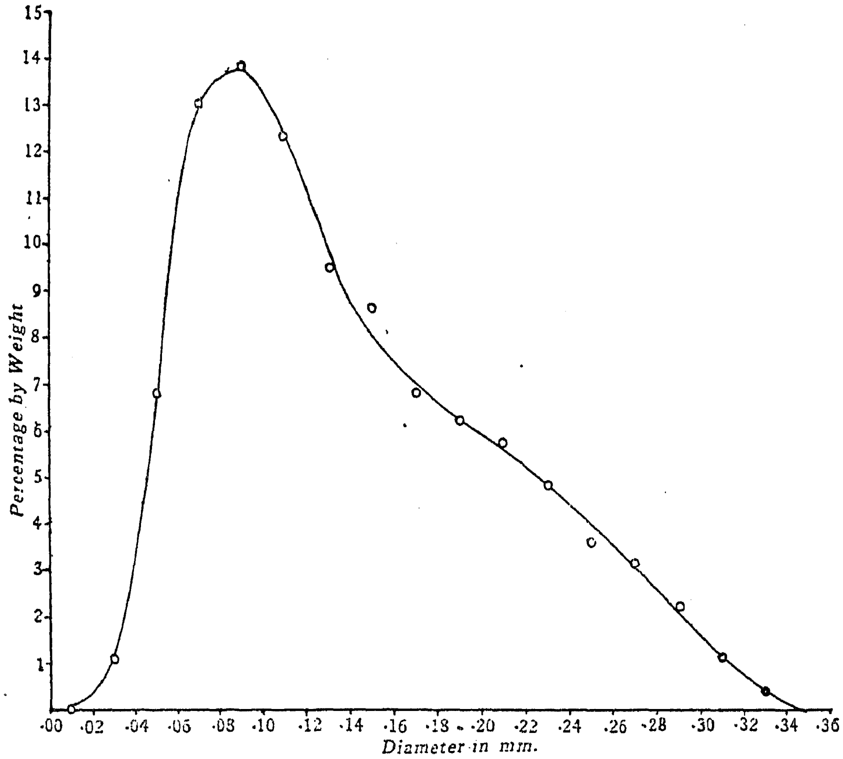

FIG. 3. Size distribution curve of very fine sand

The four curves in Fig. 4 show the effect of evaporation on the movement of water-level in the tube M, when the cylinder L is packed with

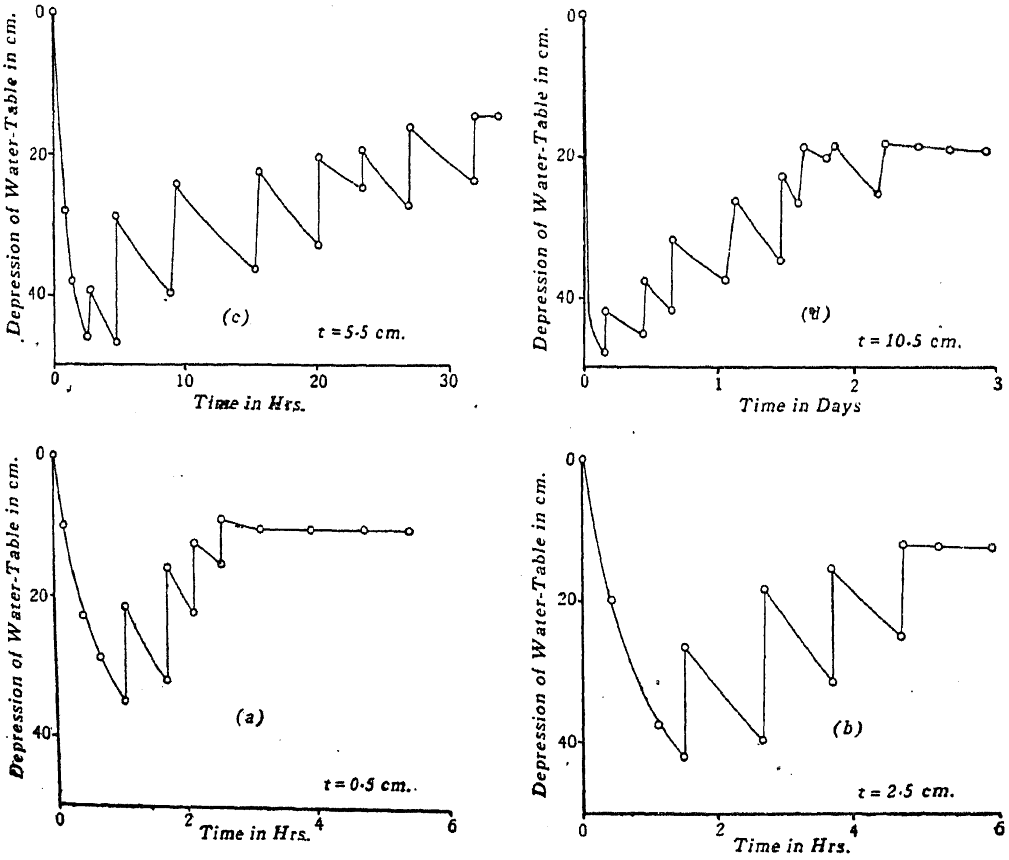

FIG. 4. Fine sand with stratification

coarse sand at the bottom and layers of different thicknesses of fine sand are packed at the top. The thickness *t* of the layers is varied from 0·5 cm. to 10·5 cm. as shown in the figure. In all the four cases investigated, there is an initial rapid fall of level. This rapid fall then ceases and a rise begins. Finally the water-level in the pipe attains an almost steady state when it has risen to about 10 cm. below the surface of the coarse sand. In the case of the thinnest layer, this state is attained in about three hours, whereas with the thickest layer this takes about three days. This level is characteristic of the lower coarse stratum only. The composition of the top layer does not seem to affect this final steady level, though the initial fall is controlled by the top layer. It will also be noticed that the rise of water-level is not smooth, but is attained by a series of quantum-like movements.

Fig. 5 shows the results of experiments similar to those referred to in Fig. 4, but here the top layers were composed of very fine sand. The

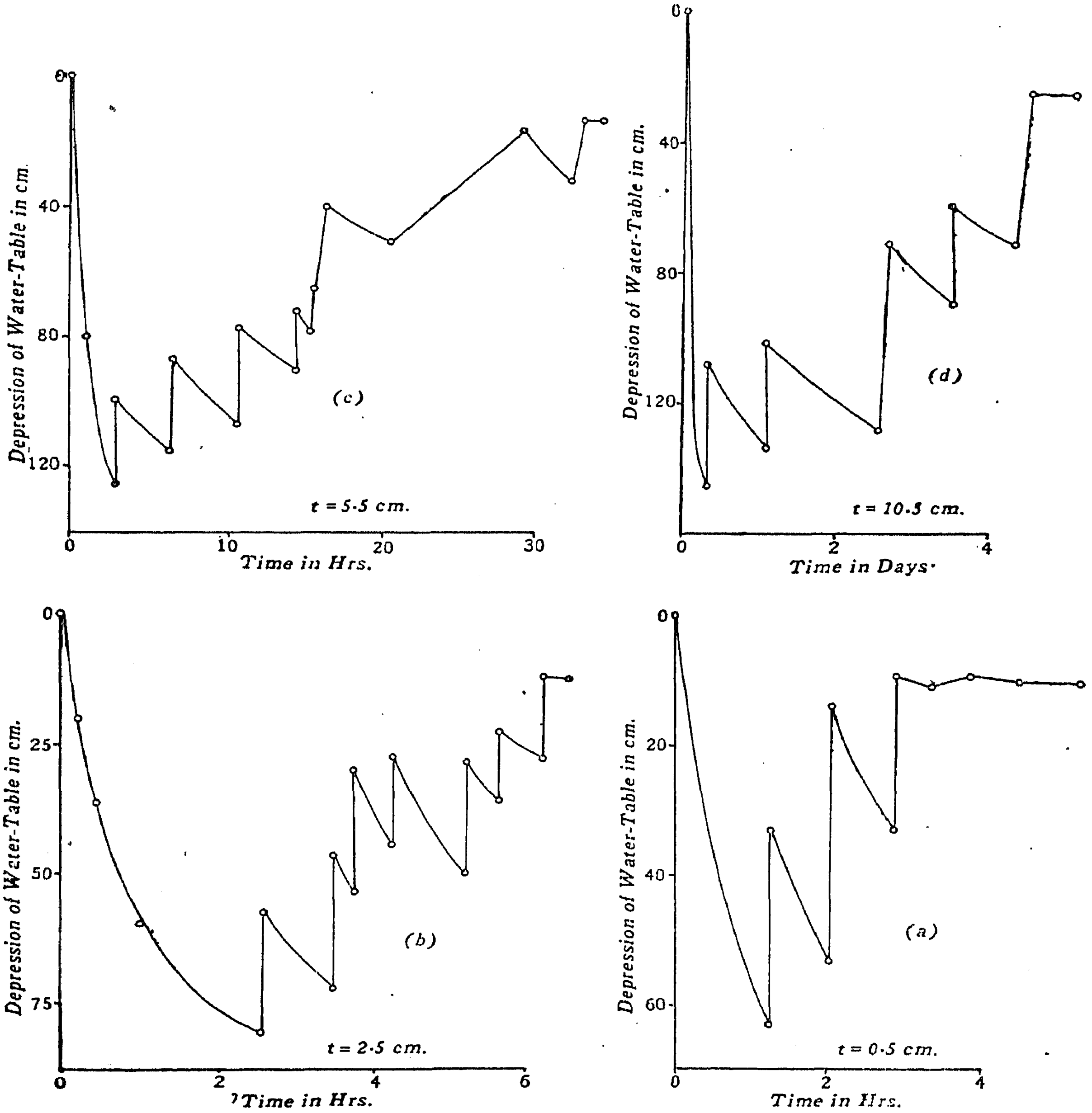

FIG. 5. Very fine sand with stratification

nature of the curves is similar to that for fine sand, but the initial fall of level is greater as would be expected. Thus, whereas the initial fall in case of fine sand with a layer of 0·5 cm. thickness at the top is about 30 cm., it is 70 cm. for very fine sand. The final steady level attained after the reversals are complete, is the same as that for fine sand referred to before, because the bottom layer determines the level and the coarse sand is similar in both cases. The time taken for the final level to be attained is longer in this case than that in the case of fine sand, but as the various grades and thicknesses were not investigated under exactly similar atmospheric conditions of temperature, humidity, etc., a quantitative comparison of the time factor cannot be made. The rise of water-level after an initial fall and the quantum-like upward movements brought about by stratification are new phenomena and are of great significance.

Discussion of Results

It will be seen from the description of the results that the experiments fall under two heads: The first investigation is with homogeneous strata and the second with heterogeneous strata. These will be discussed in turn in sections (*a*) and (*b*).

(*a*) The results in Fig. 1 with homogeneous strata show that in the initial stages, a certain amount of water (say Q) lost by evaporation produces a depression in the water-level in the pipe much more than at the later stages. In the usual method of calculation, if A is the effective area of cross-section of the cylinder, the depression in water-level in the pipe will be equal to Q/A for a loss of Q. If the pore space is about 40 per cent., the effective area A is equal to 40 per cent. of the area of cross-section of the cylinder. For very coarse sand, the initial fall is about ten times that calculated from Q/A, while for fine and very fine sand, they are about 80 and 250 times respectively.

These results show that the fall of water-level is dependent upon particle size under similar conditions of evaporation. The same amount of evaporation has widely different effects on the different specimens. Also if a small amount of water is sprayed on to the surface of very fine sand in the tank, the level in the tube M was found to rise much more in the case of fine sand than that in coarse one. The effect of evaporation is opposite to that of spraying of water on the sand surface. It may be pointed here that these effects are shown when the level in the pipe is within capillary height of the soil from the surface.

The observation here is of practical significance. When water-level in a pipe is not deep, it may be expected that it is within the capillary height,

such a case, rainfall, irrigation or seepage decreases the pressure defici-
cy, so long as there is an air-water-soil interface anywhere between the
ter-level in the pipe and the surface of the soil. The pressure deficiency
pends on the curvature of the water menisci at the top of the capillary
lumn and, hence, on the particle size. There is thus no direct quantita-
e relation which can exist between the rise of water-level in a well or
pe on the one hand and irrigation, rainfall or seepage on the other.
e case of the depression of water-level in a well due to evaporation
similar to the above phenomenon. A pipe embedded in a soil
asures the pressure deficiency characteristic of the grain size of the soil
the air-water-soil interface. It appears from our investigations in the
oratory, that this pressure deficiency attains its maximum at about
0 cm. in very fine sand as judged from the portion corresponding to
3C in Fig. 1. This value is not in conformity with that of Keen.[3]
en, even in heavy loam obtained a steep fall of level of only 90 cm.
s curve resembles in form those obtained by us, but his final value is
ch smaller and also the period in which the phenomenon occurred in
present investigation is less than a day, whereas in Keen's deduced
rves the period extends to a few months.

According to Keen's experiments a rapid initial fall is marked to about
cm. in coarse sand, 70 cm. in fine sand and about 85 cm. in heavy
m. In the present investigation, the value for coarse sand is about
m., that for fine sand about 45 cm. and that for very fine sand about
0 cm. One may therefore expect that in heavy loam the value will be
ll greater. The classification coarse, fine, etc., as is given usually in
h papers, is only qualitative. The analyses of the specimens of sand used
the present investigation are given in Figs. 2 and 3. The main point
re is that Keen from his observations deduces that even in heavy soils,
range over which capillarity can be regarded as effective in supplying
y quantity of water in a reasonable time is only about 90 cm. or 3 feet.
the interpretation which Keen puts on the observations is correct then
value of 90 cm. does not appear to be correct.

But it seems that Keen's interpretation of the results is not correct.
bases the rapid initial fall in free water-level in the pipes on the experi-
nts of Haines. Keen states that "from a consideration of the suction
ssure or pressure deficiency, as developed by Haines, the reason for the
id initial fall is evident. Haines' curve for the relation between pressure
ficiency and moisture content of the soil shows that just below saturation
moisture content changes very slightly for an appreciable increase in
ssure deficiency, above its initial zero value at saturation."[3] (page 507,

line 25). This is not the case and there is no appreciable increase in pressure deficiency for slight changes of moisture content just below saturation as will be seen by the following experiment. A porous pot was embedded into a vessel containing sand packed under water and saturated. The porous pot was connected to a sensitive mercury manometer and filled with water. The pressure at saturation was of course zero.

A second specimen of the same sand with a quantity of water slightly less than that required for saturation was similarly packed and the manometer reading was noted. The moisture content was determined at the beginning and end of each experiment. Practically no difference was obtained in the values of the moisture content for very little evaporation was allowed to take place during the period of each experiment. A series of values for pressure deficiency and different moisture contents were thus obtained, each set of the values being the result of a separate experiment. The first set was carried out on the specimen of sand referred to in Fig. 2. The result is shown in Fig. 6 (Curve *a*). The curve is very smooth down to full saturation and no abrupt change as referred to by Keen[3], was obtained. A mixture of the same specimen of sand with another soil was again investigated but with similar results. There is therefore no experimental evidence in support of such an explanation as offered by Keen for the rapid initial fall of water in the pipes. Secondly, Haines has also stated that "the main features of the pressure deficiency curve, namely a distinct bend at each end with a flat intervening portion, become smoothed out as the particle size becomes less uniform, for there is then a smooth wide gradation in the pore spaces. Thus the measurements recorded for actual soils by Kornev show an almost uniform slope for the curve".[4] Whatever therefore might have been the case for glistening dew or such materials having all particles of uniform size, in the case of ordinary sands no abrupt

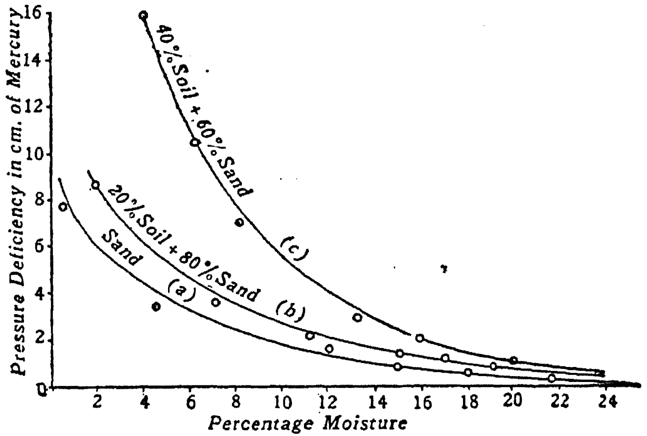

FIG. 6.

change of pressure deficiency with slight fall of moisture content is obtained.

The initial rapid fall in the free level in the pipes cannot therefore be explained on the hypothesis of Keen. On the other hand, this fall is caused by the pressure deficiency due to the curvature of the water menisci at the top of the capillary column. There is therefore no unsaturation in the body of the sand above the free level indicated by the pipe. The sand is saturated almost to the top but there is no plane water surface, innumerable menisci having been formed at the top of the capillary column in the sand and giving it the curvatures, which in turn cause the pressure deficiency. It is thus a meniscus effect reflected in the pipe. The difference here is quite fundamental, because it clearly negatives the idea that in the sand above that of free level of water in the pipe, the zone is unsaturated.

Another evidence, if necessary, in support of the meniscus theory is that in the present investigation the rapid initial fall was complete in a few hours. During such a short period, the water-level in the body of the sand cannot have sunk by more than a few millimetres, while the pipe shows a fall up to 150 cm. in very fine sand. The theory of unsaturation cannot hold for it is not possible in a few hours for the whole body of sand to become unsaturated. This point is only indicated here as an additional support for our explanation, though the experimental evidence was sufficient to disprove the unsaturation theory as offered by Keen.

Another point to which attention may be drawn here is that Keen deduced the composite curves[3] as a result of a few months' work and states that it thus represents " an extreme and simplified state of affairs unrealizable in practice in temperate climates although the great draught of 1921 afforded a fairly close approach to this condition "[3] (page 509, line 8). In the present experiments the rapid initial fall took place in a few hours and the condition was very easily realisable, *i.e.*, a steep fall and then a smooth one as is shown in his curves. It is true that the climate in the Punjab is dry and hot and not like that at Rothamsted, but it is difficult to understand why such a condition cannot be realized in temperate climates within a reasonable interval, if the experimental conditions are suitably arranged. One essential condition to realize this state quickly was found to be that the diameter of the pipe should be small compared with that of the cylinder containing sand, so that the water in the pipe itself shall not act as a source of supply of water to counteract the effect of evaporation and secondly the bottom of the pipes should not get choked as was quite possible in such experiments of long duration as done by Keen.

(*b*) The experiments on the movement of water-level in the pipes in the cases of heterogeneous strata will now be discussed. They show that as evaporation proceeds over a stratified medium, the top layer being finer than the lower one, the water-level in the pipe undergoes a rapid depression. After a certain time usually of the order of hours, the falling water-level begins to rise.

This phenomenon of the reversal of a falling water-level is shown by fine as well as very fine sand with coarse sand as the bottom layer. Within the limited ranges of thickness of the top layers which have been investigated, this reversal takes place in all cases and the phenomenon itself is not dependent on the thickness.

The initial fall of water-level as observed in very fine sand is greater than that in fine sand, for the same thickness of the top layers. This may be explained by the fact that in very fine sand the pores, on the average, have smaller cross-sections than those in fine sand, so the menisci lying at the soil-water-air interface in very fine sand will have a greater curvature, thus exerting a greater pressure deficiency. Hence the level falls to a greater depth with smaller particle size. As soon as the air-water-soil interface comes in contact with the coarser stratum below, the curvature of the menisci flattens, so the pressure deficiency decreases, and the water-level in the pipe begins to rise. Though at first sight it would appear that this phenomenon is strange, it is as would be expected according to capillarity. The phenomenon of the reversal can thus be explained, by the decrease in the curvature of the water menisci as they leave the fine stratum and enter the coarser one.

Though the phenomenon itself is independent of the thickness of the top layer, the magnitude of the initial fall is not independent. Thus in fine sand, while a top layer 0·5 cm. thick causes an initial fall of 35 cm., the top layer of 10·5 cm. causes a fall of 45 cm. This difference is even more pronounced in the case of very fine sand. In this latter case, the layer of 0·5 cm. causes a fall of 65 cm., whereas a layer of 10·5 cm. causes an initial fall of 140 cm. It thus appears, that to a certain extent, the magnitude of the initial fall of level is dependent upon the thickness of the top layer. This may be explained as follows:—

As evaporation proceeds over a saturated soil column, the pressure deficiency begins to develop due to the formation of the menisci at the surface. The curvature of these menisci goes on increasing for a certain length of time. Before the maximum pressure deficiency characteristic of that particular soil is developed, air penetrates through certain points to the lower coarser layer. As soon as this happens, the pressure deficiency cannot develop any further. As the penetration of air occurs through a thinner layer sooner than that in a thicker one, the pressure deficiency developed is less in the former case than that in the latter. Of course, when the thickness is sufficient to develop the maximum pressure deficiency before the penetration of air into the lower layer occurs, any further increase in the thickness will have no effect on the magnitude of the initial fall, which would have attained its maximum value with this optimum thickness.

After the first fall, the water-level in the pipe begins to rise, but the rise is not smooth. As will be seen from the nature of the curves, the upward movement consists of a series of quantum-like reversals. It appears that this quantum-like movement is in some way associated with the non-uniformity of the particles of sand in the top layer. This is under investigation.

After this quantum-like rise has ceased, the level of water in the pipe becomes more or less steady. Subsequently there is a very slow fall. This fall is slow because, it is now caused only by the loss due to evaporation and not by any change in pressure deficiency. Evaporation has to take place through the top layer and so the rate of evaporation is slow and hence the rate of fall also is very slow. Thus in about a period of one month the level only fell by 4 cm. after the steady state was reached. This value is not shown in the curves but was obtained in subsequent observations.

Another factor is the thickness of the top layer in relation to the time taken to attain the final steady state. Here, thicker layers take more time than thinner ones because in the former case the menisci take more time to penetrate and establish contact with the lower stratum than in the latter. The final state is attained when all the water menisci, which constitute the top of the capillary column, have left the top layer and made contact with the coarse stratum below. Thus, while the steady level is attained in four hours when the layer is 0·5 cm., four days are required when the top layer is 10·5 cm. This factor is of significance, because in field, if a top layer is a few feet thick and is finer than the stratum down below, the phenomenon of reversal may take months to occur. Meanwhile rain might occur and disturb the phenomenon which would otherwise have been observed.

These phenomena have an application to the case of seepage drains. Seepage drains are generally dug in water-logged areas with their bed below the water-table, the water-table being indicated by the level of water in the pipes. The object is to drain away the water from the top layers of the soil. When the drain begins to operate, some water is drawn into it, but due to the removal of water by drainage, pressure deficiency is developed at the natural surface. Evaporation from the natural surface considerably helps the development of this pressure deficiency. Due to these two causes, drainage will decrease and finally cease even if the soil above the level of the bed of the drain is still saturated. If therefore, it is desired to prevent the soil from being staurated for a reasonable depth below the natural surface, the capillary height of the soil must be considered before the drain is constructed. Thus for example if the capillary height of the soil in the area is found by experiments to be say 5 feet and the water is to be kept free from a saturated state for a depth of 6 feet from the natural surface, the bed of the drain should at least be 11 feet below the natural surface. The problem of the effect of capillarity on drainage is under investigation.

It will be seen from what has been observed and discussed in the foregoing pages that the water-level in a pipe embedded in a soil or a well responds to conditions not associated with a water-table. Sprinkling of water or evaporation raises or lowers the water-level in the pipe respectively out of all proportion to the amount of water added or removed. The water-level reverses when there is stratification and a rise of a falling water-level occurs without the addition of any water. To what does then the level of water in a pipe or well correspond ?

It has been considered so far that the level of water in a pipe or well is that of the water-table in the surrounding soil. The implications of such a definition have not been known and there was no doubt about the cause of rise of level of water. It was always thought that a certain amount of water added to the soil by irrigation or rainfall contributed directly to the rise of a well level or water-table both being assumed to be identical. Conversely, evaporation removed a certain quantity of water and the well level fell and it was thought that the water-table also fell by the same amount. It was not suspected that the mechanism by which the level fell in a pipe or well was due to the development of pressure deficiency consequent upon the increase of curvature of the menisci at the soil-air-water micro interfaces. It will be seen from the investigation that if we take the well level as that of the water-table it will bring us to the anomalous position that water-table can rise or fall without the addition or removal of water and that the same additions or removals of water will cause very great differences in well levels according to grain size of the soil.

It is obvious that such a conception of water-table is of no practical use. It, therefore, becomes necessary to distinguish between the level of water in a well or pipe and the water-table.

It is clear that the free surface of water in a well or pipe embedded in a soil is at atmospheric pressure and that at the same level there must exist a surface of water in the subsoil at atmospheric pressure, because there is a saturated connection. This surface is sometimes called the phreatic surface. This phreatic surface is not a free air-water interface in the subsoil, because within the soil the pores are full of water to a certain height above it. The height to which this moist belt extends in the subsoil above the phreatic surface depends on the grain size of the material. When a bore is made, the soil grains are removed and the phreatic surface is exposed, the water standing as in a pipe or well. A well or pipe indicates, like a manometer, only the movement of this phreatic surface. The phreatic surface is sensitive to changes of pressure caused by the increase or decrease of curvature of the water menisci at the surface of the capillary column in the soil as is shown by the investigation.

As was mentioned in the previous paragraph there exists in the subsoil a moist belt above the phreatic surface, the height of which depends upon the grain size of the material. In this moist belt, the forces are due to capillarity and gravity. As we move up this moist belt, a continuous soil-air-water interface will be encountered at a certain height above the phreatic surface. For simplicity if we take the grain size and packing as uniform this interface will be in a horizontal plane if the whole macro-surface is considered. This macro-surface will consist of an infinite number of menisci at the micro interfaces of the soil particles. It is the change of curvature of these micro interfaces which is responsible for the change of pressure at the phreatic surface.

If we now consider this macro-surface as a whole, the pressure above this surface is atmospheric, but below it, the pressure is less than that. This macro surface will move up or down only by the actual contribution of water; that is to say, if Q is the amount of water contributed and A is the effective area of cross-section, then the movement will be Q/A. In this respect it behaves quite differently from the phreatic surface. The difficulty is that the former surface cannot be observed because as soon as a bore is made, the capillaries are removed and only the phreatic surface is exposed and this latter is observed in a pipe or well. This macro-surface marks the limit below which the soil is saturated and for purposes of waterlogging, it is this surface which counts. In the field this macro-surface may be considered as the water-table and not the free level in the pipe as is observed in the surveys. The latter is only an indication of the phreatic surface and is a measure of the pressure deficiency caused by the curvature of the menisci at the micro surfaces of the capillary column.

In nature, since the grain sizes composing a soil will not be uniform, the water-table according to the new definition will not be in a horizontal plane. Since the various processes such as evaporation, rainfall, irrigation or seepage do take place in nature, the phreatic surface is seldom static, but is fluctuating. But as stated before, its fluctuation is not a measure of the quantity of water added to or subtracted from the subsoil. The conditions stated here mainly refer to a high water-table. When the water-table is low and deep strata of partial saturation exist above the water-table, conditions are probably not so simple as stated here. But when the water-table is low there will be no water-logging and the case is not of practical interest. Experimental difficulties also increase considerably in the latter case. It will be attempted in due course.

The investigation leads us to an explanation of the abnormal rise of water-level, very often noticed in the Punjab, during the onset of rains. As for example, it has been noticed that about a quarter of an inch of rain raises the water-level in many shallow wells by about a foot. As soon as a canal is opened the wells in the vicinity rise and attempts were made to connect this rise with the amount of water lost from the canal by seepage. A detailed consideration would have shown that there was some unknown factor as otherwise such abnormal rise could not happen. Theories such as pressure transmission from under the soil or an abnormally high transmission constant, etc., were sought for the explanation. But it is now seen that these explanations were not correct.

Summary and Conclusion

Experiments have been conducted to study the effect of evaporation on the subsoil water movement in soils consisting of homogeneous and heterogeneous strata. The samples were packed in cylinders 200 cm. high and 8 cm. in diameter. The level of free water in the subsoil was measured in a side tube. The first series of investigations were carried out when the tank was completely filled with (1) coarse sand, (2) fine sand, and (3) very fine sand. The specimens of fine and very fine sand have been mechanically analysed. The second series of experiments were carried out with coarse sand at the bottom and different thicknesses of layers of fine or very fine sand at the top, *i.e.*, with stratification.

In all cases, levels of water have been measured in a side tube when evaporation was allowed to proceed under atmospheric conditions.

The main conclusions are that (1) when there is stratification, the top layer of the soil being finer than the bottom one, *a falling water-level as observed in a pipe, will begin to rise, without the addition of any water*, the top of the soil being exposed to the atmosphere. This rise is not smooth, but consists of a series of reversals, the water-level generally rising at each reversal. So far as known to us this is a new phenomenon, hitherto not observed. The phenomenon is caused by a decrease in the pressure deficiency brought about by the flattening of the water menisci at the surface of contact of the two layers of soil. When there is no stratification, there is a rapid initial fall followed by a very slow one.

(2) A pipe measures the phreatic surface in stratified or uniform medium.

(3) Simple quantitative relation, between movement of water-level in a pipe and rain, irrigation, seepage or evaporation cannot therefore be expected to exist.

(4) When the water-level is within the capillary height of the soil from the surface, its fluctuations due to rainfall, irrigation, seepage or evaporation are many times greater than when it is beyond the capillary height.

(5) Seepage drains, the depths of which are within the capillary height cannot remove the subsoil water, because of the development of pressure deficiency on the soil surface due to evaporation and drainage.

(6) Keen's conclusion, that the maximum range over which capillarity is effective in supplying any quantity of water in a reasonable time is only about 90 cm. even in heavy loam, is not confirmed by our experiments. A rapid initial fall of 150 cm. was obtained in very fine sand in the present investigation when there was no stratification. The explanation which Keen has offered for the phenomenon of rapid initial fall in the pipes as based on Haines' curves, *i.e.*, of a rapid increase of pressure deficiency with slight fall of moisture content just below saturation is not found to be correct. On the other hand, the rapid initial fall is caused by the curvature of the water menisci at the soil-air-water micro interfaces on the top of the capillary column.

(7) The free level of water in a pipe or well corresponds to the phreatic surface in the subsoil. Since the pores are full of water to a certain height above the phreatic surface, the free level in a pipe may be distinguished

from the water-table. The water-table should be considered as that surface below which the pores are full of water and may include what is called the capillary fringe. From the point of view of water-logging, it is the latter definition which is of practical use.

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