THE WATER BALANCE AS A BASIS FOR IRRIGATION RESEARCH

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Provided one has at ones disposal data on ground- and ditch water depths and if also data are available on rainfall and computed evaporation, an insight may be obtained into storage and evaporation variations occurring in the soil. This is made possible by the fact that ditch- and ground water levels constitute a measure for subsoil drainage, the pertinent data rendering it possible to convert pressure head losses into discharge in mm. per time unit.

To secure an impression of the relation between these variables, one may subtract the rainfall (r) and the estimated evaporation from an open water surface (E_o) from each other as a first step. Furthermore, for small sections of the rise or fall of the water level (ΔH) as occur in the unit of time over which rainfall and evaporation data have been obtained, data may be gathered on the pressure head loss between the water level (H) and the ditch water level (d) and also on the discharge ($r-E_o$). If, for the cases with approximately identical ΔH-values, the values found for $r-E_o$ are plotted, for each month separately, against those for H–d, scatter diagrams as shown on fig. 1, are obtained. Comparison of the scatter diagram for January with that for June reveals a relationship which is depicted by a curve identical in shape but shifted to a lower level for $r-E_o$. This is due to the fact that the E_o has been taken too high. The actual evaporation is smaller by a factor x. When the vertical shift of the curve for June is measured with respect to the curve for January, an approximation is obtained for the difference $x_{Jan.}-x_{June}$, the actual evaporation E_w being equal

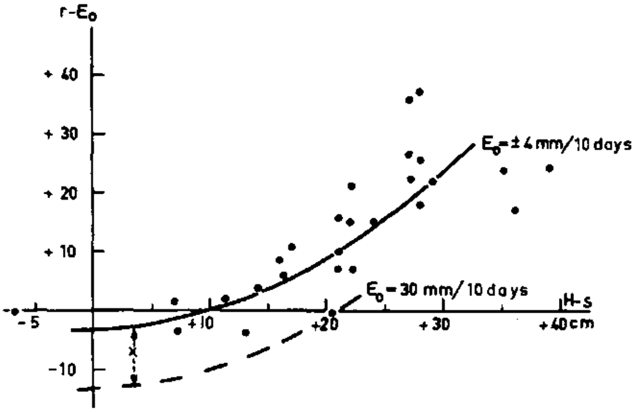


FIG. 1. The H – d value, being a measure of the prevailing pressure head and the $r-E_o$, being a measure of subsoil drainage, together give rise to the drainage curve, which from month to month shows different levels. The vertical difference x is a measure of the reduction factor for evaporation

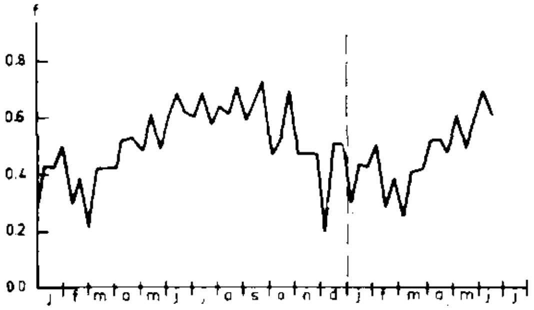


FIG. 2.
The reduction factor is derived from an analysis of the water balance, but is subject to marked variation due to easily evaporating, recently fallen, rain

to E_o–x_{June}. In this way the actual evaporation could be determined if a month with no evaporation at all should happen to be available. As the evaporation is however, only very small in winter the error introduced with respect to x is only very small if, through extrapolation from the available data for autumn and spring, the reduction factor $f = E_w/E_o$ is estimated and from this the factor x for the winter season is deduced. Fig. 2 gives an impression of this.

A good approximation of the reduction factor is then available for the remaining months. This factor appears to be highly variable, however, due to a large number of deranging factors, so a further study of these additional factors is called for. One should also guard against accidental errors.

The accuracy of the curve, which is obtained as a mean for the discharge r–E_o against H–d, may be checked with the existing drainage formulas. The drainage formula

$$q = \frac{8k_oD\,(H-d)}{L^2} + \frac{4k_b\,(H-d)^2}{L^2}$$

may be rendered

$$\frac{q}{(H-d)} = \frac{8k_oD}{L^2} + \frac{4k_b\,(H-d)}{L^2}$$

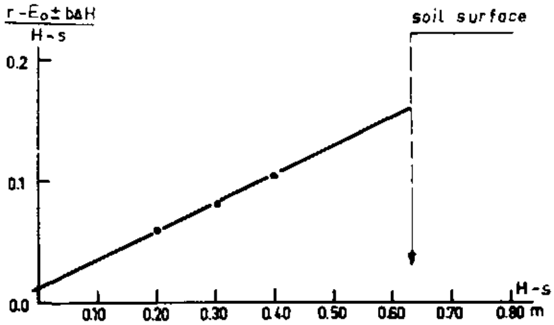
$$\frac{q}{(H-d)} = A + B\,(H-d)$$

q = drainage in mm. per time unit = $r - E_w - b\Delta H$
k_o = permeability factor subsoil
k_b = permeability factor surface soil
D = thickness of aquifer
b = storage factor
L = half the distance between drainage ditches

In plotting the value found for r–$fE_o \pm b\Delta H$ divided by H–d, against H–d, a straight line must result which should hold good for all months of the year. This check on the accuracy of the mean drainage function provides at the same time a reliable check on the value found for f, see fig. 3.

When in this manner a clear insight has been obtained into the function by means of which the groundwater depths may be converted into drainage rates, it is possible to go deeper into the problem, since actually the process used is of the approximative type. For instance, the variations in moisture content are adequately accounted for in ΔH, in as far as groundwater is concerned,

FIG. 3.
The drainage curve, as is apparent from a drop of the variables recorded along both axes through H – d, accurately follows the drainage formula



but the drainage term has not yet been corrected with the variations in soil moisture (ΔV) above the groundwater level.

The reduction factor f is furthermore a highly variable quantity. Soils wetted with rain will show a higher rate of evaporation than soils containing an equal amount of moisture, but evenly distributed over the entire profile. Also the amount of evaporation will be affected by such factors as moisture discharge or depth of groundwater, type of crop grown and other conditions.

One may now go on by determining the rate of discharge for all periods from (H–d). In addition, the periods with approximately identical values for r and ΔH may be combined into groups. By plotting drainage discharge (A) against the evaporation of the open water (E_o) for the various groups of values in the different r, ΔH groups individually, a picture will be obtained as represented in fig. 4. This figure gives a somewhat different representation of the water balance than does fig. 1, use having been made of the circumstance that any water that evaporates cannot flow off via a subterranean route. If the E_o should actually provide a picture of the true evaporation, the line showing the relation between E and A ought to run at an inclination of 45°. However, since the E_o deviates from the E_w, this becomes apparent as a deviation from this 45° angle of inclination, the tangent of inclination of this line indicating the value of the reduction factor f.

The reduction factors f may now be arranged according the values found for r and ΔW, resulting in a graph as given in fig. 5. This figure illustrates the extent to which evaporation in a soil recently wetted by rain increases, provided

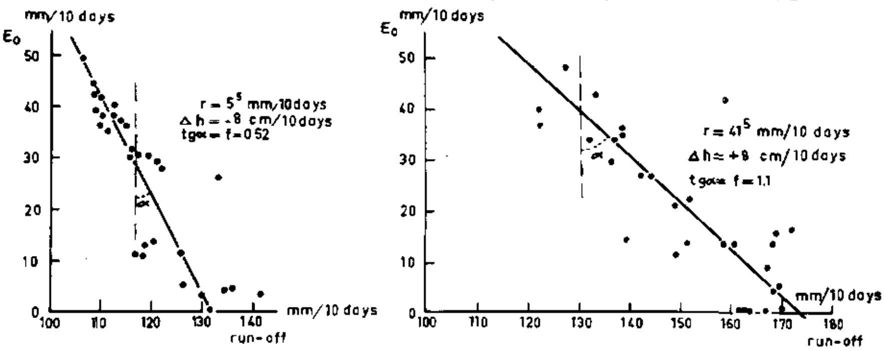


FIG. 4. The magnitude of the reduction factor, but also the value of the seepage can be more accurately determined by plotting E_o against the drainage for periods with approximately identical precipitation and storage values

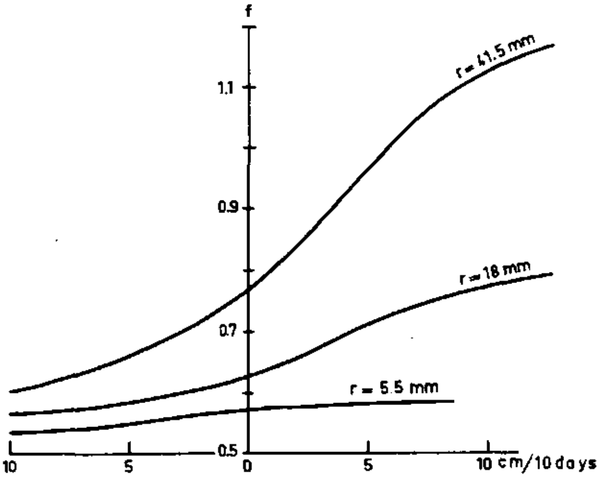


FIG. 5.
Recently fallen rain appears to cause increasing evaporation, the increase being dependent on the amount of rain fallen and the amount of water draining away towards the groundwater

the precipitation has saturated the soil profile concerned, as is shown by the rising of the water level ΔH. If, notwithstanding the fallen rain, the groundwater level should register a drop, it is apparent that the loss of water from the soil profile will be larger than the amount of water received from the rainfall. The total result will be an increased loss of water from the soil and an insignificant increase in the reduction factor. If the precipitation should be insufficient to make the soil thoroughly wet, evaporation losses will be a little more than those from a soil which has not been exposed to rain.

This type of elaboration of the water balance data may, however, also suggest a number of other conclusions. The depletion of moisture from the soil profile, or the increase in storage in the upper layers, may be determined by diminishing the amount of rain actually fallen with the relevant drainage, evaporation and groundwater storage values. Total moisture losses may be found by summation. This value may be used to correct the evaporation with respect to the degree of moisture depletion from the soil profile involved. By incorporating the water level data for various areas and soil profiles in these figures and by comparing the results, it is possible to estimate the influence of groundwater depth and water holding capacity of the soil profile on evaporation and over-all moisture losses. Indeed, there are many aspects and details of the water balance which are open to study in this manner. Gradually a better grasp on evaporation might thus be acquired. In those cases where the groundwater depth may be utilized as a measure of subsoil drainage, statistical analysis of the water balance should be considered to provide a versatile and universal method in hydrologic research.

RÉSUMÉ

Etude d'équilibre hydrologique comme base de recherches d'irrigation

L'équilibre hydrologique peut être étudié en plein champ, pourvu qu'il y ait moyen de mesurer la décharge. Or, cette mesure est possible à partir de la diminution de pression dans la direction du courant, que l'on peut mesurer à l'aide de sondes de niveau souterrain. En marquant dans un diagramme pour une même augmentation ou diminution du niveau des eaux souterraines dans la période de mesure la différence entre les mm de pluie et les mm

d'évaporation en eau ouverte en fonction de la diminution de pressions, et cela séparément pour les différents mois de l'année, on obtient une collection de points environnant des lignes courbes, de forme égale mais situées à des hauteurs différentes pour chaque mois (voir fig. 1). La différence de hauteur (x) indique de combien l'évaporation en eau ouverte (E_o) dépasse l'évaporation réelle (E_r). En évaluant E_r pour le mois à évaporation minimum, on peut calculer pour toute l'année les valeurs E_r à partir de $E_o - x$ ou bien déterminer le facteur de réduction $f = E_r/E_o$. La figure 2 montre le résultat. La courbe de la décharge, qui en forme le résultat graphique, se trouve en très bonne concordance avec la formule de drainage (voir fig. 3).

Le facteur de réduction est très variable, les conditions d'évaporation étant très différentes. Or, en groupant les résultats de chaque période de mesure en classes d'augmentation égale du niveau des eaux souterraines et d'intensité de précipitations égales, le diagramme de la décharge, calculée selon l'opération décrite ci-dessus, par rapport à l'évaporation E_o fait voir un rapport linéaire (voir fig. 4), qui indique que ce qui ne s'évapore pas doit être déchargé. Mais puisque E_o ne représente pas l'évaporation réelle E_r, mais bien E_r/f, l'inclinaison des droites trouvées selon la fig. 4 se trouve représenter la valeur f.

Or, il apparaît que l'évaporation dépend fortement de la quantité de pluie tombée, tandis qu'en ce cas, la hausse ou la baisse du niveau des eaux souterraines font fonction de mesure du dessèchement ou de l'excès d'eau et influencent également considérablement l'évaporation. La figure 5 en montre un exemple.

ZUSAMMENFASSUNG

Die Wasserbilanz als Grundlage für Bewässerungsuntersuchungen

Die Wasserbilanz kann im Felde studiert werden, wenn nur die Möglichkeit gegeben ist, die Abfluss zu messen. Dies ist nun möglich aus dem Druckgefälle in der Richtung der Strömung, die man mit Grundwasserstandsröhren messen kann. Wenn man für ein gleiches Steigen oder Sinken des Grundwassers während der Messperiode die Millimeter Regen abzüglich der Millimeter Verdünstung von offenem Wasser auf das Druckgefälle für die einzelnen Monate des Jahres einträgt, so erzielt man einen Punktenschwarm um gebogenen Linien, die von gleicher Form sind, aber für jeden Monat eine eigene Höhenlage haben (siehe Figur 1). Der Höhenunterschied x zeigt an, um wieviel die Verdünstung von offenem Wasser E_o grösser ist als die wirkliche Verdünstung E_w. Nimmt man für den Monat mit der kleinsten Verdünstung eine geschätzte E_w an, so kann man für das ganze Jahr die E_w-Werte berechnen aus $E_o - x$ oder den Reduktionsfaktor $f = E_w/E_o$ bestimmen. Figur 2 zeigt das Ergebnis dieser Berechnungen. Die Abflusskurve, die das Resultat einer graphischen Bearbeitung ist, stimmt sehr gut mit der Dränierungsformel überein, wie aus Figur 3 ersichtlich ist.

Der Reduktionsfaktor ist sehr variabel, weil die Voraussetzungen für die Verdünstung sehr ungleich sind. Wenn man nun die Resultate für die Zeiteinheiten der Messung in Klassen gleicher Zunahme des Grundwasserniveaus und gleicher Regenintensitäten einteilt, so ergibt die Eintragung der laut obenerwähnter Bearbeitung berechneten Abfluss auf die Verdünstung E_o einen gradlinigen Zusammenhang (siehe Figur 4), der anzeigt, dass das, was nicht verdünstet, abgeführt werden muss. Weil jedoch E_o nicht die wirkliche Verdünstung E_w darstellt, sondern E_w/f, geht aus der Neigung der nach Figur 4 gefundenen Linien den Wert von f hervor.

Es zeigt sich nun, dass die Verdünstung in hohem Grade abhängig ist von der gefallenen Regenmenge, während in diesem Falle das Steigen oder Sinken des Grundwassers als Massstab dient für das Mass der Vertrocknung oder den Wasserüberschuss und ebenfalls einen starken Einfluss auf das Mass der Verdünstung hat. Davon gibt Figur 5 einen Beispiel.

DISCUSSION

LYSHEDE:

Ich möchte fragen nach Art und Grösse der besprochenen Abflussgebiete.

Answer:

The size of the areas is limited by the location of the ditches if a test-well was object of study. The area is then somewhere between 0.5 and 1 ha. Where a whole polder is taken, the size of the catchment area may differ. We studied a polder of 200 ha. and one of 1200 ha. They are in most cases larger, but the larger areas are often less interesting due to heterogeneities.