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NIINIVAARA'S METHOD FOR ESTIMATING THE EVAPORATION FROM WATERSHED AREAS

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In watershed areas evaporation generally increases when precipitation increases. Evaporation also depends on the temperature of the air and its relative humidity. As the influence of the latter factors appear simultaneously if the saturation deficit is used as a basis for estimation, methods for determining regional evaporation have been proposed, in which the saturation deficit is the only variable. (1, 3, 7).

In Southern Finland the annual rainfall is 600-700 mm and in Northern Finland 400-600 mm. A great portion of the rainfall is stored in snow, and this flows into the water courses when the snow thaws in spring. The maximum water value of snow in spring in Southern Finland is generally 15-25% of the total annual rainfall, and in Northern Finland 25-40%, but, on account of the evaporation being less, the runoff of the winter season is generally at least one third, or even more than half, of the total yearly runoff, even in Southern Finland. Autumn rains have an essential significance on the amount of water flowing in the water courses, as the saturation deficit of the air is relatively low in this season. During the early summer when the amount of rainfall is smaller and the saturation deficit of the air is great in comparison with the autumn, the bulk of the rainfall may be stored in the pores of the soil which occur as a result of evaporation and transpiration. According to figures given by Mustonen (4), runoff in May during the period 1953-1962 in some small areas of the rainiest part of Finland was on an average 12-14% of the rainfall; in June-July it was 1-5%, in August 7-9%, and in September-October 12-27% of the precipitation. As those factors which essentially influence the amount of evaporation, such as the amount of precipitation and the saturation deficit, are different in the beginning of the summer from the end of summer and during autumn, Niinivaara (5,6) has developed a method for estimating evaporation in such a way that both these factors can be taken into consideration simultaneously. The basic theory is as follows:

The common equation for the water balance of a watershed area is:

$$P = A + E + (R - B). \tag{1}$$

and here: P = precipitation, A = runoff, E = evaporation, R = the regional water reserve in the drainage area at the end of the period of observation, and B = the water reserve at the beginning of the period. P and A can be determined by direct observation. Because the diminishing of the watershed area's water reserve is caused partly by runoff and partly by evaporation, Niinivaara changed the above equation to:

$$P = A + E + (R_A - B_A) + (R_E - B_E) \tag{2}$$

In this equation the term $(R_A - B_A)$ represents that part of the change in the water reserve in the ground which is principally caused by runoff, and $(R_E - B_E)$ represents that part which depends on evaporation. Niinivaara determined the term $(R_A - B_A)$ by observations during the dry seasons occurring after the spring thaw or after heavy rains.

On account of fluctuations occurring in the saturation deficit and in summer rainfall the soil moisture contents decrease in the beginning of the summer in Finland after having been at their greatest immediately after the spring thaw. At the end of summer they increase again until at the end of October and beginning of November they are approximately as great as in spring. On the basis of these conditions Niinivaara first determined the evaporation during May-October in each observation year, which period represents the summer half of the hydrologic year in Finland. Then, with the aid of observations made over a period of years, he drew up a straight line of regression showing the interrelations between evaporation and precipitation (line «a», fig. 1) and he assumed that the line of regression shows how evaporation depends on rains at an average summer saturation deficit, at the same time as it evens out any small evaluation errors which may possibly occur due to relatively small variations in the soil moisture contents or some other factors. Evaporation, which took place at other saturation deficit values he determined by taking the average evaporation value of the whole observation period to be that of the winter and July-August. Taking into account the average saturation deficits of these periods, (lines «b» and «c» in fig. 1), he drew a nomogram from which evaporation may be estimated with the aid of the precipitation and the saturation deficit of the air. He justified taking the values for July-August into account by the argument that the variations of the ground water reserves are generally insignificant at the beginning and also at the end of this season, and that they will even out when an average is taken over a long period of time.

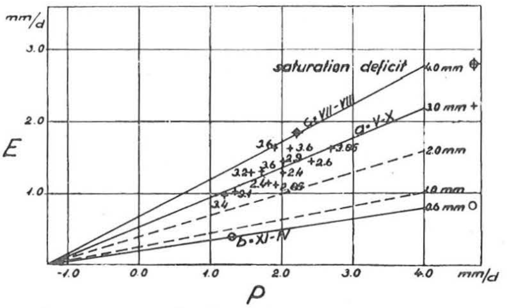

Fig. 1 — Niinivaara's nomogram in the Latosuo area for the estimation of evaporation (E) according to precipitation (P) and the saturation deficit. The numbers by the + signs indicate the average saturation deficit values during different years; the position of the + sign has been determined according to the P-values observed and the E-values which were calculated on the basis of the P values and the runoff during May-October. The line *a* was drawn on the basis of these.

Niinivaara's research was based upon six watershed areas near the South-Eastern border of Finland. The sizes of these areas varied from 4.5 square kilimetres to 66 km^2. It may be pointed out, that as a result of this research he could show smaller evaporation caused by rain at the beginning of summer than that which had been thitherto assumed. This was a result of scarce rainfall in the early summer. Correspondingly, he reached the conclusion that the evaporation at the end of the summer was greater than, for instance, when it is calculated only with the aid of the saturation deficit. As I attempted to determine to which degree expressly these results hold true, factors appeared which even more generally illustrate the nature of the runoff caused by summer rains in conditions where the rainfall and evaporation are comparatively slight. In Finland, for instance, a 24-hour rainfall of 30 millimetres is exceptionally heavy, representing the maximum rainfall which occurs on an average once a year. To begin with I carried out the examination on the basis of the material presented by Niinivaara, focusing my interest especially on the autumn season during which the greatest runoff caused by summer rains occurs.

In figs. 2 and 3 the results of comparisons regarding the end of the summer in three areas are shown. The Latosuo and the Huhtisuo regions are forest and swamp, and there are no lakes in them. Their area is approximately 4.5 square kilometres; about 20% of Latosuo is cultivated. In the Alasenjärvi area 28% is covered by lakes, while the main part of the rest is forest, the total area being 66 km^2. In the drawing

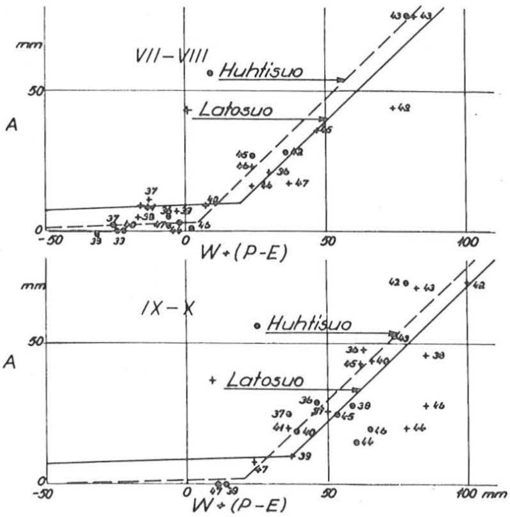

Fig. 2 — The probable runoff lines determined on the basis of runoff, the A and the $W + (P - E)$ values (W = relative moisture contents of the soil, P = precipitation, E = evaporation) in the Latosuo and Huhtisuo areas in July-August and September-October. The numbers indicate the year in question (44 = 1944).

given, the runoff is shown on a vertical axis. Niinivaara determined it in two-month periods (V-VI, VII-VIII and IX-X). The factor $W + (P - E)$ is on the horizontal axis, W indicating the relative moisture contents of the drainage area at the beginning of the period of examination. In determining the term W precipitation and runoff observations may be used, as well as estimated values for E. In the cases in hand, I carried out this in such a way that I took into account the estimated $(P - E)$ values for the preceding months during years when the runoff was less than average. In such years,

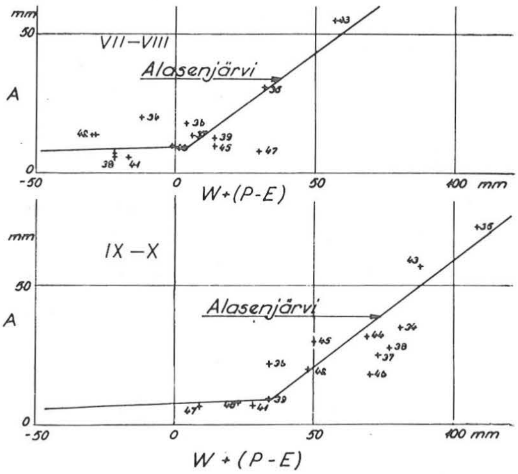

Fig. 3 — The lines of probable runoff in the Alasenjärvi area (compare with fig. 2) in July-August and September-October.

again, during which the runoff of the preceding months had been exceptionally great, the relative moisture contents of the soil was estimated to be 5-20 millimetres greater. On the basis of the observations, the individual characteristics of an area can be taken into consideration here.

A line showing the inter-relationship between the runoff and the term $W + (P - E)$ has also been drawn in the figures by eye. There appeared a distinct turning point on the line at the point where the storage capacity of the area begins to increase. In the following I will name this line "the line of probable runoff". I have drawn these lines so as to make their shape and the position of the turning points on the vertical axes similar on the same area during summer. The position of these lines concerning the Latosuo and the Huhtisuo areas (fig. 2) in regard to each other has been the same during VII-VIII and IX-X. It can be observed that the development of the line of probable runoff to the left of the turning point mentioned depends on the $(P - E)$ values only to a slight degree, and it can be assumed that here the storage in the ground plays a dominant role. On the right side of the turning point, again, the runoff seems to increase to a somewhat straight line as the $(P - E)$-values increase; and the difference between rainfall and evaporation in the Latosuo and Huhtisuo areas has then escaped almost entirely by runoff. Accumulation also occurs in the Alasenjärvi area. The

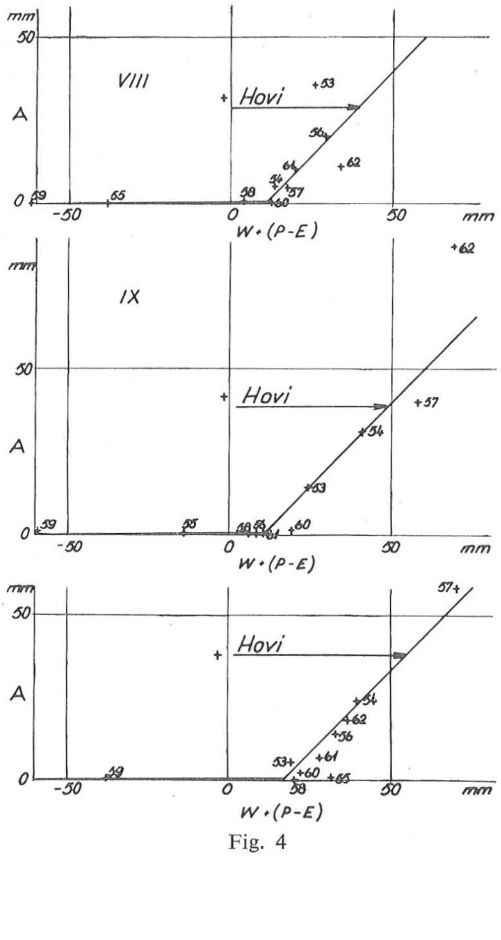

Fig. 4

turning point seems to come at slightly greater $W + (P - E)$-values during the late summer than before. This may, however, be partly due to some factors pertaining to the estimation of evaporation which I shall come to later. As the influence of the water storage of the lakes in the Alasenjärvi basin has not been separately accounted for, the deviation of observations from the line of probable runoff during some years is greater than normal. In the Latosuo and Huhtisuo areas the reason for this may be partly traced to the meteorological conditions. The average dispersion of the deviations as compared with the average runoff of the corresponding months varied between 20 and 50 per cent. When the runoff is less than one third of the evaporation, a small dispersion of evaporation causes noticeably great relative diviations on the observed runoff values as compared with the line of probable runoff. It should be also noted

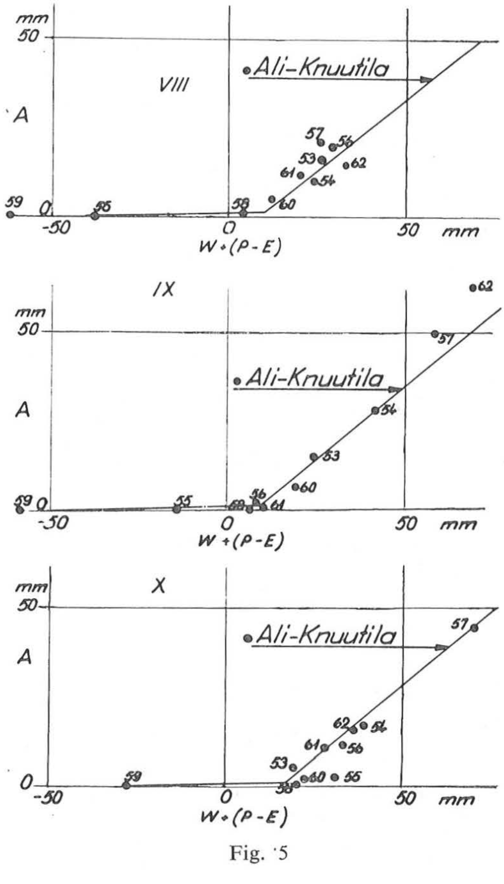

Fig. 5

that observations pertaining to the estimation of the saturation deficit have been carried out at meteorological observation points which lie at a distance of 50 to 70 kilometres from the areas. The fact that the estimations have been made within the limits of periods of time up to two months long also influences the results. In spite of the deficiences in the material, a interdependence between the runoff and the $(P - E)$-values can be observed.

Mustonen (4) has carreid out research on the influence of summer rains in 3 small observation areas in Southern Finland, using unit-hydrograph and infiltration methods developed specially by American hydrologists. The Hovi area is 12 hectares and all of it is cultivated. The Ala-Knuutila area is 24.6 hectares, of which 58% is field and garden and 42% is forest. The Yli-Knuutila area of 6.8 hectares is all forest.

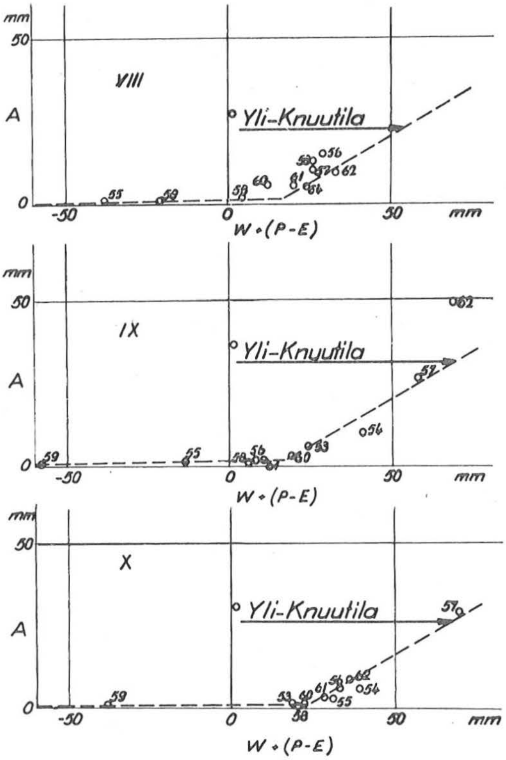

Fig. 4-6 — The lines of probable runoff in the Hovi, Yli-Knuutila and Ala-Knuutila areas (compare with fig. 2) in August, September and October.

Using precipitation and runoff values presented by Mustonen I have made a calculation by Niinivaara's method within the limits of monthly values, the results of which are shown in figure 4-6 for the end of the summer. The nomogram used in the estmation is shown in fig. 7. When drawing it up I deviated to some extent from the principles drawn up by Niinivaara. It appeared that at low values of saturation deficit Niinivaara's shading gives evaporation values which are too low. This presumably is a result of the fact that no transpiration takes place in winter, and part of the humidity in the air — especially in warm weather — is condensated in the snow cover giving different values from those prevailing in summer at a corresponding saturation level. Likewise, during very rainy months the evaporation is greater to such an extent that I had to make some kind of correction even to the nomogram shown in fig. 7. Thus, as I drew up a draft nomogram which would best suit the observations made, I tried at the same time to reach a result which could be used in all three areas, since there were no observations available showing the saturation deficit of the air in forested areas.

When the values for different years in fig 4-6 are studied, it is observed that the line showing the probable runoff follows the same pattern as that drawn up on the basis of Niinivaara's material. As the shape of the lines of probable runoff has been similar for the same watershed areas, the monthly observations support one another. When I used observation periods of two months the deviations were greater than when periods of one month were used. It is possible that observation periods under one month should be used for such small areas as these, a fact which became apparent in the determination of *W*-values during two years when the rains were concentrated at the end of the month. In the Yli-Knuutila area the line indicating probable runoff clearly deviates from the lines of the other areas. This is probably partly caused by the fact that ground flow bypassing the measuring point takes place in this area, and this seems to have been greater during rainy periods than during dry ones. The fact that the turning points of the lines of probable runoff for the autumn period do not differ so much from those of earlier months as in Niinivaara's observations is likely to be partly due to the nomogram used.

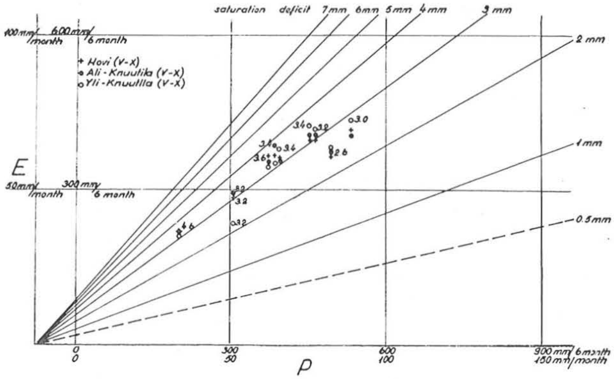

Fig. 7 — The nomogram used in the Hovi, Yli-Knuutila and Ali-Knuutila areas for the determination of the monthly evaporation with the aid of rainfall and the saturation deficit of the air. The numbers indicate the average saturation deficit in May-October during different observation years. The points of one year for different areas are on the same vertical line.

In the values for the various years, attention is caught by the great deviation in September 1962 and that of the Hovi area in August 1953. During these months exceptionally heavy 24-hour rains occurred. Mustonen (4) has shown that for the rainfall in September 1962, direct runoff took place to such an extent that the $(P-E)$-value does not give a true picture of the runoff in these cases. If we assume that a certain portion of such rain flows off the area without having time to evaporate, even the above-mentioned exceptional values will come close to the line of probable runoff. In wooded areas the influence of such rains is clearly less. It is obvious that the size of the area influences the result in a similar manner. When these factors are taken into account, the average dispersion of the deviations in the period August-October has been 15-60% of the average runoff and about 5-20% of the average evaporation of the corresponding months.

The above examination has been made principally in order to show that it seems to be possible to find out the influence of precipitation and the saturation deficit of the air on the evaporation by using Niinivaara's method. The results from the Hovi, Ali-Knuutila and Yli-Knuutila watershed areas show that the evaporation during the autumn should be still greater than Niinivaara supposed. The reliability of the results depends very much on how the evaluation nomogram is drawn up. The observation material at my disposal is, however, insufficient to serve as a basis for drawing up detailed rules for its use in estimating runoff. The determining of the value of W especially requires further clarification. The fact that the same nomogram was used in the three different areas above indicates that it may be possible to draw up general nomograms for various types of climatic conditions. This assumption is also supported by the fact that in Niinivaara's examination the nomograms which were drawn up on the basis of observations show remarkable uniformity with conditions in nearby areas. It may be possible to take the influence of the characteristics of the watershed area into account with the aid of probable runoff lines. As regards Niinivaara's method, the fact to which one should attach special interest is its simplicity and its applicability in different areas. Because the method may be used in connection with hydrologic observations to be carried out in the watershed area, it also shows the influence of the individual features of the areas.

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