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AN ESTIMATION OF EVAPOTRANSPIRATION BY MEANS OF THE WATER BALANCE OF A SOIL COLUMN

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In this paper water-balance studies of a soil column at an observation site at Ulvsunda, Stockholm, are reported. The change of the water storage in the soil was obtained from soil moisture measurements, which were carried out by the neutron scattering method. The precipitation was also measured. The percolation from the soil column was estimated from the change in ground water storage beneath the column. It has not been possible to measure the evapotranspiration directly but it has been calculated from the water-balance equation for every month during 1964-66.

The content of water in soil changes with time partly depending on the existing meteorological conditions, partly on the kind of vegetation and its stage of development. The variations of moisture in a certain soil-volume depend on the relation between the quantity of water added by infiltration of precipitation water and by moving subsoil- and capillary-water and the quantity which is subtracted by evaporation, transpiration, and drainage. The difficulties of the water-balance studies have been to follow the variations of the water content in the soil from one period to another, as this requires measurements made repeatedly in the same soil-volume. No doubt, the neutron-scattering method offers a better possibility.

At the Swedish Meteorological and Hydrological Institute (SMHI) the neutron method has been used since June 1963 for studies of soil moisture by means of Danish equipment. Apparatus, method, sources of error, and calibration are described by Jensen & Somer (1967), Ølgaard (1965), Ølgaard & Haahr (1967), and Milanov (1966).

In comparison with conventional methods (see for instance Andersson 1947) of soil moisture measurements the advantages of the neutron method are many: it is very rapid; it does not require soil sampling; it is independent of temperature; and it is possible to measure continuously in the same soil-volume.

In this paper an estimation of evapotranspiration by means of the water balance of a soil column at an observation site at Ulvsunda, Stockholm, is reported. First a short presentation will be given of the geology of the area.

SOIL EXPLORATION

In the area where measurements of soil moisture were carried out geological pre-explorations of the soil profile were made by the National Swedish Road Research Institute. The soil exploration was carried out by test-boring with an auger in four different places. A sketch of the observation site is shown in Fig. 1. Many soil samples were taken at different depths, and hygroscopicity, ignition loss, and content of water were determined in percentage of weight. The results are given in Table 1.

The hygroscopicity (W_h), the ignition loss (GL), and the content of lime were determined only in order to make it possible to classify the type of soil. The hygroscopicity has been given in percentage of weight of water absorbed in the presence of 10 % sulphuric acid after air-drying. The value is very high, about 10 per cent, which means that about 15 mm of water can be absorbed in a stratum of clay of 1 dm. The ignition loss states the percentage of the loss of weight in heating dry soil to glowing. A high content of mould increases the hygroscopicity. The content of lime is determined because it influences the ignition loss by loss of carbonic acid.

It is evident that the species of soil at Points 1-4 show little variation concerning stiffness. From the geological point of view all species of the soil can be characterized as heavy clay, i. e. more than 40 per cent material is less than 0.002 mm.

SOIL MOISTURE MEASUREMENTS

Soil moisture measurements were carried out by the neutron-scattering method at the measuring site mainly to investigate the usefulness of the neutron method.

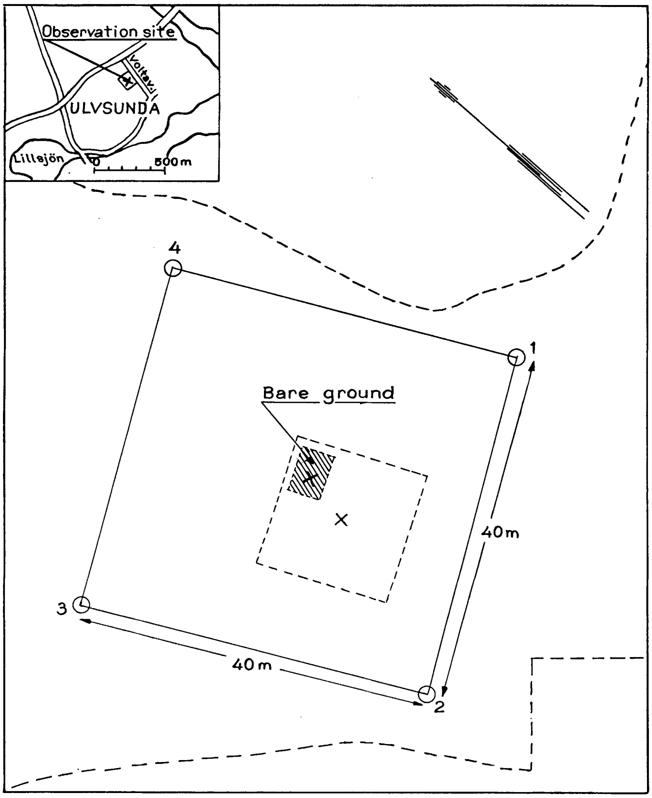

Fig. 1.
A sketch of the observation site at Ulvsunda, Stockholm.
O location of geological exploration.
× location of moisture profile measurement.

The observation site is a flat and grassed area. Measurements were made 1-6 times a month. The moisture was measured every dm from 10 to 180 cm depth. The results obtained from the scaler, expressed in counts per minute, were converted by means of the calibration curve into water content expressed in g per cm^3.

From the moisture profiles the quantity of water between the surface and the 120 cm level, expressed in mm, was obtained by integration. In the top soil (0-20 cm) it was not possible to measure the content of water directly by the moisture probe but the water content has been extrapolated from the measure-

Table 1.
The soil classification of profiles

Soil profile	Depth (cm)	W_h	GL	Soil water (%)	Lime	Species of soil
1	37– 40	10.0	4.7	25.5		Heavy clay without mould
	56– 60			27.7		Heavy clay
	82– 88	10.9	3.6	28.8		Very heavy clay
	102–107			30.8		Very heavy clay
	130–134	12.0	4.9	37.3		Very heavy clay
	162–167			27.8		Very heavy clay
2	30– 35	9.2	5.2	21.2	1.7	Heavy clay without mould
	55– 59			22.9		Heavy clay
	74– 77	10.4	3.5	28.6		Very heavy clay
	94– 98			31.0		Very heavy clay
	120–124			41.0		Very heavy clay
	145–150	13.1	5.0	44.1	2.2	Very heavy clay
3	35– 40	8.7	4.4	18.8		Heavy clay without mould
	53– 57			22.3		Heavy clay
	70– 74	8.7	3.1	24.3		Heavy clay
	97–100			29.8		Heavy clay
	127–130			37.9		Heavy clay
	151–155	9.6	6.9	32.7	9.5	Heavy clay
4	26– 30	9.0	4.6	19.0		Heavy clay without mould
	42– 48			21.0		Heavy clay
	64– 68	9.3	3.6	24.6		Heavy clay
	98-102			30.9		Heavy clay
	121–125	13.7	4.1	39.2		Very heavy clay
	159–163			31.7		Very heavy clay

ments at the levels of 20 cm and 10 cm. The radius of influence of the moisture probe is less than 20 cm and therefore at the 10 cm level a systematic error is introduced which, however, disappears when computing the change in water storage. The measurements at the levels of 20 cm and 10 cm give good information about the content of water in the top soil. The content of water in the strata between 120 cm and 170 cm was constant during the whole measuring period. Fig. 2 shows the variations of the content of water for every month during 1964-66.

The moisture variations in the ground can be followed in detail. During win-

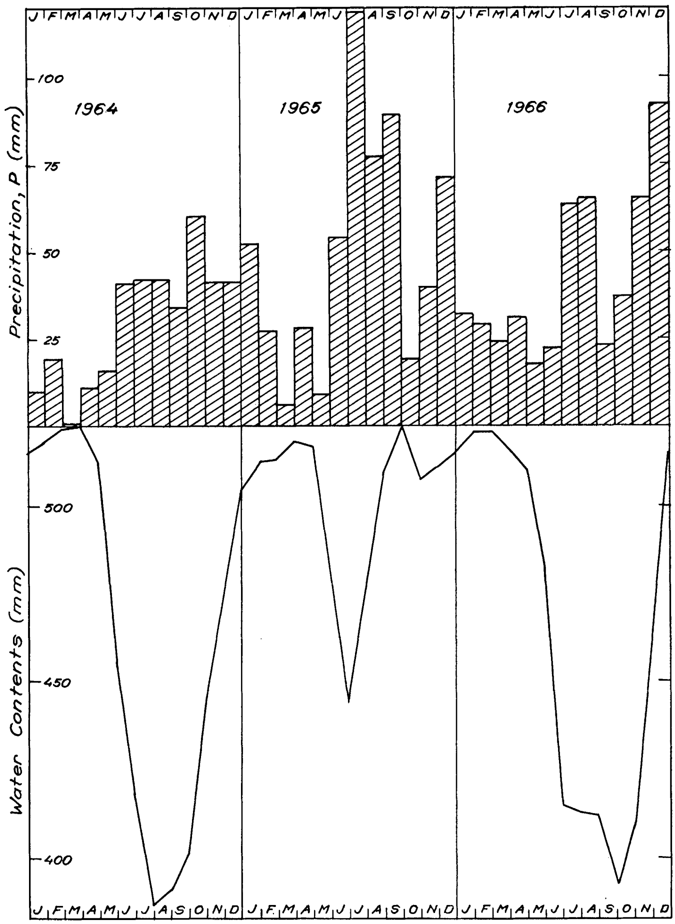

Fig. 2.

Diagram of the variations of water content in the levels 0-120 cm and the precipitation in every month during 1964-66 on grassed ground.

ter and spring up to the time of vegetation the lower soil strata were normally saturated with water to the field capacity. During summer the total quantity of water decreased, as precipitation was less than potential evapotranspiration. During the periods Aug.-Sept. 1964, July-Dec. 1965, and Oct.-Dec. 1966 the infiltration of precipitation caused an increase of water in the ground. The Figure also shows that the change of water content in the strata during the summer 1965 was much less than during the summers 1964 and 1966. Summer

1965 had a very high precipitation (281 mm fell in July-Sept.), enough to saturate the soil with water to the field capacity already at the end of August.

For the calculation of the monthly evapotranspiration one thus ought to make soil moisture measurements regularly, normally once a month in winter and 2-4 times a month during the vegetation period. The number of measurements in the winter can be much smaller than in the summer because the soil is normally filled with water to the field capacity during winter, Fig. 2.

The measurements have been performed in order to test the apparatus in the field. In the beginning no measurements other than soil water measurements were planned. However, sporadic measurements of ground water were later made in a borehole by means of an electrical apparatus (Fig. 3). The measurements were made mainly during the most critical period March-May when the infiltration of melted water and precipitation are greatest because of the thawing of frost in the ground.

WATER BALANCE

The water balance of a vertical soil column has been analyzed by studying the following terms:

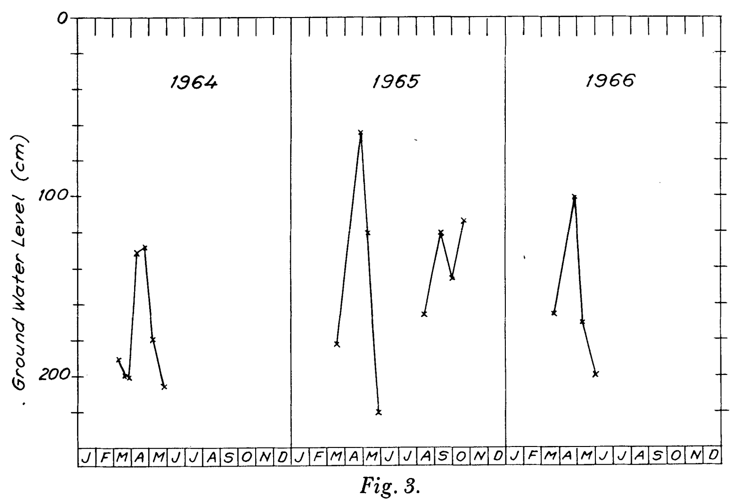

Fig. 3.
Variations of the ground-water level.

(1) Water brought to the soil column by precipitation, P in mm, corrected for storage in snow pack, ΔM_s.
(2) Water brought to the soil column by surface and ground water flow, T_y and T_g in mm.
(3) Water taken away from the soil column by surface and ground water flow, A_y and A_g in mm.
(4) Water taken away from the soil column by percolation, D in mm.
(5) Change of storage of water in the soil column, ΔM_m.
(6) Water taken away by evapotranspiration, E in mm.

The water-balance equation is

$$P + T_y - A_y + T_g - A_g - D - \Delta M_m - \Delta M_s - E = 0 \qquad (1)$$

The different quantities entering the equation were obtained in the following way.

The precipitation P was obtained from Bromma Airport.

Since the observation plot is located in a flat area, T_y and A_y in Equation (1) can approximately be put equal to zero.

T_g and A_g are presumably small in comparison with the other quantities and can therefore be neglected.

The change of the water storage in the soil, ΔM_m, was obtained from soil-water measurements.

The change of the snow storage, ΔM_s, was estimated from the measurements of snow at Bromma Airport.

The percolation, D, from the soil column was estimated from the change in ground water storage beneath the column.

Accordingly the equation of the water balance in the observation soil-volume is

$$P - \Delta M_m - \Delta M_s - D - E = 0 \qquad (2)$$

In Fig. 4 the water-balance data at Ulvsunda in 1964-66 are shown. From the other quantities measured the evapotranspiration can be obtained as the difference between these quantities. The change of the soil moisture equals the quantity of water taken away or added to the soil-volume.

From the water balance the evapotranspiration was calculated to be 363 mm in 1964, 410 mm in 1965, and 413 mm in 1966. The comparatively low evapotranspiration during 1964 mainly resulted from the low precipitation that year. The evapotranspiration was in fact 3 per cent higher than the precipitation due to the fact that the precipitation falling in the autumn of 1964 was not enough to fill the soil with water. The surplus of the evapotranspiration was taken from the water stored in the soil. In 1965 and 1966 the evapotranspiration was 29 and 16 per cent respectively lower than the precipitation.

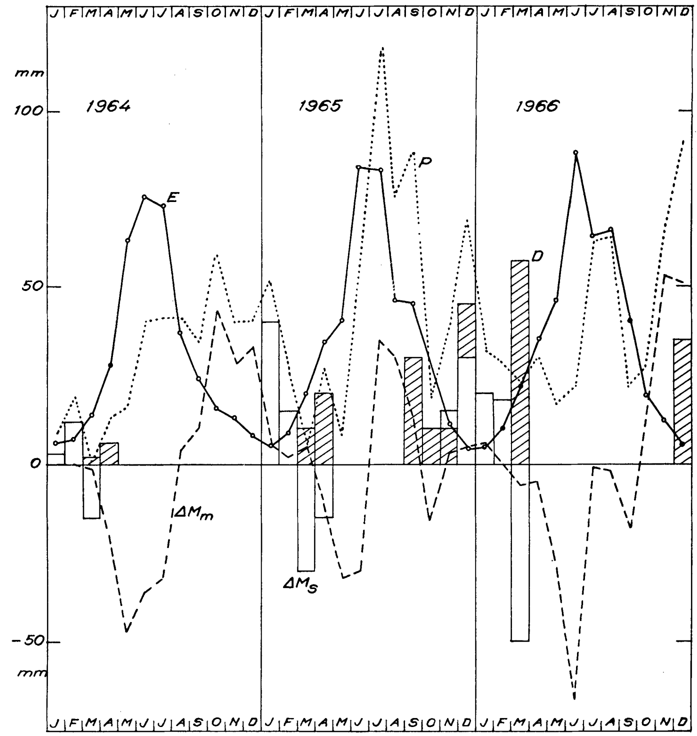

Fig. 4.

Diagram of the variations of the actual evapotranspiration, E; the precipitation, P; the change of storage of snow pack, ΔM_s; the percolation, D; and the change of storage of soil water, ΔM_m, in mm, during 1964-66.

The resulting monthly evapotranspiration amounts from the investigated soil column at Ulvsunda seem to be reasonably correct, especially for the vegetation period. For the winter months, however, there is a certain inaccuracy in the calculations of the evaporation due to difficulties in measuring the snow storage. The observations of the ground water were erratic and therefore the estimation of the downward percolation in Fig. 4 of the water balance can be considered as inaccurate for certain periods. Thus for a more precise calculation of the water balance in a soil-volume or a drainage area regular observations of the ground water have to be performed in addition to the soil moisture measurements.

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