I. THE DEVELOPMENT OF WATER BALANCE RESEARCH IN THE NETHERLANDS

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1. The hydrology of the top soil

Discussing the part the top soil is playing in the hydrological cycle, the soil layer under consideration has not to be confined to the ploughed or the sod layer, but will run generally from the soil surface to the groundwater table or, when the depth of the latter is more than say 2 meters, to about maximum rooting depth. This rooting depth is depending, besides on the groundwater level, on the kind of crop and on the profile.

The top layer of the soil defined in this way is from a hydrological point of view the intermediary between ground water and atmosphere. An intermediary however which is not only passing water upwards or downwards, but which is storing water during a certain period too. So the top soil is acting as a kind of hydrological buffer.

The water management of the top soil is a complicated one. Generally this layer consists of a three phases system (soil - water - air). Moisture transport through such a system happens by means of capillary conduction, diffusion or distillation. The quantitative way of handling the first two mechanisms was becoming much clearer during the last ten years. The meaning of the distillation however in a quantitative sense is still obscure.

On his upper end the top soil borders the atmosphere. In the day-time radiation energy from the sun and from the vault of heaven is absorbed here and converted into heat. This heat is used mostly by evaporation of water, the rest is warming up adjacent layers of the soil and the atmosphere. During the night the soil surface is cooling down due to the domination of the radiation of heat. By that, moisture from the atmosphere and from the top soil will condense in the soil surface, which is delivering heat. So a change of phase of water taking part in the hydrological cycle occurs in the interface between top soil and atmosphere. Besides, the greatest temperature gradients which are possible in soil and atmosphere appear on both sides of this interface. They are changing rather quickly and are influencing the moisture transport.

The buffering action of the top soil introduces the factor time. Rain water can be retained for a shorter or longer time and will disappear then into the atmosphere or be added to the ground water. A small part will join in chemical, microbiological or physiological processes, which show their most manifold and intensive occurrence just in the upper layer of the top soil.

The factor that is complicating the hydrology of the top soil highly, is the vegetation. It is acting as a large and complex pumping system. The feature of this system is the extensive network of pump-barrels (roots), by which water can be withdrawn from all layers of the top soil. It is however subjected continuously to alterations, due to the origination, growth and death of roots. The growth of roots "towards the water" is very important if moisture cannot move towards the roots at great pF-values.

The evaporation from a soil surface overgrown with plants occurs by means of the leaves principally. These leaves possess in their stomata a regulating mechanism for the evaporation of water, which will be discussed in chapter II. Because evaporation from a soil surface bearing a vegetation, occurs as well from the leaves (transpiration) as directly from the soil surface (evaporation), it is named evapotranspiration usually.

The vegetation is influencing the hydrology of the top soil not only by the way uptake, transport out of the soil and transpiration of soil water take place, but also by its effect as an insulating layer for heat in the energy exchange between soil and atmosphere, which is affecting the moisture transport in the soil and the evaporation. Another effect of a plant cover is the interception of precipitation. A certain part of the rain for instance is not reaching the soil, but evaporates directly from the wet leaves and stems. In chapter IV this will be discussed. Especially in trees a part of the rain water catched by the tree top, is flowing down along branches and trunk, giving a heterogeneous distribution of the water entering the soil.

The remarks on the hydrology of the top soil mentioned above do not pretend giving a complete picture. They will make clear only that the problem is very complicated; reason why the top soil from a hydrological point of view has been "terra incognita" for a long time. Calculating groundwater movements in behalf of drainage or sub-irrigation problems for instance, the true hydrology of the top soil is left out of consideration generally and it is supposed that water transport through this soil layer happens vertically and quantitatively. This means that the hydrological buffering capacity is neglected. It is allowed to do so for long hydrological periods, e.g. years. The shorter the period, the more important factors as water storage in the top soil, habits of under- and overground parts of plants, weather, season a.s.o. are. After Worldwar II the interest in the Netherlands for water balances in short periods was growing quickly, due to the strongly increased need of fresh water in agriculture and horticulture, as well as in industry and housekeeping. Therefore a closer investigation of the water management of the top soil was becoming necessary.

The obvious way to handle this problem is to consider the top soil with its vegetation as a sort of reservoir, which has storage capacity and can take up and lose water as well on top as on its bottom, and to determine these intakes and losses in certain periods. This means that there must be made a study of the water balance.

2. The water balance of the top soil

The items of the water balance are:

a. as incomings the *precipitation R* from above and the *infiltration I* from below,
b. as outgoings the *evapotranspiration E* upwards and the *run-off D* downwards and
c. as gain the *increase S of the moisture content* of the top soil.

Influences of dew, horizontal components of moisture movement and superficial run-off are neglected. The continuity equation is giving then the *water balance formula:*

$$(R + I) - (E + D) = S$$

The aim of the study of the water balance is to learn what these five items are as functions of time. It is sufficiently to measure four of them, after which the fifth can be derived from the balance formula. This method however meets two types of practical difficulties:

a. measurement of the different items with a sufficient accuracy is often not simply and
b. gathering results for the numberless possibilities of different soil profiles, vegetations, weather conditions and other circumstances takes a very long time.

Both will be discussed more in details, because they were determining the development of the research of the water balance of the top soil in the Netherlands to a great extent.

3. Measurements of the items of the water balance

Precipitation

At first sight the determination of the precipitation with the well-known rain gauge looks very simply. There are however some difficulties.

The so-called wind effect of rain gauges, which is greater when the top of the gauge is situated higher above the soil surface and which can be annoying, particularly in measuring snow-fall, causes the obtained value of R to be too low. Further the effect is depending on the wind field in the neighbourhood of the rain gauge, which in turn is related to the local situation (vegetation, fences, hedges, grazing cattle, buildings a.s.o.), that alters often in the course of time.

Interception and run-off along trunks and stems make it difficult to determine what part of the precipitation enters the soil. Therefore in the study of the water balance of a top soil bearing a vegetation it is practical to consider soil and plant cover as a whole and to embody the direct evaporation of intercepted water in the evapotranspiration.

Infiltration

Generally it is difficult to determine infiltration from the ground water into the soil directly. In some cases it is possible to estimate infiltration from measurements of the vertical pressure gradient in the ground water. Usually however it is obtained indirectly from the balance formula. In fact ELINK STERK (1897/'98) has applied already this method estimating the infiltration of the Haarlemmermeerpolder by comparing the water balance of this polder with that of the drainage district Rijnland. With an artificial infiltration (e.g. subsoil irrigation) the quantity of water supplied in that way can be measured usually.

Run-off

This item can be determined in the field in a rather simple way if only the groundwater level is so high that the drainage system is running or if there is a sub-soil run-off to the ditches with no infiltration. Therefore as early as the end of the 18th century one has had recourse to separating and walling in soil monoliths, that is to say in constructing lysimeters. These have to be so large that border effects are negligible. Then however it is nearly impossible to place a bottom under the monolith and one has to construct either large filled-in lysimeters like those in Castricum or lysimeters without bottom, but with a nearly constant groundwater level above a dense system of tile lines as in the Rottegatspolder (WIND, 1958). Smaller lysimeters can produce valuable data if containing a soil without a considerable swell and shrinkage.

Evapotranspiration

Direct measurement of the evapotranspiration is not possible. Usually it is calculated as closing entry from the water balance or estimated from meteorological data. For the last way different methods are available, from which that of PENMAN (1948) is well-known. It is based on measurements of the incoming radiation energy, the humidity and the temperature of the air and the wind velocity. This method which comes up in chapters IV and V, determines in fact the evaporation from a free water surface. The evapotranspiration can be derived from this free water evaporation by multiplying it by an empirical factor, depending on the type of vegetation and on the time of year. In that way it is possible to obtain evapotranspiration results for a vegetation optimally provided with water (potential evapotranspiration), if the period under consideration is not too short (say two weeks or longer) and if the area in question is not too small (say a few times ten hectares). Conversion of the potential evapotranspiration into the actual one in case of sub-optimal water supply needs an empirical relation, in which density and growth of the root system are playing a part. Here again it appears how vegetation on the soil surface is complicating the evaporation problem, making it necessary to have recourse to the use of empirical conversion factors. A great advantage of PENMAN's method however is the possibility of utilizing available series of meteorological observations when the conversion factors are known.

The same drawback of moving the difficulties from the direct measurement of the evaporation to the determination of conversion relations and coefficients as arising with PENMAN's method, appears with the use of evaporimeters and evaporation pans (see chapter IV).

A determination of the evapotranspiration which is somewhat more directly, is the calculation of the vertical vapour transport, based on the theory of the humidity and wind velocity exchange in an eddying atmosphere and on measurements of vertical humidity and wind velocity profiles within a few meters above the soil surface or the vegetation. This method which is tested thoroughly by DEIJ (1960, *) in the Rottegatspolder, has the advantages of requiring an apparatus that can be moved fairly easy and yielding data for very short periods (e.g. hours). Disadvantages are the great deal of labour required by working out the records and especially the fact that the theoretical foundations hold only for stationary circumstances and an infinitely extensive area with a certain hydrodynamical roughness. A grassland area with short grass and without ditches, fences, live-stock and other obstacles meets these requirements to a certain degree, but they don't apply to waving wheat fields and other areas fluctuating in surface roughness.

It is also possible to derive the evapotranspiration from the energy balance of the soil surface. For that the net incoming radiation and the heat flux entering the soil are measured. The release of heat on the air is proportional to the heat required for evaporation. The ratio can be calculated from the temperatures and vapour pressures on two different altitudes. Then the energy balance is giving the evapotranspiration. Just as the method of the vertical vapour transport this energy balance method, with which there is only little experience in the Netherlands till now, can give hourly values, but is also requiring much labour for working out the measurements. It is still unknown however if here the vegetation is also causing an irrelevancy of the theoretical foundations.

Change of the moisture content of the soil profile

At first sight the determination of this change seems to be very simple: take undisturbed samples from the different soil layers at the beginning and at the end of a balance period and determine their moisture percentages (in vol. %). The distribution in the soil of the moisture percentage however appears within short distances to be so heterogeneous, not only in a vertical but also in a horizontal direction, that a great number of samples is required to obtain the change of the moisture content correct to a few millimeters. The following example may illustrate this.

To determine change S in moisture content of the top 80 cm of the profile on the drainage-lysimeter field in the Rottegatspolder (PEERLKAMP, 1955) with the degree of accuracy just mentioned, it appeared to be necessary that each time bore holes were made on 360 different places, from which 2160 samples were obtained. The great variability of a single determination of S is caused partly by the fact that in sampling it is impossible to take a sample a second time from the same place. Using the modern neutron scattering method however, determinations at the beginning and the end of a balance period can be made on the very same places and a much smaller number of measuring spots suffices (on the drainage-lysimeter field just mentioned for instance 20 spots and 10 depths per spot). Although this method needs corrections for a certain inconstancy of the neutron source and eventually for the use of variant types of measuring tubes, it allows to work with short balance periods (e.g. two weeks). Just as with the methods of the vertical vapour transport and of the energy balance normal operation of the obtained data is requiring much work. It is necessary to consider the possibilities for operating an electronic computer.

Summarizing it can be said that generally simultaneous measurements of the different items of the water balance of the top soil, in so far as they can be done, are giving several difficulties and are expensive.

4. AIM AND SET-UP OF WATER BALANCE RESEARCH

Generally the study of the water balance results from the wish to obtain quantitative data about a certain item of that balance as a function of time, profile, vegetation, groundwater level a.s.o. Function of time means here in fact function of the development of weather and since this is showing a great variability, the demand for quantitative data leads to the problem of statistics of the item in question. In the present hydrological problems a balance period of a year is no more sufficiently, but the evapotranspiration in say two weeks must be obtained. The most useful results would be frequency tables, from which could be read for instance the chance of a certain evapotranspiration in a certain period of two weeks, one thing and another differentiated according to type of soil, vegetation a.s.o.

The most obvious way to come to grips with the problem would be to take observations during some decennia, e.g. with lysimeters with different soil profiles and vegetations, in which the changes in moisture content are determined by means of neutron scattering. There are however different objections to this working-method: it takes too much time before the results are available, it will be rather expensive, and the question arises if and so yes how the lysimeter results can be extended to field circumstances.

Therefore water balance research has the task to discover ways and to develop methods for obtaining the data in question in a quick and relatively inexpensive manner. For that it must try to find relations between evapotranspiration and quantities of which long series of observations are already available or to be determined in a very simple way. Doing so it will be impossible generally to escape the use of empirical parameters. The results of the research with lysimeters may render good services in deriving and testing the necessary relations and in determining the required parameters.

5. Water balance research in the Netherlands

In the Netherlands about a quarter of the yearly precipitation disappears into the ground water and must be drained in an artificial or natural manner. The dune water companies near the west coast are managing large winning areas and for them it was a question what vegetation would give the biggest quantity of useful precipitation. This has made, that before Worldwar II as well in agriculture as in water management and in the supply of drinking-water the run-off through the top soil was the centre of interest. Some lysimeter installations were built to determine this run-off and drainage measurements of polders were carried out to study infiltration. The discharges of the catchment areas of some rivulets were measured too.

These run-off data were giving values of evapotranspiration as a "by-product", obtained from the balance formula with the use of precipitation data. Generally however it was only possible to get evapotranspiration values in this way for a period of a year, since the moisture content of the top soil in about February may be considered as constant by first approximation.

After Worldwar II the demand for fresh water was increasing strongly, especially in summer. It appeared that agriculture and horticulture could increase their yields considerably by means of sprinkling or sub-soil irrigation, more drinking-water and industry-water was needed and the fight against high salt percentages in canals and ditches, especially in the western part of the country, was requiring an increasing quantity of fresh water. Storage and distribution appeared to be necessary and since in summer the greater part of the stored water disappears by evapotranspiration, the latter was becoming the centre of interest. It was, especially in view of the distribution, not only important to know the total quantity which was required, but also how it was divided among the different periods, e.g. weeks. This brought a need of evapotranspiration values of short periods and consequently of non-destructive methods for measuring the change of the moisture content of the soil profile. The lysimeters were changing from run-off meters into evaporation meters and the Commission for Hydrological Research T.N.O. founded (in 1949) the Working Group for Lysimeters, with the original task to develop the lysimeter technique. It is curious that the research done by the working group was leading just to the opposite, viz. the development of methods for the determination of evapotranspiration, which were making the lysimeters superfluous. The reasons (limited transferability, expensive apparatus, long series of measurements necessarily) are mentioned already.

The working group however does not agree with the statement of ELINK STERK (1897/'98) that "lysimeters should disappear from memory of men as quickly as possible". The group thinks the importance of the lysimeter can be based especially on the possibilities of producing and testing empirical parameters and relations between hydrologically important quantities, and not so much on the fact that evapotranspiration can be determined by means of it.

The investigations of the Working Commission for Evaporation Research, started in the Rottegatspolder after Worldwar II, also have had the aims to make the lysimeter superfluous. They were testing the method of the vertical vapour transport. Unfortunately practical application of the theoretical principles underlying this method appeared to be strongly limited as is mentioned already. Nevertheless, the work done by the Working Commission for Evaparation Research has given not only a storehouse of observation data, published in the reports (*) of the commission, but also valuable contributions to the investigations of the Working Group for Lysimeters T.N.O., with which the commission is co-operating closely.

Summarizing it can be stated:

- that the development of the investigation of the water balance of the top soil in the Netherlands was moving last twenty years towards the evapotranspiration research,

- that vegetation is complicating the problem of the evaporation highly,
- that direct measurement of the evaporation from an overgrown soil surface is not (yet) possible,
- that due to the multiplicity of weather, soil and vegetation circumstances indirect measurements with lysimeters are requiring several decennia of observation and are expensive,
- that at present evaporation research in the Netherlands is moving towards the search for relations with known meteorological quantities and/or factors that can be determined rather easily, from which evapotranspiration can be derived, if possible with the aid of an electronic computer.

In the following chapters results from this attempt will be treated.

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