Linking meteorology and hydrology: measuring water balance terms in Cabauw, the Netherlands

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ABSTRACT

Climate models need information about energy and water fluxes at the soil surface. In Cabauw (Netherlands) these fluxes and the belonging balances are measured. Water balances have been set up for a summer and a winter period to check the correctness of these fluxes.
In winter precipitation is the largest input term and outflowing discharge the highest output term. In summer inflowing discharge is the largest input term and evapotranspiration the highest output term.

1. INTRODUCTION

In many meteorological models the interface between atmosphere and soil compartment is implemented as a lower boundary, but from a hydrological viewpoint this interface is the upper boundary. Complex exchange processes occur at the surface and uncertainty in water and energy fluxes across the model boundaries is a source of model errors. Understanding and quantifying these flux processes through observation can help to improve both meteorological and hydrological models.
At the Cabauw experimental site for atmospheric research (CESAR) in the Netherlands all meteorological quantities as part of the surface radiation and energy balances are measured. Accordingly, the Hydrology and Quantitative Water Management Group of Wageningen University installed equipment to complete the terrestrial observation program by quantifying the water balance terms.
Hydrologists often use water balances to determine the size of water fluxes across catchment boundaries. In this research project a water balance is set up for a water system in Cabauw.

2. FIELD SITE

The "catchment" of approximately 0.5 km^2 is part of a polder area, see Figure 1. It is drained by small, man-made channels. The soil consists of heavy clay on peat and is mainly covered with grass or cultivated for maize. The area is flat and at an elevation of approximately one meter below sea level and may be influenced by the varying waterlevels of the river Lek.

In Figure 1 the yellow lines indicate the catchment boundaries. Within the catchment of 0.5 km^2, a sub-catchment of 0.3 km^2 is nested.

Water flows from the more elevated Wielse Kade into the catchment via two routes: through a pipe with constant discharge ($Q_{in,cst}$) or through an adjustable inlet, resulting in a variable discharge ($Q_{in,var}$). Then it continues to follow the main watercourse (orange line) via the outlet (weir 1) of the sub-catchment ($Q_{out,1}$) and via the outlet (weir 2) of the whole catchment ($Q_{out,2}$) and flows out into the Maalvliet.

The water levels of surface water inside and outside the catchment are regulated. However, different levels are maintained for summer and winter.

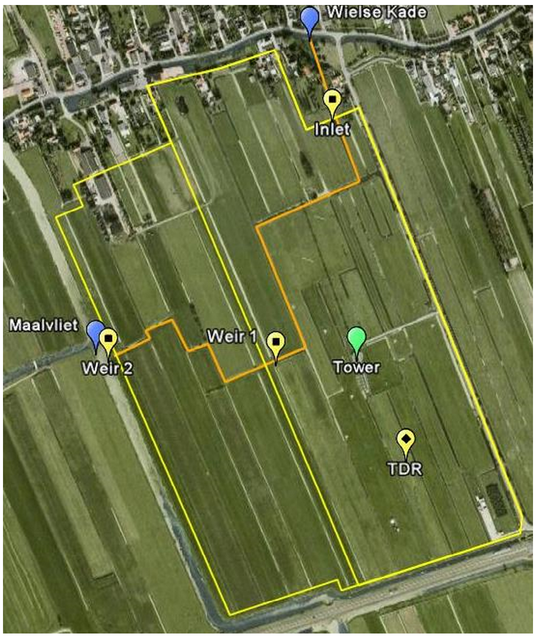

Figure 1. Overview of the catchment [1].

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

3. MEASUREMENTS

Hydrologists often use water balances to determine the size of water fluxes across catchment boundaries. As said before, this project aims to be a water balance study for the Cabauw area. Therefore we installed a rain gauge network, weirs to measure discharge of the adjustable inlet and of the two outlets, groundwater tubes and a TDR-system to measure soil moisture.

Measurement errors always occur. Since data analysis is work in progress, probably not all (minor) errors have yet been corrected. However, as demonstrated by the results in the Figures and Table, there can be good confidence closing the waterbalance for the selected periods.

3.1. Discharge

Downstream of the inlet ($Q_{in,var}$) a V-notch weir has been installed. At the outlets of the sub-catchment ($Q_{out,1}$) and the whole catchment ($Q_{out,2}$) Rossby-weirs have been installed. Upstream of the weirs Keller water level sensors have been placed. Discharge is derived from the registrated waterlevels and a stage-discharge relationship obtained in the laboratory. In April 2009 a magneto-restrictive sensor has been installed upstream of the inlet to measure water levels directly. This type of sensor is considered to be free of zero point drift.

For the waterbalance in mm/d volumetric discharges can be converted using catchment sizes. Accurate discharge data are available since May 2007.

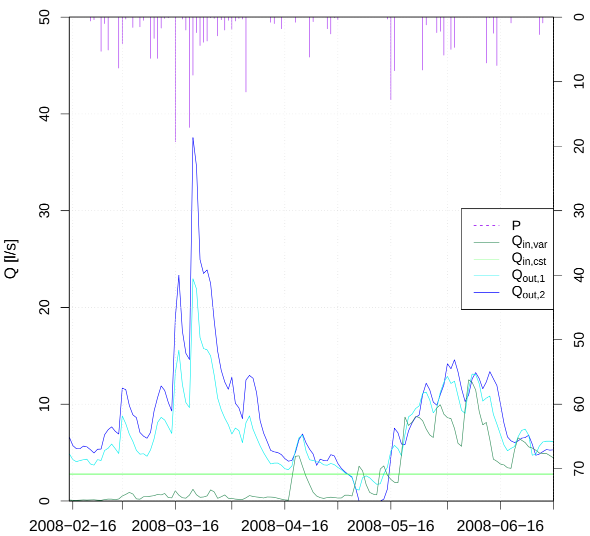

Figure 2. Part of the discharge and precipitation series.

In Figure 2 a four-month window of the streamflow hydrograph is shown. Because the catchment is very small, discharge responds quickly (hours) to rainfall events. Furthermore we see that $Q_{out,1}$ and $Q_{out,2}$ are in phase as expected.

Before 16 April $Q_{in,var}$ is small and variations in $Q_{out,1}$ and $Q_{out,2}$ are caused by variation in precipitation. After 16 April $Q_{in,var}$ becomes dominant and the effect of precipitation upon discharge is strongly tempered by soil moisture depletion due to evapotranspiration.

3.2. Soil moisture

In 2003 a TDR-system has been installed in the field [2]. This system consists of 6 arrays (3.5 m apart) of 6 sensors at 5, 15, 30, 45, 60 and 72.5 cm depth. It measures 36 volumetric water content (ϑ) values on a daily base.

Soil moisture data are available since November 2003, but few data are available for June and July 2007 and for July and August 2008 due to system collapses.

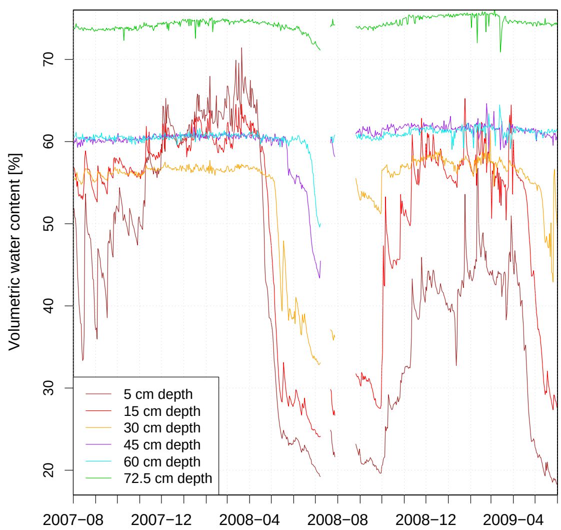

Figure 3. Volumetric water content, averages over 6 sensors at the same depth.

In Figure 3 ϑ is shown for the period 1 August 2007 - 1 July 2009. These values are averages of six sensors at the same depth.

In clayey soil, saturation is reached when ϑ is approximately 60%. The sensors at 72.5 cm depth are located below the clay layer in peat. Peat can contain more water than clay and therefore ϑ can reach 75%. At 5 cm depth ϑ reaches 68% in the winter of 2007-2008. This can be explained by the presence of organic material in the top soil, containing extra water as well. The lower sensors (45-72.5 cm depth) are nearly always saturated during the winter season, which means that the ground water table is often higher than 45 cm below surface as observations confirm.

At some days in June 2009 mean ϑ of the sensors at 5 cm depth decreases to 14%. It is for sure that plants encounter water stress when ϑ is this low.

It should be stressed that these soil moisture sensors represent one location in the catchment and that ϑ can be highly variable in space. Additional errors arise when clayey soil becomes dry and due to fracturing contact between sensors and soil becomes sub-optimal.

3.3. Precipitation and evapotranspiration

Daily precipitation sums (P) have been collected by the rain gauge network and by the KNMI at the automatic weather station in Cabauw. These last data have been used here for illustration.

Potential evapotranspiration rates (ET_{pot}) have been estimated with the method of Makkink [3]. For this method daily sums of global radiation and daily mean temperatures from the same KNMI station have been used. Crops may encounter water stress in persevere dry periods. If so, actual evapotranspiration (ET_{act}) will be lower than ET_{pot}.

4. WATER BALANCE

4.1. Theory

Water balances consist of several terms, which can be different for different catchments. Choice of terms depends on catchment characteristics, climate, human influence and other factors. The water balance for the Cabauw catchment is given as

$$P + Q_{in} - Q_{out} - ET = dS \qquad (1)$$

and can be set up either for the whole catchment or for the sub-catchment. The terms in this water balance are

- P: precipitation [mm/d].
- Q_{in}: inflowing discharge [mm/d], composed of a constant $Q_{in,cst}$ and a variable $Q_{in,var}$ part.
- Q_{out}: outflowing discharge [mm/d]. Either $Q_{out,1}$ (sub-catchment) or $Q_{out,2}$ (whole catchment) is used.
- ET: evapotranspiration [mm/d]. This ought to be ET_{act}, but here ET_{pot} has been taken as a preliminary term.
- dS: change in soil moisture storage [mm/d]. It is computed from the soil moisture contents observed in the upper 80 cm of soil (dS_{sm}) or resulting as rest term from the balance (dS_{rest}).

Storage change as a rest term (dS_{rest}) is computed in the following way:

$$dS_{rest} = P + Q_{in,cst} + Q_{in,var} - Q_{out,2} - ET_{pot} \qquad (2)$$

The expression considers no reduction in evapotranspiration.

In theory the water balance should close, but in practice it never closes completely, which can mainly be attributed to (1) measurement errors, (2) difference between ET_{pot} and ET_{act} and (3) water balance terms that have been omitted. For instance, in Cabauw there may be upward seepage from the river Lek into the catchment during periods of high water.

Presented results in the next section are illustrative for the whole catchment.

4.2. Results

Water balance terms vary during the year. We selected a 2-month winter period (Fig. 4) and summer period (Fig. 5) for which daily sums of water balance terms are shown in more detail. Total sums of waterbalance terms over both periods are shown in Table 1.

Table 1. Sums of water balance terms over a two-month period in winter (1 Nov. 2007 - 1 Jan. 2008) and summer (1 May 2008 - 1 July 2008).

	Winter	Summer
P	140	73
$Q_{in,cst}$	28	28
$Q_{in,var}$	5	56
$Q_{out,2}$	150	75
ET_{pot}	19	203
dS_{sm}	18	-114
dS_{rest}	4	-121

From 1 November 2007 to 1 January 2008 all terms are smaller than 1 mm/d except P and Q_{out} (Fig. 4). ET_{pot} is small because temperature and radiation intensities are low in this period. $Q_{in,var}$ is nearly zero because natural drainage maintains acceptable water quality in the polder area. Because ET_{pot} is also small in winter, Q_{out} is strongly linked to P.

From 1 May 2008 to 1 July 2008 ET_{pot} is the largest term in the water balance (Fig. 5). No longer a strong link exists between P and Q_{out}. During this period the sum of $Q_{in,var}$ and $Q_{in,cst}$ exceeds $Q_{out,2}$, which means that water is episodically infiltrating out of the channels. The process of evapotranspiration extracts water stored in the soil, creating a soil moisture deficit. During this 2-month period we see that this moisture deficit is not only replenished by precipitation and capillary rise from shallow groundwater, but also by water infiltrating from the channels into the soil.

The lower graphs in Figures 4 and 5 show the daily fluctuation in dS_{sm} and dS_{rest}. In winter dS_{sm} and dS_{rest} are fluctuating around zero, but in summer they are nearly always smaller than zero, which means that ϑ decreases. The observed amount of water stored in the upper 80 cm of soil increases from 478 mm on 1 Nov. 2007 to 496 mm on 1 Jan. 2008 and it decreases from 453 mm on 1 May 2008 to 339 mm on 1 July 2008.

Both dS_{sm} and dS_{rest} show peaks before and after rainfall events, which are sometimes even correct in height. In dry periods, dS_{sm} and dS_{rest} have different values and fluctuations. Although individual fluctuations of dS_{sm} and dS_{rest} are different, the sums over the period are quite close together (Table 1).

5. CONCLUSIONS

Climate models need information about radiation, energy and water fluxes at the soil surface. In Cabauw

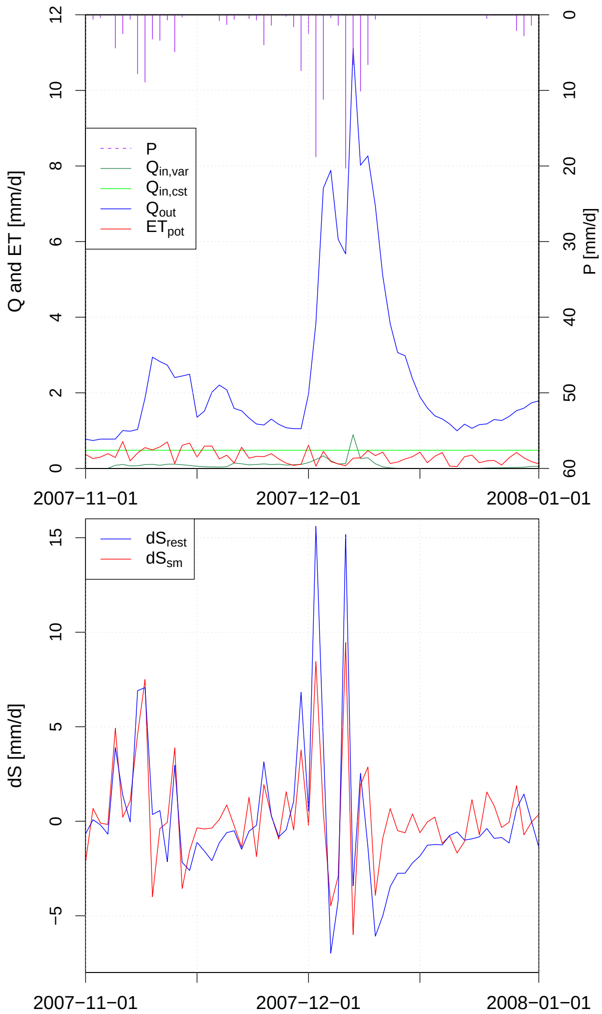

Figure 4. Daily sums of water balance terms for a winter period for the whole catchment (top) and storage change computed as rest term and from soil moisture data (bottom).

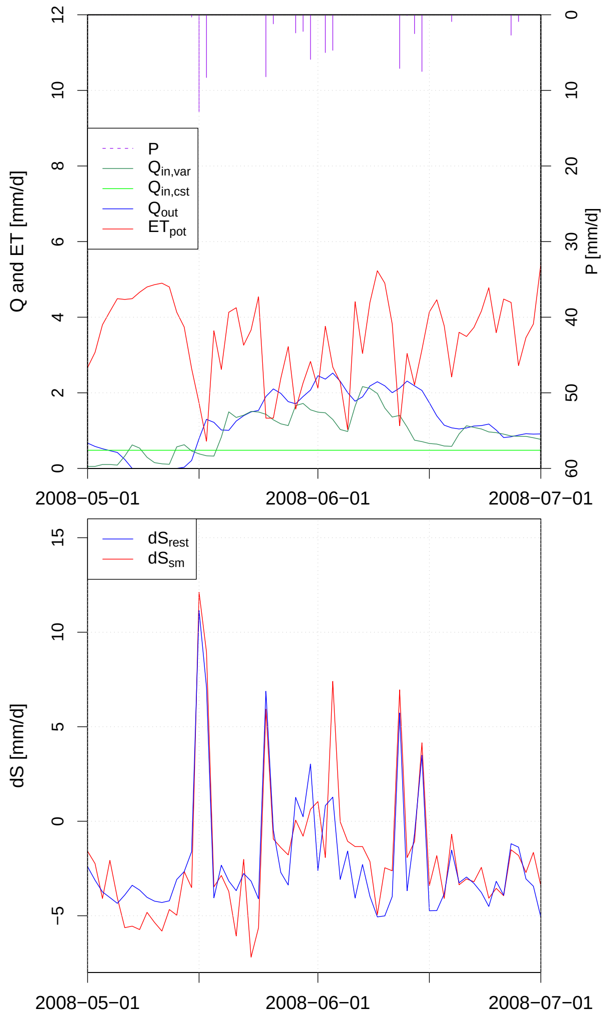

Figure 5. Daily sums of water balance terms for a summer period for the whole catchment (top) and storage change computed as rest term and from soil moisture data (bottom).

these fluxes and the belonging balances are measured. Water balances have been set up for a summer and a winter period to check the correctness of these fluxes.

In Cabauw the most important water balance terms are precipitation, evapotranspiration, inflowing and outflowing discharge and change in storage. In winter precipitation is the largest input term and outflowing discharge the highest output term. In summer inflowing discharge is the largest input term and evapotranspiration the highest output term.

There are still some difficulties in setting up this water balance. (1) It is not yet clear whether upward seepage from the river Lek is a term that has to be taken into account. (2) Implementation of actual evapotranspiration data is necessary. We soon hope to obtain these data. (3) Generally, a good spatially representative method to measure soil moisture is needed.

Our intention is to continue this hydrological field study over a period of several years for modelling purposes.

ACKNOWLEDGMENTS

We thank the KNMI for cooperation and for delivering precipitation, temperature and global radiation data.

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