Data description document for **surface water measurements** Cabauw Experimental Site for Atmospheric Research (CESAR)

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1 Measurement

The "catchment" around the tower is 0.5 km^2, and can be divided into two sub-catchments (see Figure 2). The upstream catchment is 0.3 km^2 and covers the area between $Q_{\mathrm{in,var}}$ and $Q_{\mathrm{out,1}}$. The downstream catchment is 0.2 km^2 and covers the area between $Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$. Water is supplied upstream into the area from a more elevated water course through a variable inlet controlled by the water authority (Hoogheemraadschap De Stichtse Rijnlanden) and through two small pipes with relatively constant discharge. Downstream of the outlet ($Q_{\mathrm{out,2}}$) is a larger water course, from which water is pumped into the river Lek (at ~1 km). It is important to note that there is no pumping station within the catchment and hence drainage is driven by gravity. It is reasonable to suppose, however not investigated, that water flows through the soil from the river Lek into the catchment. Temporal variation in Lek water levels cause temporal variation in this seepage flux. The surface water levels are regulated by two weirs (where also $Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$ are measured), which are set 10 cm higher in summer than in winter. The variable inlet is used to maintain these surface water levels. For more information, see Brauer et al. (2014a,b); Brauer (2014).

Discharge has been measured at three locations (Table 1). At these locations, measurement weirs have been installed in May 2007 to estimate discharges accurately[1]. A V-notch weir is used to measure the inflow of surface water into the catchment near the Wielse Kade ($Q_{\mathrm{in,var}}$). Trapezoidal Rossum weirs have been installed to measure outflow ($Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$), of which the stage-discharge relations have been obtained by laboratory calibration.

The uncertainty associated with the discharge measurement can be considerable in some cases. The weir to measure $Q_{\mathrm{out,1}}$ was often submerged due to the small topographical gradient. The weir to measure $Q_{\mathrm{in,var}}$ was sometimes submerged and leakage through the planking around this weir also occurred. In addition, the two small inlets (pipes) with relatively constant discharge were maintained by local residents and could not be measured continuously.

Note that next to these surface water level measurements performed by Wageningen University, surface water levels have been measured by the KNMI. Those data are also available through the CESAR database.

The employed stage-discharge relations are for $Q_{\mathrm{in,var}}$:

$$Q = 1.97 \cdot 1000 \cdot (h + 0.0008)^{5/2} \ ,$$

for $Q_{\mathrm{out,1}}$:

$$Q = 1.6252h^2 + 0.0289h - 0.00003 \ \text{if} h < 0.037$$

$$Q = -0.1036h^3 + 1.047h^2 + 0.0655h - 0.00006 \ \text{if} h \geq 0.037 \ ,$$

and for $Q_{\mathrm{out,2}}$:

$$Q = 2.247Q^2 + 0.0391Q - 0.00006 \ \text{if} h < 0.0307$$

$$Q = -0.4176Q^3 + 1.409Q^2 + 0.089Q - 0.00008 \ \text{if} h \geq 0.0307 \ ,$$

with h in m with respect to the weir crest elevation and Q in $\mathrm{l\,s^{-1}}$ (Table 2). The relation for the V-notch weir is an ISO standard and the relations for the trapezoidal weirs were found after calibration in the Laboratory for Water and Sediment Dynamics of the Hydrology and Quantitative Water Management Group at Wageningen University.

[1] water levels have been measured before 2007, but conversion to discharges is too inaccurate because the Q-h relationships were not reliable

2 Dataset

There are data files for each year, with daily and hourly resolution:

- cesar_surfacewater_dischargedaily_la1_t1d_v1.0_yyyy.nc
- cesar_surfacewater_dischargehoury_la1_t1d_v1.0_yyyy.nc

Discharges are given in $\mathrm{l\,s^{-1}}$, averaged over all measurements during one hour or one day. Original measurements are every 15 min.

Table 1: Available data.

Weir ID	Weir type	Measurement period
$Q_{\mathrm{in,var}}$	V-notch	2007-10-01 – 2011-10-21
$Q_{\mathrm{out,1}}$	Rossby	2007-10-01 – 2011-10-21
$Q_{\mathrm{out,2}}$	Rossby	2007-10-01 – 2011-10-21

Table 2: Elevations of the crests of the weirs.

Period	Elevation [m a.m.s.l.]
$Q_{\mathrm{in,var}}$	
2007-10-01 – 2011-10-21	-1.361
$Q_{\mathrm{out,1}}$	
2007-10-01 – 2007-11-16	-1.448
2007-11-16 – 2008-05-06	-1.529
2008-05-06 – 2008-10-15	-1.496
2008-10-15 – 2009-04-15	-1.576
2009-04-15 – 2009-11-12	-1.494
2009-11-12 – 2010-05-25	-1.576
2010-05-25 – 2010-09-24	-1.495
2010-09-24 – 2011-04-29	-1.576
2011-04-29 – 2011-10-21	-1.495
$Q_{\mathrm{out,2}}$	
2007-10-01 – 2007-11-16	-1.613
2007-11-16 – 2008-05-06	-1.713
2008-10-15 – 2008-05-06	-1.613
2008-05-06 – 2009-07-29	-1.713
2009-07-29 – 2009-10-31	-1.613
2009-11-12 – 2010-04-28	-1.713
2010-04-28 – 2010-09-24	-1.613
2010-09-24 – 2011-04-29	-1.713
2011-04-29 – 2011-10-21	-1.613

3 Gap filling

Measurements have been corrected and gaps have been filled. A quality code is supplied with every measurement:

1 The original data are used (no corrections).

2 The original data are used (no corrections), but something special may have happened or there are doubts about the data quality. For example, weirs have been lowered (autumn) or elevated (spring), causing a sudden increase or decrease in discharge.

3 Data have been corrected (gap filling or correction for submergence).

3.1 Instrument malfunction

If $Q_{\mathrm{in,var}}$ is not available, it is assumed that the position of the inlet has not changed and the last measurement is repeated until data are available:

$$Q_{\mathrm{in,var,t}} = Q_{\mathrm{in,var,t-1}} \ .$$

If $Q_{\mathrm{out,1}}$ is not available, the ratio between $Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$ of the last available measurement and the measurements of $Q_{\mathrm{out,2}}$ are used to fill the gap:

$$Q_{\mathrm{out,1,t}} = \frac{Q_{\mathrm{out,1,t-1}}}{Q_{\mathrm{out,2,t-1}}} Q_{\mathrm{out,2,t}} \ .$$

The opposite is done for $Q_{\mathrm{out,2}}$:

$$Q_{\mathrm{out,2,t}} = \frac{Q_{\mathrm{out,2,t-1}}}{Q_{\mathrm{out,1,t-1}}} Q_{\mathrm{out,1,t}} \ .$$

$Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$ were never unavailable together.

3.2 Submergence

The water level measured just upstream of $Q_{\mathrm{out,1}}$ is used as estimate of the water level downstream of $Q_{\mathrm{in,var}}$. If the water level measured just upstream of $Q_{\mathrm{out,1}}$ is higher than the weir level of $Q_{\mathrm{in,var}}$, the weir of $Q_{\mathrm{in,var}}$ is assumed to be submerged and the last measurement is repeated until the downstream water level has dropped below the weir level:

$$Q_{\mathrm{in,var,t}} = Q_{\mathrm{in,var,t-1}} \ .$$

The water level measured just upstream of $Q_{\mathrm{out,2}}$ is used to compute the water level downstream of $Q_{\mathrm{out,1}}$. The equation of Chézy is used

Figure 1: Top row: (1) V-notch weir near the variable inlet ($Q_{\mathrm{in,var}}$), (2) Rossby weir at the outlet of the first subcatchment ($Q_{\mathrm{out,1}}$) and (3) Rossby weir at the outlet of the whole catchment or second subcatchment ($Q_{\mathrm{out,2}}$). Middle row: (1) variable inlet; water flows under the road (called Wielse Kade) from right to left, (2) inflow of the first constant inlet (a small pipe is located below the water surface next to the Wielse Kade), (3) outflow of the first constant inlet in a private garden (the downstream end of the pipe is located below the water surface; the inlet causes circular waves). Bottom row: (1) inflow of the second constant inlet (a small pipe is located below the water surface next to the Wielse Kade), (2) outflow of the second constant inlet in a private garden on the other side of the Wielse Kade, (3) the effect of different surface water levels between summer and winter is visible as the browned part of the ruler.

to estimate the additional level change between $Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$. The equation of Chézy is

$$Q = A \cdot C\sqrt{R\frac{\Delta h}{L}} \ .$$

The channel is estimated to be 2 m wide and 0.3 m deep. The cross-sectional area A is $2 \times 0.3 = 0.6$ m. The hydraulic radius R is computed as A/P, using a wetted perimeter P of $2 + 0.3 + 0.3 = 2.6$ m, leading to $0.6/2.6 = 0.23$ m. The Chézy constant C is assumed to be discharge-dependent. It is determined empirically using several manual measurements of water levels downstream of $Q_{\mathrm{out,1}}$ and upstream of $Q_{\mathrm{out,2}}$ during different flow conditions and reads $C = Q \cdot 0.15 + 5$. The distance L between $Q_{\mathrm{out,1}}$ and $Q_{\mathrm{out,2}}$ is 400 m.

$$h_{\mathrm{downstr.,out,1}} = h_{\mathrm{upstr.,out,2}} + \frac{\frac{Q}{1000}^2 \cdot 400}{0.6^2 \cdot 0.23 \cdot (Q \cdot 0.15 + 5)^2} \ ,$$

with Q in $\mathrm{l\,s^{-1}}$ and h in m with respect to the weir elevation. If the weir is submerged, the ratio between upstream and downstream levels is

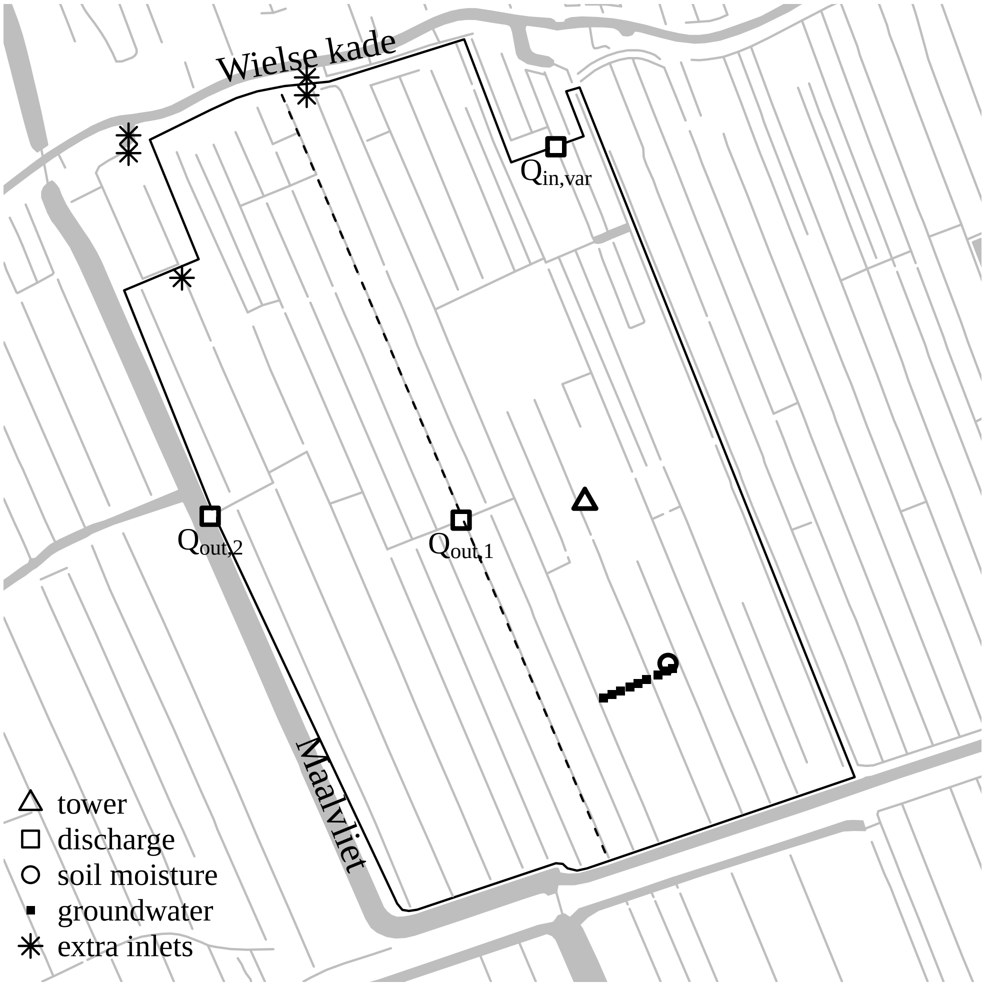

Figure 2: Location of the discharge and other hydrological measurements.

computed:

$$R = \frac{h_{\text{downstream}}}{h_{\text{upstream}}}$$

and used to correct the discharge (Boiten et al., 1994):

$$Q = Q_{\text{original}} \cdot \left(1 - 0.8R^3 + 0.305R^2 - 0.09R\right)$$

The weir at $Q_{\text{out},2}$ is never submerged, so no correction procedure is necessary.

3.3 Leakage at variable inlet

The planking around the $Q_{\text{in,var}}$ weir is somewhat weathered and water seeps through the boards. The seepage increases with upstream water level. An additional term to account for this seepage was added to the discharge:

$$Q = Q_{\text{original}} + h_{\text{upstream}} \cdot 3.33\ ,$$

with h in m with respect to the weir elevation. This equation was empirically determined with manual measurements of the seepage.

4 Set-up NetCDF files

The NetCDF files contain the following columns:

- `date`: date (as yyyymmdd) or date-time (as yyyymmddhh)
- `Qinvar`, `Qout1`, `Qout2`: discharge in liters per second at each location
- `code_invar`, `code_out1`, `code_out2`: data quality code at each location
- `DOY`: all days in the year in question (belongs to `valid_dates`)
- `valid_dates`: vector with 1 and 0 indicating if data for that day are available

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