

ered seem promising and will hopefully lead to a better description and modelling of the hydrological characteristics of the Keuper soils under natural forest. Relations between abiotic and biotic factors are also of large interest and form an interesting object for further research. On a longer term, the effects of forest management can be studied as the forest will be partially cleared by cutting some of the beeches and hornbeams to improve the conditions for other trees. Heavy machinery used in the forest to extract trees might be expected to destroy many of the macropore systems and to alter the hydraulic properties of the soil, making the drainage of the forest even more difficult than it already is.

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A METHOD FOR THE SEPARATION OF TOTAL DISCHARGE INTO BASE FLOW, OVERLAND FLOW AND CHANNEL PRECIPITATION FOR WATER QUALITY MODELLING OF A SMALL WATERSHED IN THE NETHERLANDS

W. Bleuten, Utrecht

Summary

For surface water quality modelling all contributing discharges, each with different loads of dissolved matter have to be considered separately. Apart from physical and (bio)chemical interactions, water quality is the result of all inputs, both in volume and mass. For this reason dynamic modelling of water quality is possible only when the processes leading to the temporal variability for each different type of input can be modelled as well.

In the Netherlands almost all inland watersheds discharge considerable amounts of groundwater. During storm events however, surface runoff is an important factor even in these flat areas. Other discharge sources to be modelled are channel precipitation and effluent discharges.

A dynamic one-dimensional numeric discharge model has been developed for

a catchment area in the central part of the Netherlands, with distinct subareas where infiltration or seepage is dominant. Model output is daily discharge of the three most important discharge components (groundwater discharge, overland flow and channel precipitation) and total catchment outflow.

From these components groundwater discharge has been calculated using recorded levels of groundwater and surface water. Because precipitation volumes per day can be computed from meteorological data and surface water area, and effluent discharges usually are well known, overland flow discharge modelling was possible.

1 Introduction

The modelling of the quality of surface water requires detailed and quantitative information on discharge variability, both in time and space. Surface waters contain certain amounts of dissolved matter, originating from various sources. During transport these ions interact with (suspended) solid materials in the water,

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| | K ⁺ | | Na ⁺ | | Cl ⁻ | | HCO ₃ ⁻ | | NO ₃ | | PO ₄ ³⁻ | |
|----|----------------|-------|-----------------|--------|-----------------|--------|-------------------------------|--------|-----------------|--------|-------------------------------|--------|
| | mean | (sd) | mean | (sd) | mean | (sd) | mean | (sd) | mean | (sd) | mean | (sd) |
| PD | 10.2 | (4.4) | 14.5 | (4.6) | 24.7 | (11.1) | 115. | (41.) | 18.7 | (13.1) | 2.7 | (1.7) |
| BF | 4.3 | (2.1) | 22.4 | (17.6) | 40.1 | (30.5) | 184. | (37.) | 5.1 | (6.1) | 2.0 | (1.4) |
| OF | 4.7 | (3.1) | 14.9 | (6.5) | 24.7 | (8.8) | 148. | (120.) | 40.5 | (41.3) | 2.7 | (3.4) |
| E | 18.4 | (7.1) | 71.3 | (36.0) | 79.6 | (54.0) | 84. | (41.) | 63.2 | (36.3) | 34.8 | (17.3) |
| P* | 0.1 | | 1.7 | | 3.1 | | 0. | | 3.8 | | 0.0 | |

PD = peak discharge
 BF = base flow (mainly groundwater discharge)
 OF = overland flow
 E = effluent water from purification plants
 P = precipitation
 * data from KNMI-RIVM, 1979

Tab. 1: Means of measured ion concentrations in surface water during peak discharge and base flow conditions and in overland flow water ($\text{g}\cdot\text{m}^{-3}$).

the soil below the water and with living organisms. In modelling of water quality these interactions should be taken into account. Furthermore, each discharge component has its own quality properties, reflecting the environmental conditions in its source area. Therefore the various discharge components have to be separated in a quantitative way in order to facilitate real time modelling. In this context base flow (BF) resulting from groundwater discharge only, has physical and chemical properties quite different from precipitation, overland flow (OF) or effluents. Mean concentrations of six ions in surface water in the study area (see below) for BF conditions for OF and for the mixed surface water during peak discharge (PD) conditions, demonstrate clear, ion dependent, differences (tab.1).

Overland flow water compared to precipitation water has higher concentrations (SÜSSMAN 1983) because the first is enriched with soluble ions (in manure and fertilizer) from the top soil. Manure and fertilizer remnants on top of the soil can deliver these ions because of the common agricultural practice (over-

dosing, manure spreading in winter).

Peak discharge concentrations seem to be the result of mixing of the three discharge components. For sodium, chloride and bicarbonate PD concentrations are dominated by inputs of OF and channel precipitation (P). In this area both OF and P have lower concentrations than groundwater. For nitrate and to a lesser extent also for phosphate PD concentrations are increased because of OF inputs.

From a comparison between percentile values the differences between BF conditions and PD appear to be significant for some ions (fig.1). In these comparisons percentiles of the sorted field data are used because in surface waters ion concentrations are not normal distributed in time.

In particular nitrate and potassium concentrations are increased during PD periods (storms), probably resulting from the combination of OF and reworking of bottom sediments. The potassium increase can only be explained by the second cause as both OF and P concentrations are lower than PD concentrations.

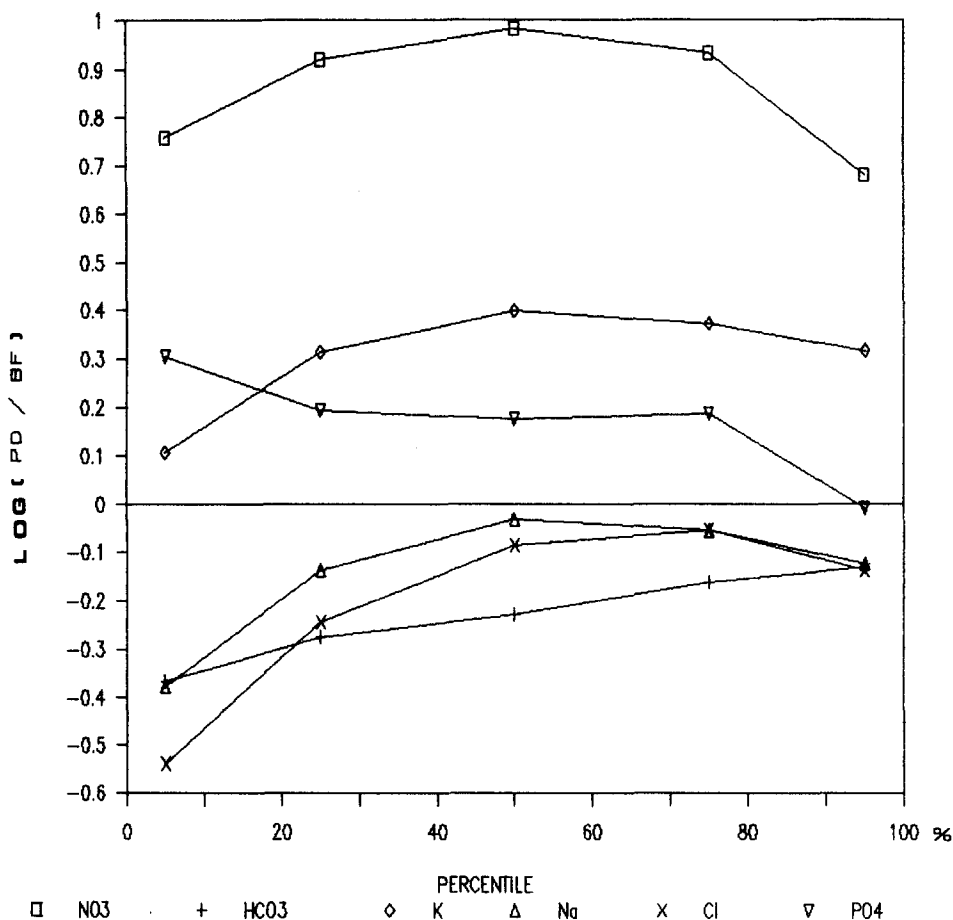


Fig. 1: Quotient of measured concentration percentiles during base flow (BF) and peak flow (PD) conditions.

The results point to the need to split total runoff into the various discharge components when modelling water quality. Channel precipitation discharge (QP) can be calculated from water surface areas (estimated or measured). Effluents from point sources usually are well known and quantified. Overland flow will be the component most difficult to measure in a representative way for whole catchments. However, if base flow is quantified, overland flow can be com-

puted.

2 Study area

The catchment studied (16 km²) is situated in the centre of the Netherlands (Southeast of the town of Utrecht). Geomorphologically the area can be split up into three main parts (fig.2).

The Northeastern part consists of a morainic ridge ("Utrechts Heuvelrug") composed of ice pushed Pleistocene

same magnitude. Thus, base flow conditions occur when:

$$Q_{t+1} < Q_t < 1.02 * Q_{t+1} \quad (3)$$

where

Q = discharge

t = current day

$t + 1$ = next day

In the study area this condition (3) is satisfied within 3–5 days after a storm event with peak discharge. This means that after 5 days the total discharge consists of seepage. For computing the relation between water level differences (H) and groundwater discharge, only those measurements done 6 days after rain storms were selected. As expected from equations (1 and 2) the groundwater discharge appeared to be correlated strongly ($r = 0.9$; $p \leq 0.001$) with water level differences (H) by a first order function (fig.3). Up to a level difference (H) of 0.6 m the groundwater discharge can be predicted very well. At (almost) bankfull discharges the linear discharge-to-level difference relation no longer holds true, so the function loses its validity. Because in the studa area bankfull discharge occurs only once every 2–3 years and the canals never dry out, the regression function can be used for continuous computation of groundwater discharge. The first order equation has been incorporated in a discharge model of the study area.

3.2 Discharge due to channel precipitation

The discharge resulting from channel precipitation is computed from the measured total water surface area and channel banks are above the water level. Both areas are dependent to water level chang-

charge depletion curves constructed following weir elevation changes were used to calculate initial area sizes. These calculations were checked by map analyses and field work.

3.3 Overland flow discharge

Overland flow discharge has been modelled based on infiltration capacity and surface storage potential. In the flat study area overland flow occurs only on clay soils used for agricultural production. Infiltration capacity of clay soils depends strongly on their moisture conditions (BOUMA 1977). Therefore 'wet' and 'dry' infiltration capacities have to be differentiated in modelling overland flow. In places where surface storage occurs the soil is completely saturated with water, resulting in a very low ('wet') infiltration capacity (WIC). By shrinking of the clay during dry periods deep cracks are formed, resulting in very high 'dry' infiltration capacity (BOUMA 1977), or more accurate: the soil storage capacity increases. For modelling purposes an actual infiltration capacity (AIC) is computed with a simple function based on precipitation history (fig.4). This function is derived from the antecedent precipitation index equation of CHOW (1964). The discharge resulting from overland flow can be computed on a daily basis from precipitation and evaporation data after model calibration with a separate data set from a well recorded and documented peak discharge period. With the same data set the parameter values (IC, WIC, R) for the study area are set by means of iterations.

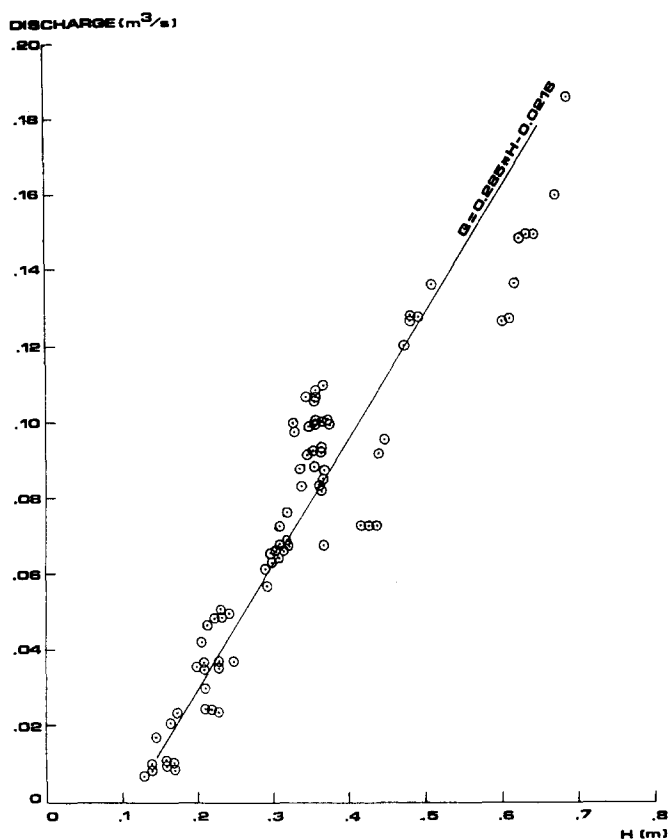
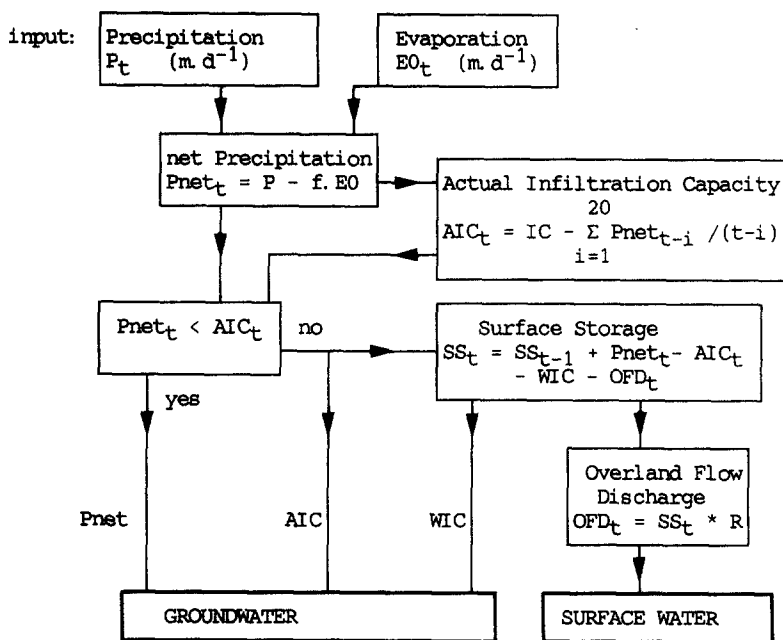


Fig. 3: Relation between groundwater discharge in dry periods and the difference (H) between groundwater level and surface water level.

| discharge components | sand area type II | clay area type III |
|---|----------------------|-----------------------|
| total ($10^6 \cdot \text{m}^3 \cdot \text{y}^{-1}$) | 1.2 | 4.8 |
| groundwater discharge % | 97. | 68. |
| overland flow discharge % | -. | 29. |
| channel precipitation % | 3. | 3. |

Tab. 2: Total annual discharge and percentage of contribution of separate discharge components for two parts of the study area.



IC = Mean infiltration capacity for unsaturated top soil (m. d^{-1})
 WIC = Infiltration capacity for saturated top soil (m. d^{-1})
 R = resistance factor.
 f = evaporation reduction factor.

Fig. 4: Flow scheme for computation of overland flow discharge.

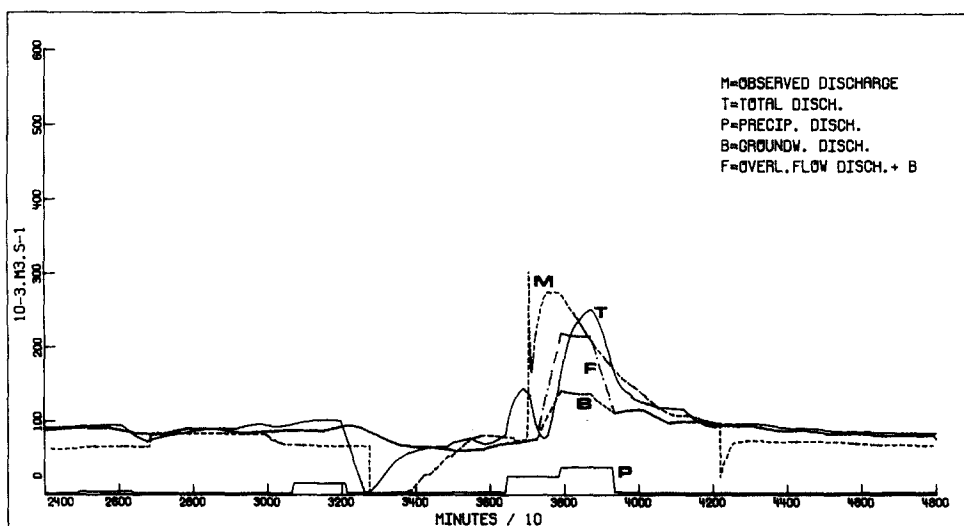


Fig. 5: Computed and observed discharge components.

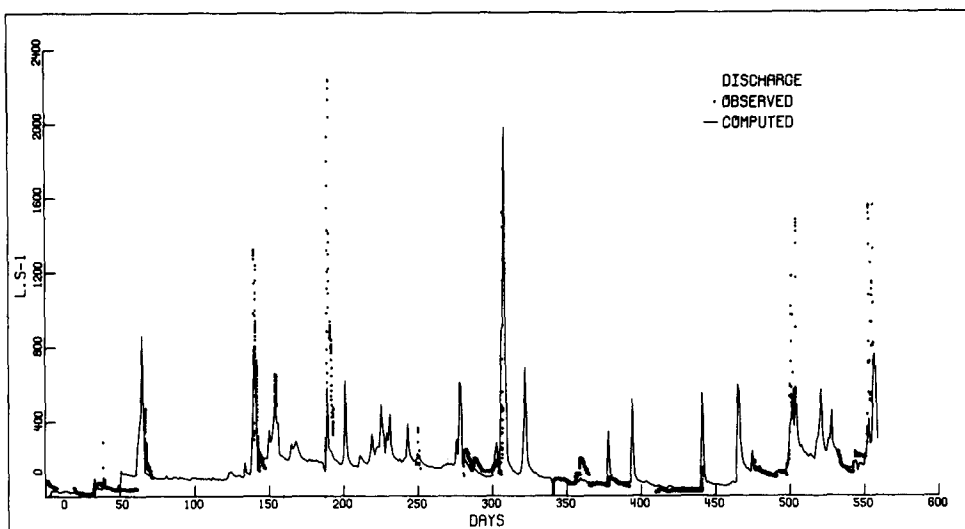


Fig. 6: Computed and observed total discharge from October 1978 – February 1980.

4 Results

The sum of the three discharge components forms the input of the discharge model of the study area. Discharge at the outlet of the catchment is computed from:

$$Q = Q_{BF} + Q_{OF} + Q_P - S/t \quad (4)$$

where

S = Storage volume

Channel storage is computed from the difference between input volume and outflow capacity (volume), which in turn depends on the computed water level (wh) in the actual time step. For discharge computation, after testing for the study area the empirical formula (5) according ANN (1967) has been used.

$$Q = c_w * B * (wh - wch)^{3/2} \quad (m^3 \cdot s^{-1}) \quad (5)$$

where

c_w = weir dependent constant

B = weir width (m)

wh = water level (m)

wch = weir crest height (m)

This means that for computations the weir crest height should be well known from field observations.

Although part of the input data consist of daily figures the chosen time step is one hour, to obtain convergence in the calculations. In fig.5 the results of the computations for period June–August, 1981 are plotted together with the observed total discharge. Except for precipitation the plotted curves give the moving averages of 5 hour blocks. The model structure brings on a one day delay compared to reality. In the observed hydrograph sudden changes occur. These result from farmers interfering with weir elevations.

In tab.2 the discharge components for a whole year are added. On a yearly base overland flow in the clay soil area appears to contribute up to almost 30% of the total discharge, a quantity which cannot be ignored.

In fig.6 computed and observed discharges at the outlet of the catchment

are shown for the period October 1978 – February 1980. Base flow discharge is computed very accurately. Computed peak discharge does not always fit. This may result from underestimation of overland flow. The lack of field data regarding weir elevation changes can lead to miscalculations in both 'observed' and 'computed' discharges. This makes a goodness of fit test less meaningful. After logarithmisation, thus depressing the importance of peak discharges, the correlation between 'observed' and 'computed' discharges was reasonable ($r^2 = 0.73$). For modelling water quality, which is the ultimate purpose of this discharge model this correlation is acceptable.

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