HYDROLOGICAL EFFECTS OF DRAINAGE IMPROVEMENT IN THE HUPSELSE BEEK CATCHMENT AREA IN THE NETHERLANDS

NOTA 64

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Abstract*

The effect of drainage improvement on the hydrological regime in a small catchment area in the Netherlands is analysed.
When compared with records in an unaffected benchmark situation, water-table records generally indicate a lowering from the time of amelioration onwards.
The effects on the runoff regime are studied by optimizing the Wageningen Model II for data of winter periods prior to amelioration. This model is subsequently applied to rainfall data of post-amelioration winter periods.
Deviations between computed and observed hydrographs of outflow demonstrated an increase of losses and an increase of non-linearity of the runoff system.
Also the portion of the effective precipitation that passes through the slow component of the runoff system was found to have increased.

* Contribution to the International Conference on Environmental Management of Agricultural Watersheds, Smolenice, CSSR, April 1979.

Introduction

From 1961 to 1967 a detailed hydrological study was carried out in the catchment area of the Leerinkbeek river near the eastern border of the Netherlands (Fig. 1.).

Insufficient discharge capacities of the brooks and poor conditions of the detail drainage systems were the cause of frequent flooding in that region. Around 1967 amelioration works were carried out. These works included improvements of the detail drainage system and the corresponding increase of the discharge capacity in the main channel system.

When these amelioration works were started, it was decided to continue the hydrological study in a restricted area. This was the Hupselse Beek catchment area which is a sub-basin of the Leerinkbeek river.

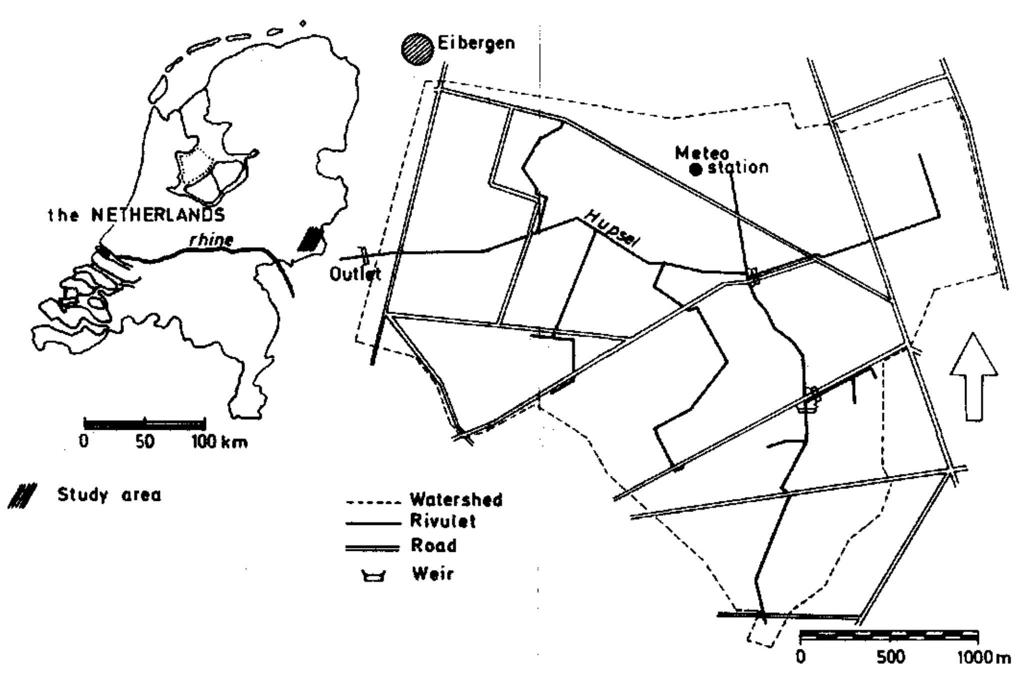

Fig. 1 : Experimental catchment " Hupselse Beek "

Thus series of observations, which were started in 1961 and continued after the amelioration works, are available for a study of the effects of amelioration on the hydrological regime. This paper describes some results of this study.

Description of the catchment area

The Hupselse Beek runs from east to west through a slightly undulating rural landscape in the eastern part of the Netherlands near the township of Eibergen (Fig. 1.). The catchment area is 6.5 km^2. Its groundlevel varies from 33 m above mean sealevel in the east to 24 m near the outlet in the west. Within the catchment the rivulet Hupselse Beek is 4 km long and it has 7 small tributaries ranging in length from 300 to 1500 meters. The top of the underlying thick tertiary formation of impermeable marine clays is found at shallow depths in the east and slopes down to the west. These marine clays are covered with younger sandy deposits. Consequently the thickness of this sand aquifer varies between 1 and 8 m from east to west. The predominant soil is a hydropodzol consisting of slightly loamy sand.
Land use is mainly agricultural: about 70% is covered with grass, 20% is arable land and 6% is covered with trees. A detailed description of the catchment can be found in an (1976) report of the study group 'Hupselse Beek' (ref. 1.).

Instrumentation and data collection

Meteorological data are collected in a central meteorological station. A record of rainfall data from 1961 is available for time units of 3 hours. The flow at the outlet is measured with an H-flume. Water stages are observed every 15 minutes and recorded on punched paper tape. Using the rating curve for the flume stage recorder data were processed to runoff data for time units of 3 hours. Runoff data are available from 1962 except for 1967 when the amelioration works were carried out. Over the same time period also groundwatertable depths are available.

Effected changes in the runoff regime

General

The traditional approach to indicate any effect of catchment change on runoff characteristics has been to compare the characteristics of of paired catchment areas before and after the change of conditions in one of them. For such a study catchment areas with similar characteristics, close to each other must be considered.

In the present case, however, only data from one catchment area are available for study. Changes in the hydrological regime can then be discovered by looking for significant changes in hydrological data. This method only yields reliable results when a sufficient length of data series is available. In this study a series of groundwater levels is compared with those in a benchmark situation. In Fig. 2 the levels of well 56 in the catchment area were plotted against simultaneous levels in well 13 which was not affected by the amelioration works.

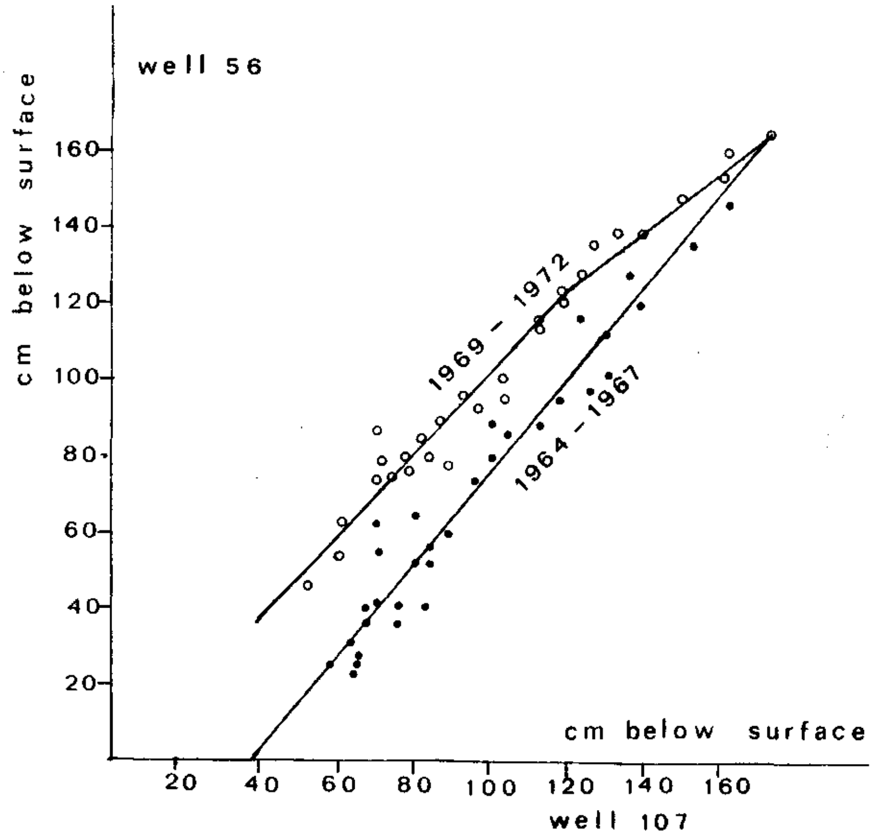

Fig. 2. Comparison of groundwater depths in well 56 in the area with depths in a well not affected by the amelioration in 1967.

Changes in the overall catchment operation can also be traced by studying the behaviour of parameters in a rainfall-runoff model as these parameters are optimized for input-output series observed before and after amelioration. This method can only be successful if certain conditions are fulfilled:

- The model must be well structured and simple. It must be physically meaningful so that it preserves the governing features of the runoff process even when it has been simplified down to a small number of linear and simply connected components. Only a few parameters must suffice to represent, in a lumped form, the major characteristics of the catchment. Thus changes of these characteristics may be recognized in changes of the fitted parameter values after the amelioration works.
- The observed rainfall-runoff series must closely represent the true input-output of the rainfall-runoff system. Considering the reasonable accuracy of the rainfall measurements and the wide distribution of winter rains, we can expect that during frost and snow-free periods measured rainfall at the meteorological station will indeed be a true sample of rainfall on this small catchment. During winter months evaporation losses are low. When these losses are accounted for by the introduction of a reduction factor the series of reduced rainfall is a close approximation of the input of effective precipitation into the rainfall-runoff system. Due to the amelioration works the drop below the outlet was increased and therefore after 1967 some increase of groundwater leakage must be expected. Nevertheless the observed discharge is believed to represent the true output closely.

The model

Although surface runoff is not a common phenomenon in rural catchments in the Netherlands, discharge peaks in the Hupselse Beek rivulet cannot be attributed only to groundwater flow. In this slightly rolling terrain also subsurface and surface runoff from temporarily waterlogged surfaces contribute to peak discharge. For this reason a model, as presented in Fig. 3. with two parallel linear elements representing the fast and slow reacting component of the flow process, was selected.

After a reduction of observed precipitation by an operator η, the effective precipitation is divided into two parts. One part (α) passes through the fast reacting component and the remainder ($1-\alpha$) passes through the slow component of the model. The sum of the results of these two transformations represents the total runoff.

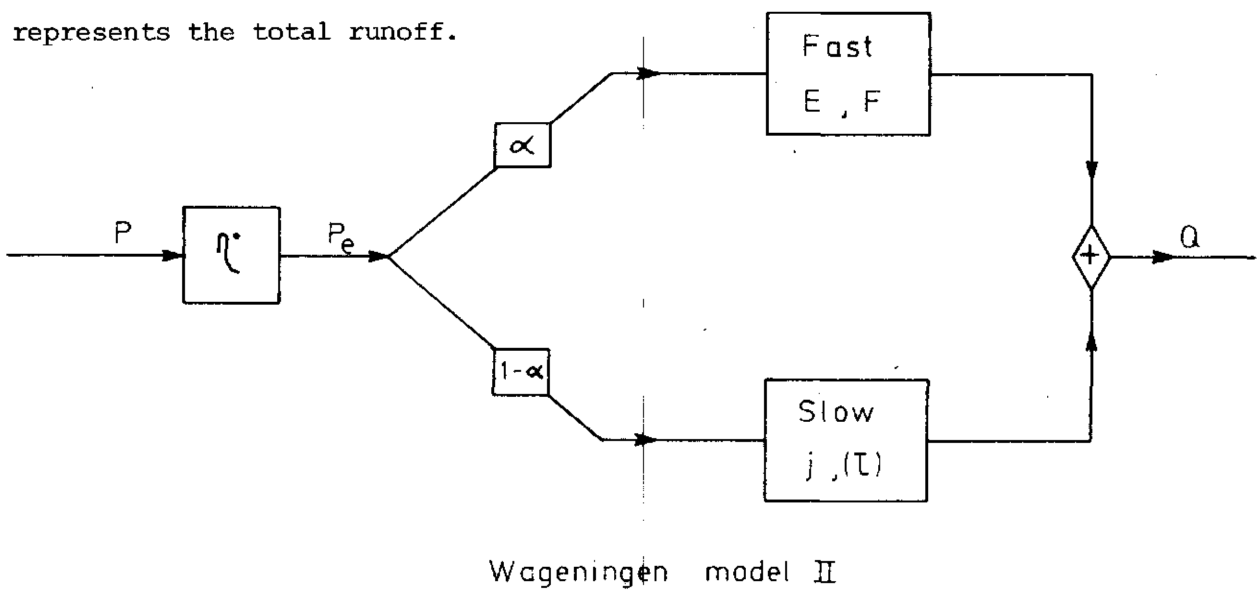

Fig. 3. Structure and parameters of the Wageningen Model II.

At the outset of rainfall-runoff studies in the Netherlands, attention was primarily given to the study of groundwater flow. Kraijenhoff (1958) derived the impulse response of non-steady groundwater flow to parallel drainage channels. (ref. 2.).

$$u(0,t) = \frac{8}{\pi^2}\frac{1}{j}\sum_{n=1,3,5}^{\infty} e^{-n^2 t/j}$$

in which:

$$j = \frac{1}{\pi^2}\frac{PL^2}{kD}$$

In this compound parameter j, indicating the characteristic time of the system, P is the active porosity of the soil, L the drainage area per unit length of drainage channel and kD the transmissivity.

In the so-called Wageningen Model I, the Kraijenhoff model was used for both the fast and the slow branch of the model, of course with different values of parameter j. This Wageningen Model I was successfully applied to some early winter periods in the Hupselse Beek catchment area (Study group 'Hupselse Beek', 1976) (ref. 1.).

In a later development of the Wageningen model it was realized that the process of surface runoff is dissimilar from groundwater runoff. Therefore, in the Wageningen Model II the fast reacting element was represented by a linear simplification of the equation of nonsteady flow in a prismatic channel (Hayami, 1951 ref.3; Harley, 1967 ref.4; van de Nes, 1971 ref.5). With inflow at the upstream end, the impulse response at a distance x is

$$u(0,t) = \frac{x}{2\sqrt{\pi D t^3}} e^{-(x-At)^2/4Dt}$$

D is the diffusion coefficient and A the translation coefficient. The equation can be simplified to a two parameter model by substituting

$$E = \frac{x}{2\sqrt{D}} \quad \text{and} \quad F = \frac{A}{2\sqrt{D}}$$

so that

$$u(0,t) = \frac{E}{\sqrt{\pi t^3}} e^{-(E-Ft)^2/t}$$

After this modification, the Wageningen Model II consisted of two branches: A groundwater model for the slow component and a flood wave model for the fast component. It thus had 4 parameters α, E, F, j, while a fifth, a pure delay τ could be added if necessary.

As more Hupsel data became available for analysis the Wageningen Model II indeed produced better hydrograph reconstructions. It was also found that a further improvement could be obtained by the introduction of a variable instead of a fixed divider α.

It is reasonable that the distribution of effective precipitation over the fast and slow branches should be some function of antecedent rainfall. In his student thesis, van Ballegooijen (1978) therefore introduced (ref. 6):

$$\alpha(t) = e^{c.API(t)} - 1$$

with the antecedent precipitation index

$$API(t) = P(t) + c_o P(t-1) + c_o^2 P(t-2) + \ldots\ldots c_o^i P(t-i)$$

The substitution of the parameter α by two other parameters c and c_o and the consequent introduction of non-linearity again provided better fits especially for discharge waves after a dry period.

The optimization of the parameters to match computed and observed runoff is done mathematically using the Marquardt (ref. 7) algorithm. The objective function F is computed as

$$F = \sum_{t=1}^{n} (QO(t) - QC(t))^2$$

where QO is the observed runoff and QC the computed runoff from the model at 3-h intervals.

Model applications

First the parameter values of the Wageningen Model II were optimized for the December 1965 period, when evaporation losses are considered negligible. Fig. 4. shows the observed and the computed hydrographs. For winter periods after 1967 the runoff appears to be smaller than the aerial rainfall, and a proportional reduction was applied to approximate the effective rainfall.

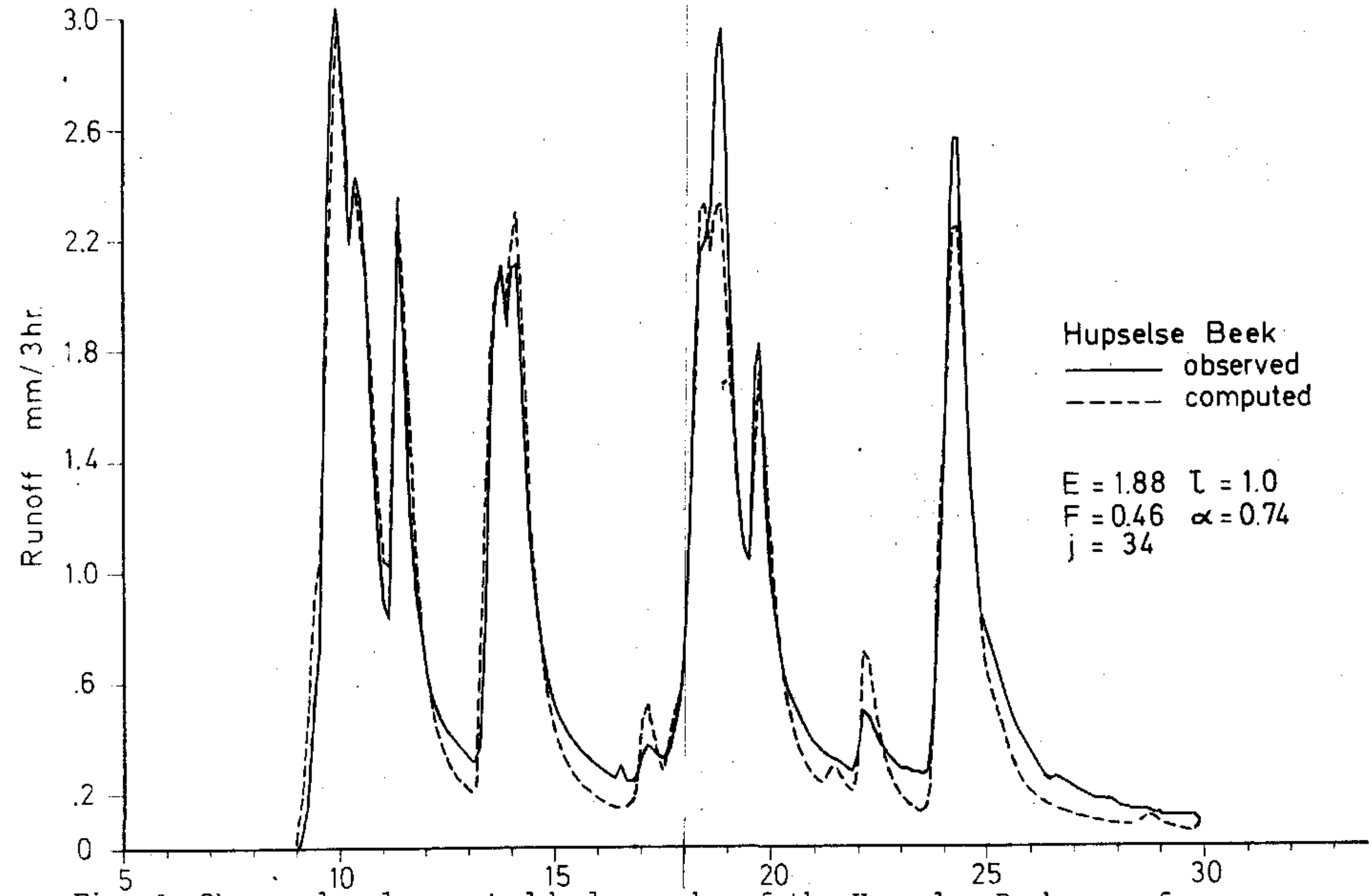

Fig. 4. Observed and computed hydrographs of the Hupselse Beek area for December 1965.

Fig. 5 shows the results for the January 1975 period. The parameters in the Wageningen Model II were again optimized. Comparison of these parameter values with those of the December 1965 period shows a marked decrease of the α value. This implies that a greater part of effectieve precipitation passes through the slow branch of the runoff system.

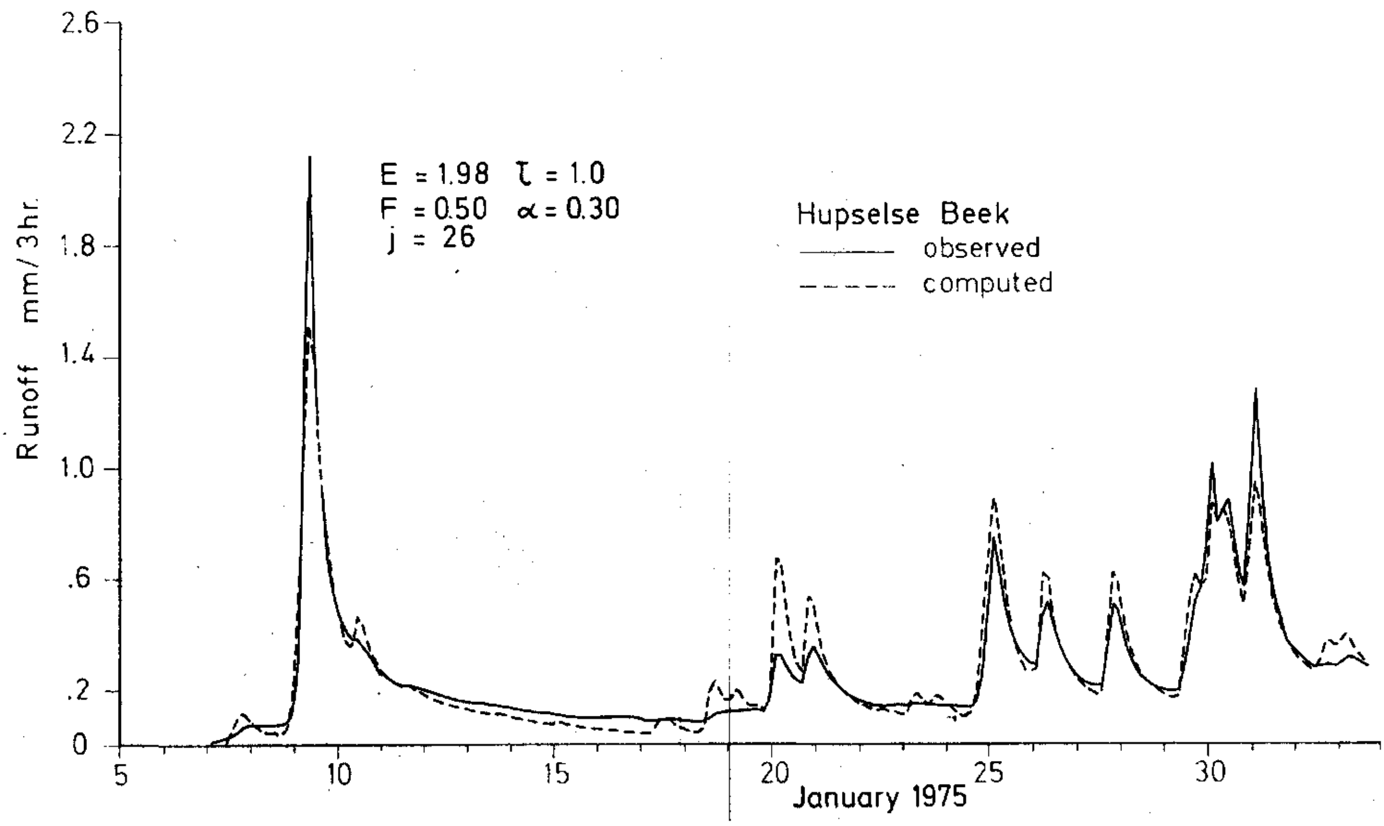

Fig. 5. Observed and computed hydrographs of the Hupselse Beek area for January 1975.

Further a distinct non-linear behaviour is demonstrated by a low calculated peak on January 10th and by an overestimation of early peaks after a dry interval of mid January. The subsequent application of a variable API dependent divider α is demonstrated in Fig. 6. A considerably better reconstruction of the hydrograph is obtained.

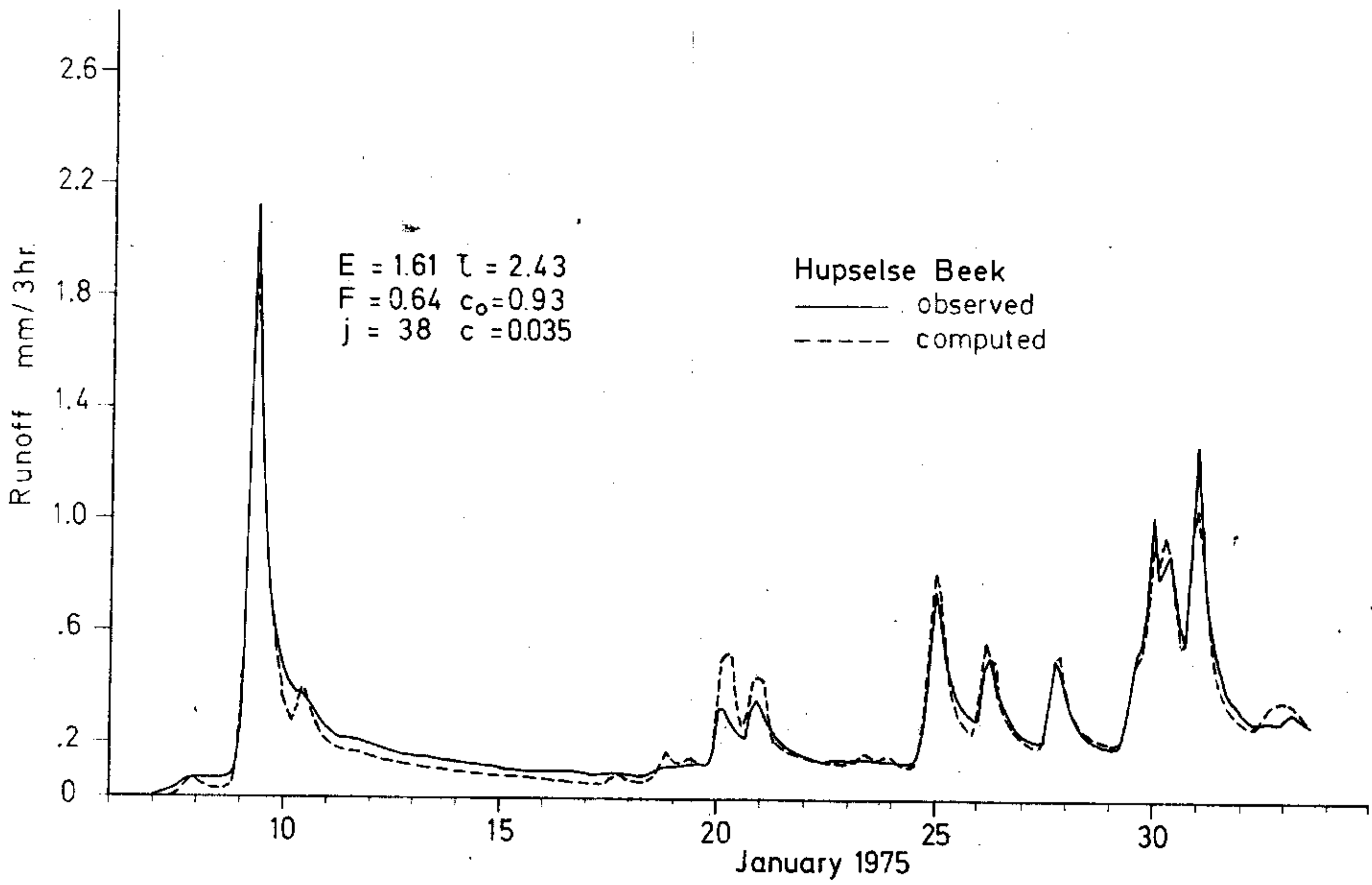

Fig. 6. The observed hydrograph and the computed hydrograph of the Hupselse Beek area for January 1975, using a variable API dependent divider α.

Lastly Fig. 7. shows the result of hydrograph reconstruction when the December 1965 pre-amelioration parameter values are maintained for the post-amelioration January 1975 period. It should be noted, however, that a proportional reduction factor η = 0,75 had to be introduced to balance input and output in the January 1975 period.

Figure 7 demonstrates the difference of overall catchment operation before and after amelioration.

Other pre and post amelioration data of winter periods have been analysed. The results were similar to the ones demonstrated above.

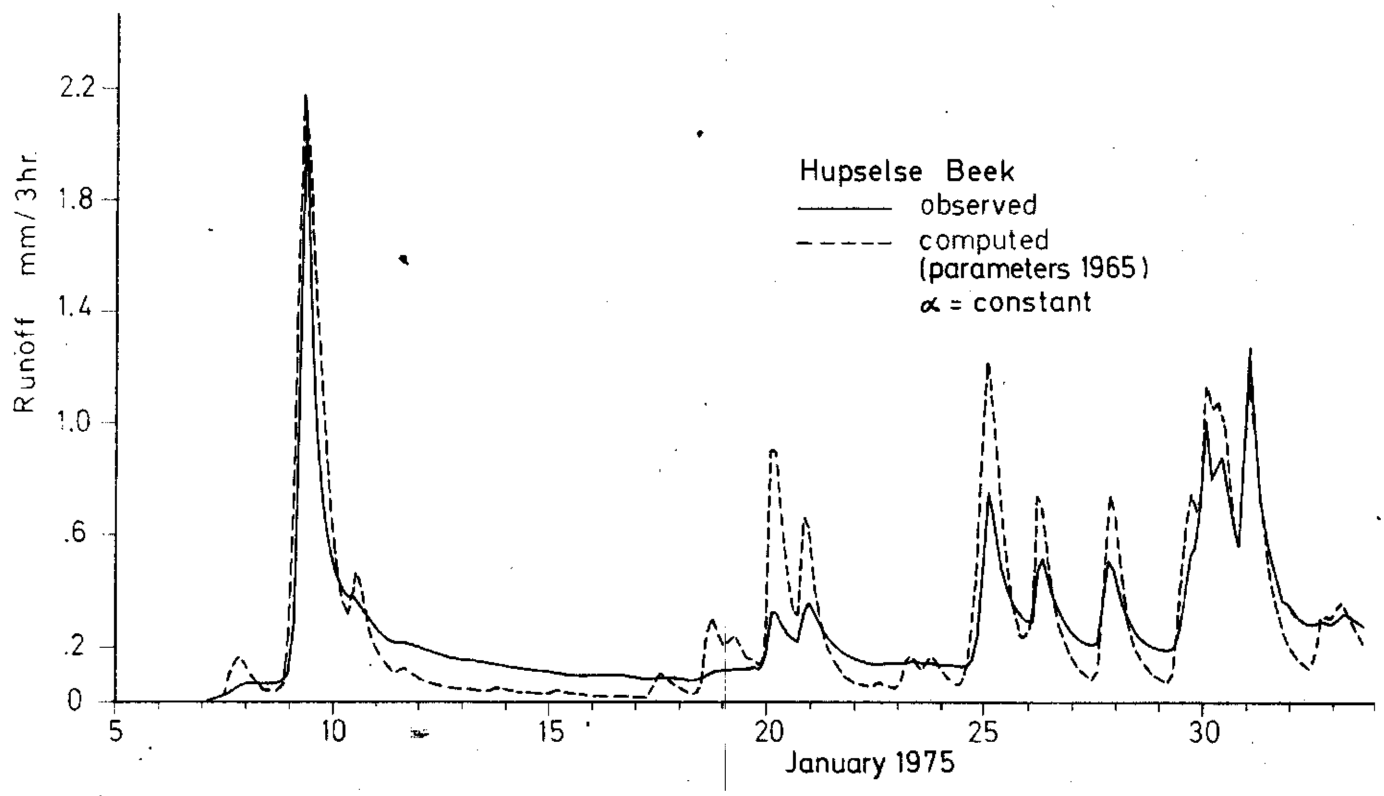

Fig. 7. Comparison of the observed and computed hydrograph of the Hupselse Beek area for January 1975, using parameter values of December 1965.

Conclusions

A general lowering of groundwater-table was found around 1967 when the drainage system in the Hupselse Beek area was improved.

The linear Wageningen Model II provides satisfactory simulations of runoff in pre-amelioration winter periods.

To account for the evident non-linearity of catchment operation in the post-amelioration period, an API dependant divider α, between the fast and slow branch of the Wageningen Model II, had to be introduced. Thus good model performance was obtained.

In the post-amelioration period a considerably higher percentage of effective precipitation passed through the slow branch of the runoff system.

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