II-77

NUMERICAL SIMULATION OF STORM RUNOFF IN A PLAIN AREA WITH HIGH GROUNDWATER LEVEL IN SOUTH-WEST GERMANY

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INTRODUCTION

The investigated area, called 'the Schutter-Unditz Basin', is located in the southern Rhine Valley in West-Germany and covers 210 km^2. It is a flat plain (slope less than 1:1000), geologically consisting of sediments deposited by the Rhine River, and is drained by a widespread system of brooks and ditches. Due to these conditions, not overland runoff but groundwater drainage plays a significant role in the rainfall-runoff process of that area. The groundwater usually reacts very quickly to precipitation. Particularly in case of the frequent storm events its level may rise up to the land surface and the capacity of the drainage channels is likely to get exhausted. Both exhausting channels and groundwater reaching surface cause large inundations, threatening the population and reducing the crop yield of the intensively farmed land.

A computer model has been developed to investigate the flood events and to obtain a basis for determining efficient measures to decrease the flood risk (Wald, Plate et. al.; 1986). The model describes the drainage process and computes the hydrodynamic runoff process in the channel system taking into account the interaction of the groundwater drainage and the water level in the channel.

MATHEMATICAL MODEL

The model consists of two one-dimensional unsteady componemts.

The DRAIN-COMPONENT is based on the Dupuit-Forchheimer assumptions, where one-dimensional flow in a homogeneous isotropic aquifer can be written as

$$T \frac{\partial^2 h(x,t)}{\partial x^2} = n_p \frac{\partial h(x,t)}{\partial t} - R(x,t) \qquad (1)$$

where h is hydraulic head (m), T is the transmissivity of the aquifer (m^2/h), n_p is the drainable pore space (dimensionless) of the aquifer, and R is the recharge rate per unit area (m/hr). Solutions and various applications are given by (Hall&Moench; 1972).

The STREAMFLOW-COMPONENT is based on the solution of the St. Venant equations consisting of the continuty equation (2) and the momentum equation (3)

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q_l \qquad (2)$$

$$\frac{\partial(\rho Q)}{\partial t} + \frac{\partial(\rho Q v)}{\partial x} + gA\frac{\partial(y)}{\partial x} + \rho g A(S_f - S_O) = 0 \qquad (3)$$

where Q is the flow discharge, y the flow depth, A the cross-sectional area, q_l the lateral inflow, v the velocity, ρ the density of water, S_f the friction slope and S_0 the bed slope. This component computes the discharge and the varying water levels in the channels, the latter being the initial conditions for the drain component.

The drain component is externally coupled to the streamflow component. At the end of each time step, the streamflow component calls the drain component, which computes the drainage rate for each reach of the channel network using the given water levels. This drainage rate represents the lateral inflow (outflow) to (from) the channel during the next time step (Freeze; 1972).

If at any time step the channel's water level exceeds the embankments' height, a lateral overspilling rate is calculated for the specific channel's reach and will be substracted from the the channel's discharge.

MODEL APPLICATION AND RESULTS

The model was applied for the first time comprehensively to simulate a disastrous flood event, which occured may 23-30, 1983. The data for the calibration of the model, like groundwater hydrographs, discharge hydrographs and the precipitation records were available, because the area is well-monitored with piezometers, water-level recorders and rain gauges.

According to the rain-records, 122 mm of rain fell over the area betwenn May 23^{rd} and May 27^{th}. The model's calculations yielded a total ammount of $7.6x10^3$ m^3 inundation water, which corresponds very well with estimations based on air photographs taken during these days.

Fig. 1 shows the calculated discharge hydrograph of the Schutter River 16.5 km above its confluence with the Rhine River; it corresponds with the observations undertaken during this time period. Note that the flattened hydrograph's peak (from the 48^{th} until the 60^{th} hour) is caused by overflow of the river upstream.

Based on the calculations of the mentioned storm event, several proposals to decrease the flooding risk of the Schutter-Unditz Basin were investigated. The effects of protection measures and their influence on the runoff process were simulated by using the model. For example, *Fig. 2* shows the original hydrograph and hydrograps that would have resulted from the same event if a storage basin had been constructed on

the upper reach of the Unditz River. It is obvious that the discharge rate of the Unditz River can be reduced significantly, the reduction-rate depending on the controlled discharge out of the basin. But it is also clear to see that a discharge reduction through a storage basin (resulting in a lowering of the water level in the downstream reaches of the channel) increases the groundwater drainage into the channel. So the storage basin's effect will be neutralized to a certain degree. This neutralization increases with the distance of the considered channel section from the storage outlet. The hydrographs shown in *Fig.2* represent the calculation results for a section of the Unditz River 1.5 km below the assumed storage basin. It is apparent that even if a complete closure of the storage outlet were implemented, the discharge at this section could not be reduced by more than about 50%.
The calculations of various drainage-runoff situation were simulated assuming different kinds of protection measures. They resulted in a proposal for an optimal system of measures, including the above-mentioned storage basin, an artificial flood plain leading to the Rhine River, raising of the channel's embankments along specific reaches of some channels, and designating of some flooding areas near some extensively used land; see {Bronstert; 1986}.

CONCLUDING REMARKS

The introduced model is of significant importance for solving practical problems of rural hydrology, where the runoff process is highly dependent on groundwater interactions. In the case of the Schutter-Unditz Basin it led to optimal planning of a protection system for the area.
Until now the computer model still neglects the effects of the unsaturated zone on the runoff process. It is the author's intention to include them in the model.

ACKNOWLEDGEMENT

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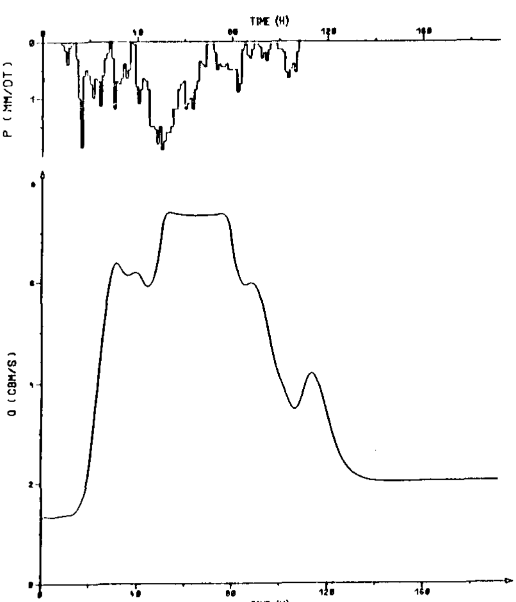

Fig. 1: Calculatrd hydrograph of the Schutter River 16.5 km upstream its confluence with the Rhine River (event of may 23-30, 1983)

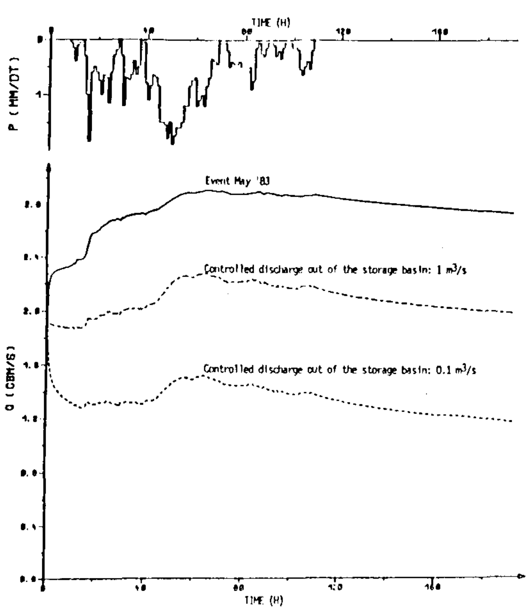

Fig. 2: Calculated hydrographs of the Unditz Piver (km 11'500) for different situations (original hydrograph of May 23-30 and hydrographs due to an assumed construction of a storage basin 1.5 km upstream)