The combined surface and groundwater flow model
MOGROW applied to the Hupselse Beek drainage basin

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Abstract In the Netherlands shallow groundwater tables prevail in many parts. The use of a combined groundwater and surface water model is necessary to predict the effect of certain measures on such complex systems. Therefore the model MOGROW was developed to simulate the flow of water in the saturated zone, the unsaturated zone and the surface water. The model is physically-based and therefore suitable to be used in situations with changing hydrological conditions. Verification of the MOGROW model was carried out in the Hupselse Beek area, an experimental drainage basin of 6.5 km². Calculated and measured groundwater levels and discharges were compared. The representation of peak discharges for such a small basin was rather difficult. The process of preferential flow was included into the unsaturated part of the model in order to give discharges closer to reality.

INTRODUCTION

The model MOGROW (MOdelling GROundwater flow and the flow in surface Water systems), has been developed to give solutions for regional water management problems. In the Netherlands, in particular, the relation between the required hydrological situation for agriculture and nature conservation is difficult to quantify. Other situations which occur are extractions for water supply or the management of surface water. For these type of questions it is necessary to simulate the flow of water in the saturated zone, the unsaturated zone and the surface water system in an integrated manner. The aim was to simulate the rather complex processes involved in such a way that it is sufficiently accurate without requiring too much input data and computer time. The model MOGROW is physically-based and can therefore be used in situations with changing hydrological conditions.

The combined surface and groundwater flow model MOGROW was verified in the Hupselse Beek drainage basin (Querner, 1993). This paper describes the schematization of the region, the important input data and significant results of the simulations. The SHE model (Abbott et al., 1986) has also been applied to the Hupselse Beek for four events, each lasting between 4-9 days (Lumadjeng & Gardner, 1989). The capabilities of both models will be briefly discussed.

THE COMBINED SURFACE AND GROUNDWATER FLOW MODEL
MOGROW

The hydrological model MOGROW consists of the surface water flow model SIMWAT
and the regional groundwater flow model SIMGRO. The model SIMWAT (SIMulation of flow in surface WATer networks) describes the water movement in a network of water courses, using the Saint Venant equation (Querner, 1986). The model SIMGRO (SIMulation of GROundwater flow and surface water levels) simulates regional groundwater flow in relation to drainage, water supply, sprinkling, subsurface irrigation and water level control (Querner, 1988).

**Surface water flow**

In the Netherlands the surface water system is often a dense network of water courses. It is not feasible to explicitly account for all these water courses in a regional computer simulation model. The surface water levels in the major water courses are important for the flow routing and to estimate the drainage or subsurface irrigation. Therefore, in SIMWAT the major water courses are modelled explicitly as a network of sections; the other water courses are treated as reservoirs and connected to this network. Also the model includes special structures such as weirs, pumps, culverts, gates and inlets, necessary for the proper modelling of all water movements within a certain region. The model was set up so that it could be combined with a groundwater model.

**Groundwater flow**

To model regional groundwater flow, as in SIMGRO, the system has to be schematized geographically, both horizontally and vertically. Land use is schematized in the first aggregation level. The second aggregation level deals with sub-regions describing moisture vertically in the unsaturated zone. The third level covers various subsurface layers for saturated groundwater flow by means of a finite element network (Fig. 1).

The unsaturated zone is considered by means of two reservoirs, one for the root zone and one for the subsoil (Fig. 1). If the equilibrium moisture storage for the root

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*Fig. 1 Schematization of water management in the model MOGROW. Main feature is the integration of saturated zone, unsaturated zone and surface water systems within a sub-region.*
zone is exceeded, the excess water will percolate to the saturated zone. If the moisture storage is less than the equilibrium moisture storage, then the result will be an upward flow from the saturated zone. The height of the phreatic surface is calculated from the water balance of the subsoil, using a storage coefficient which is dependent on the depth of the groundwater level below the soil surface. The unsaturated zone is modelled one-dimensionally per sub-region and land use (Querner & Van Bakel, 1989). Special processes were included in the unsaturated zone model, i.e: surface runoff, perched water tables, hysteresis and preferential flow.

Evapotranspiration is a function of the crop and moisture content in the root zone. The measured values for net precipitation and potential evapotranspiration for grassland and woodland must be available. The potential evapotranspiration for other crops or vegetation types are derived in the model from the values for grassland, by converting with known factors. The potential evapotranspiration for a pine forest is calculated as the sum of transpiration and interception. The model allows for a simulation of sprinkling according to a rotation scheme, depending on the water requirements of a crop.

The often dense network of water courses, related to size and density, is important for the interaction between surface and groundwater. The smaller water courses are assumed to be spread evenly over a finite element or sub-region. These water courses are primarily involved in the interaction between surface water and groundwater: commonly called the secondary water courses, the tertiary water courses and the trenches. A so-called channel system can be present as well, but in specific nodes. It should represent the larger channels, also considered in the surface water model. In this way four drainage sub-systems are used in the model for the interaction between surface and groundwater. This interaction is calculated for each sub-system using a drainage resistance and the difference in water level between groundwater and surface water (Ernst, 1978).

Link SIMWAT-SIMGRO

The geographical link between the modules is that a nodal point of the finite element grid in the groundwater module is assigned to a nodal point of the surface water module. The model MOGROW has a groundwater part that reacts slowly to changes, plus a surface water part with a quick response. Therefore both parts were given their own time step. The result is that the surface water module performs over several time steps during one time step of the groundwater module. The groundwater level is assumed to remain constant during that time and the interaction between groundwater and surface water is accumulated using the updated surface water level. The next time the groundwater module is called up the accumulated drainage or subsurface irrigation is used to calculate a new groundwater level.

APPLICATION OF MOGROW IN THE HUPSELSE BEEK BASIN

Study area and schematization

The Hupselse Beek drainage basin is situated in the east of the Netherlands near the
The area covers 6.5 km$^2$ and lies between 24 and 33 m above NAP (reference level in the Netherlands). The average slope of the area is about 0.8%. The river flows through a wide valley with a relatively steep gradient of 0.06% to 0.25%. Land use is predominantly agricultural; about 70% is pasture, 21% is arable land (mainly maize) and 6% woodland. Within the basin the main stream is 4 km long and has seven small tributaries varying in length between 300 and 1500 m (Fig. 2).

For the model MOGROW the groundwater system needs to be schematized by means of a finite element network. The network, comprising 283 nodes spaced about 200 m apart, is shown in Fig. 2. For the surface water module only the major water courses present were considered, requiring 50 nodes, 5 typical cross sections and 21 weirs.

The physical soil properties for the unsaturated zone module were obtained from Wösten et al. (1985). Six physical soil units were distinguished. For each physical soil unit the actual characteristics of the unsaturated zone, i.e. upward flux, storage coefficient and equilibrium moisture storage of the root zone, were calculated using the model CAPSEV (Wesseling, 1991). The basin was subdivided into 61 sub-regions using the physical soil properties and the layout of sub-catchments (level for modelling the unsaturated zone). Each sub-region considered five land uses: pasture, maize, cereals, sugar beet and woodland. For the saturated zone the transmissivity varied between 10 m$^2$ day$^{-1}$ in the east to 350 m$^2$ day$^{-1}$ in the north-west.
The drainage characteristics of the basin can be found by plotting the depth of the groundwater against the discharge. The result, representing an average depth from 9 observation points for the period 1981-1985, is shown in Fig. 3. Line I in this figure can be regarded as the regional flow component (base flow), which is the drainage from the main stream. Line II represents the flow to the main stream and its tributaries (secondary system) and line III the flow to the smaller ditches and to the subsurface drainage system (tertiary system). Points lying below line III indicate discharges other than from drainage, such as surface runoff. Another cause may be a variation in specific discharge within the basin. The average drainage resistance derived from Fig. 3 is approximately 450-600 days for the secondary system (difference between line I and II) and 70-90 days for the tertiary system (difference between line II and III). The procedure described here to estimate drainage resistances, is only allowed when the basin is homogeneous.

![Fig. 3 Relation between specific discharge and the average depth of the groundwater level to estimate the drainage characteristics (data from 9 observation wells from 1981-1985).](image)

**Comparison of calculated and observed groundwater levels and discharges**

Observations of groundwater levels and discharges were used to analyse the capabilities of the model MOGROW. The moisture storage in the root zone and the reduction in evapotranspiration (both measured and calculated) were compared as well (Querner, 1993). All computations were done with daily meteorological data for 1981. The time step for the groundwater module was one day and for the surface water module half an hour. It took approximately 30 minutes of CPU time to simulate one year on a VAX 4200.

**Groundwater levels** The mean standard deviation (root mean square) was used as a measure of the agreement between the observed and calculated levels. The observed groundwater level is for a certain location, whereas the calculated level is an average for the area associated with a nodal point. The groundwater hydrographs for two locations...
are shown in Fig. 4. Node 53 uses observations taken once in 14 days, but daily observations are used for node 146 (Assink meteorological site). The differences between calculated and measured groundwater levels are quite small, but increase after short periods of heavy rainfall (summer 1981 - Fig. 4). The peaks calculated are lower than observed, partly because the comparison is between point values (observed) and average values (calculated). The differences in terms of standard deviation are given in Table 1. The calculated and observed groundwater levels compare well, but two points, nodes 177 and 49, have a standard deviation greater than 0.30 m (Table 1). These high values suggest that either the input data are wrong or the schematization is inadequate in the vicinity of these two points. Six points have a deviation of 0.20 m and less. Deviations of less than 0.20 m are regarded from experience as good agreement, because in those cases the calculated groundwater levels show the same reaction in time as observed. Also given in Table 1 are the minimum and maximum differences that occurred within the calculation period, and the average difference. For seven observation points the average difference is less than 0.15 m.

The calculated variation in groundwater level is less than observed. This is partly attributable to the comparison being between observed point values and calculated average values. The other possible cause is that the storage capacity in the unsaturated zone is overestimated.

![Graph](image-url)

**Fig. 4** Calculated and observed water table for 1981 (nodes 53 and 146 are shown in Fig. 2). Daily observed groundwater levels were used for node 146 (Assink met. site).
Table 1 Mean standard deviation (root mean square) together with minimum, maximum and average differences in groundwater levels for 1981 (for location of nodal points see Fig. 2).

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<th>Mean deviation (cm)</th>
<th>Min (cm)</th>
<th>Max (cm)</th>
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**Discharge** Preliminary simulations with the model MOGROW revealed that the calculated discharges remained relatively low in summer after heavy rainfall, while the observed discharge had an appreciable peak. This might be the effect of surface runoff, interflow, hysteresis, preferential flow, or a combination of these. To analyse the observed deficiencies, calculations were done including each of these aspects singly (Querner, 1993). Including the process of preferential flow in the unsaturated zone gave discharges closer to reality. The simulated hydrograph, including preferential flow in the unsaturated zone, is shown in Fig. 5. The schematization of preferential flow process is considered simply as a fraction of the net precipitation going directly to the groundwater or is intercepted by subsurface drains. The remainder of the precipitation flows into a reservoir considered to represent the root zone.

For the analysis of the outflow hydrograph a differentiation was made into mean daily peak flows (\(> 2 \text{ mm day}^{-1}\)) and the low or base flow (\(< 2 \text{ mm day}^{-1}\)). Comparison of the peak flows gave a deviation of 1.77 mm day\(^{-1}\) occurring in 29 days in 1981, which is an appreciable disparity. The duration of one flood is also very short; only a couple of days at the most. Because the calculations were based on a time step of one day for the saturated and unsaturated zones, this difference is acceptable. It is more important to compare the difference in the peaks. The low flow conditions (\(< 2 \text{ mm day}^{-1}\)) compare much better. The deviation of 0.23 mm day\(^{-1}\) can be regarded as sufficiently small. The base flow condition as shown in Fig. 5 (occurring June, August and September 1981) has an average difference of 0.06 mm day\(^{-1}\), which is reasonable.

**Comparison with the SHE model**

The SHE model has been applied to the Hupselse Beek for rainfall periods of short
duration (Lumadjeng & Gardner, 1989). The model was calibrated with the measured hydrograph, but several combinations of different parameters were possible to simulate this hydrograph. Problems were encountered in running the model with the initial input data. The results also showed a remarkable amount of overland flow, which was not found in the field. The interaction between groundwater and surface water in SHE is modelled as one system, being the larger water courses. Therefore the artificial (sub­-surface) drainage system and the small water courses could not be included in this model. For simulations with MOGROW it is necessary to start the calculations well before the actual period. The conditions prior to the event (e.g. the retention of rainfall within the basin) greatly influence the results. Initial groundwater levels and moisture storage in the unsaturated zone will control the results, as was the case with the SHE application for Hupsel. For instance, by changing the assumed groundwater levels at the start of the run, an outflow hydrograph which matches the observed hydrograph can easily be produced (see for instance Bathurst, 1986).

CONCLUSIONS

The surface water model SIMWAT and the groundwater model SIMGRO were combined into one hydrological model MOGROW. The direct link between the unsaturated zone, the saturated zone and the surface water, enables the model to predict all the physical processes within these systems, such as drainage, capillary rise and seepage in an integrated manner.

The model verification included the comparison of moisture storage in the root zone and the reduction in evapotranspiration (Querner, 1993). The small differences found between these measured and computed values shows that the unsaturated flow processes are modelled accurately enough in this zone.
In a small drainage basin, such as the Hupselse Beek area, groundwater levels and discharges respond very quickly. The computed groundwater levels compare well with the observed levels. The simulation of the outflow hydrograph is very sensitive to variations in the input data and to the processes considered in the unsaturated zone. The simulations in Hupsel reveal that preferential flow cannot be ignored in hydrological models. This process results in less retention of water in the unsaturated zone. Preferential flow included in the model gives higher groundwater levels and higher peak discharges, which agree better with the observed values.

REFERENCES


