COUPLED GROUNDWATER-SURFACE WATER MODELLING

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Abstract

The relationship between rainfall and outflow on a hydrological system consisting of one or several surface basins in connection with deep aquifers is modelled by the mean of a conceptual representation based on the spatial discretisation of the physical parameters and mechanisms of water flow.

Four FORTRAN codes which are run in sequence take successivly in account the definition of the physical characteristics of the system, the water balance in the soil, the flow in the unsaturated zone and eventually the transfer of both surface water and groudwater coupled at the rivers.

This is a report on the results of a cooperation between France and Québec, where the National Institute of Scientific Research - Water of Québec, ORSTOM, and the Paris School of Mines worked together on the theme of joint modelization of surface and groudwater flow in a hydrologic system.

The model is based on a conceptual representation of the different links in the water cycle, which describe the relation between rainfall and outflow in a watershed, and it associates a hydrologic model (Girard, Morin, Charbonneau 1972) with a multi-layer hydrogeologic model (Ledoux 1975). These models have already been tested separately on a number of real cases and made compatible to each other by appropriate spatial discretization.

The water cycle is made up of numerous complex mechanisms which interact with each other. The fundamental characteristic of the model is, above all, to decompose the main features of the hydrologic system into independent stages, the results of which can be controlled separately. In this way one combines the obvious advantages of a global simulation of the hydrologic system with the possibility of verifying the validity of certain internal mechanisms which are often treated separately because they belong to distinct and specialized fields in water sciences.

The principle underlying the conceptualization is to generalize the multi-layer schematic representation, well-known in hydrogeology. The model takes into account : on the one hand, an upper layer, said to be the surface layer, where the available water is divided into surface water and infiltration, and where the surface transfer takes place, and, on the other, a variable number of deep layers, sites of groundwater flow, possibly interconnected, representing the vertical succession of aquifer levels which may be found in hydrogeology.

Each of these layers is then discretized into meshes to which the different parameters of the system are attributed and on which the transfer of water occurs.

At present, the modelization consists of four FORTRAN program intended for use in sequence (Ledoux 1980).

1) The GEOCOU program organizes both the spatial discretization of the underground medium and the drainage tree of the surface basins according to the physiographic data.

The initial discretization consists of a network of meshes 8a square. Locally this grid may be subdivided into submeshes 4a, 2a or a square. The discretization of certain sectors of the aquifer and of the surface layer may thus be gradually refined, if necessary, as seen in the example, fig. 1.

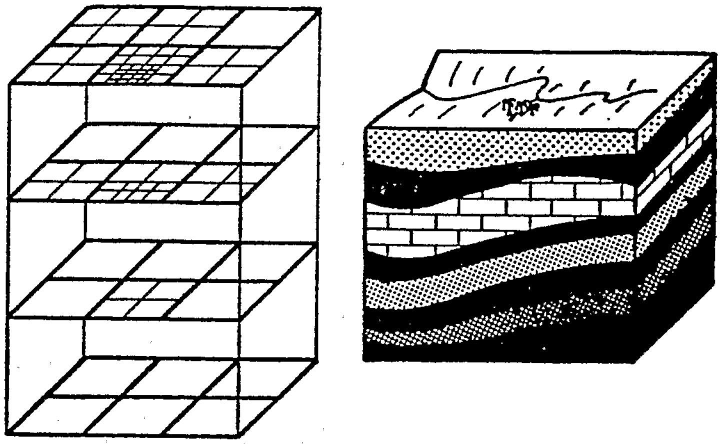

Fig. 1 : Principle of the spatial discretization.

The drainage network on the surface is made up of one or several tree-like ramifications, which are defined by the piece of data for each mesh of the surface layer relating to a unique drainage direction. This network is then divided into two categories where a distinction is made between the main hydrographic network and the zones of pure runoff.

Thus, the surface domain is broken up into, on the one hand, individual watersheds, each with ist oulet at the basis of one of the trees in the hydrographic network and, on the other hand, sub-basins marking the limits of every zone of pure runoff, which has a mesh of the main hydrographic network as its outlet.

Finally, an average drainage height as well as the areas attributed to each type of soil are introduced into each mesh in accordance with the physiographical characteristics of the watersheds. These soil types will subsequently give rise to further distinctions, when the calculations are made.

2) The MODSUR program calculates the water balance for each mesh of the surface domain as a function of time and of the chosen soil categories.

Precipitation is introduced with a regular time step on a group of zones with homogeneous rainfall measurements, defined on the surface grid in accordance with the regional characteristics provided by the measurement network.

The water balance is established by using the same time step as above for each soil type and each pluviometric zone on the basis of the depth of rainfall P, the potential evapotranspiration EPT and the state of water reserves R in the soil reservoir, as shown in fig. 2.

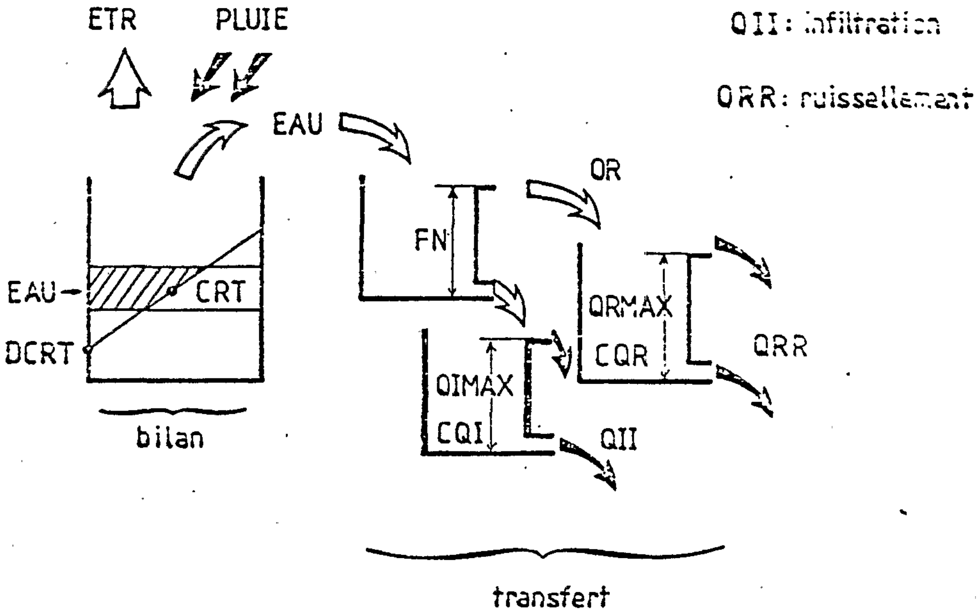

Fig. 2 : Principle of the calculation of water balance in the soil.

Finally, the quantity EAU available after evapotranspiration is divided into an infiltration quantity QII assigned to each surface mesh and a runoff quantity QRR assigned to each mesh of the main hydrographic network.

3) The NONSAT program computes the transfer of the infiltration calculated above toward the deep aquifer by treating the unsaturated zone as a succession of N linear reservoirs emptying gravitationally one into the other, each with the same time constant for emptying. The assigning of the number of reservoirs and the emptying coefficient is done on each surface mesh according to the thickness and the permeability of the unsaturated zone.

4) Finally, the MODCOU program couples the transfer of the surface waters which flow into the streams with the groundwater which flows into the aquifers represented by the different layers of the underground domain.

The necessary data, discretized according to the grid, concern the hydrodynamic parameters of the aquifers : the withdrawal and recharge of water in the system, the drainage heights of the underground outlets, the characteristics of the exchanges between aquifers and streams.

The simulation is done by repeating three operations with a computation time step defined as a multiple or submultiple of the one used in establishing the water balance.

First, one calculates the underground transfer by numerically integrating the flow equations for porous media discretized over the underground domain. Then, the flow exchanged between the shallow aquifers and the streams is evaluated, taking into account the differences between the water level in the stream and the piezometric head. At last, the water volumes found in the streams are run out by isochronisms all the way to the outlets.

The model which has just been briefly described has been applied practically to French watersheds of various types and spatial scales (Ledoux 1980, Girard, Ledoux, Villeneuve, 1982).

This model, called the "coupled model" addresses itself to an essential part of the water cycle and thus constitutes a tool for putting together a comprehensive picture of the water resources in a hydrologic system. The use of the conceptual approach makes this model suitable for receiving the quantitative information which may be acquired concerning a basin and turns it into a simulation tool capable of taking into account external changes to which the system may be subjected, e.g. development projects.

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