ABSTRACT. This chapter deals with the joint modeling of surface and groundwater flows by presenting and describing the MC model. The purpose of this deterministic physically-based model is to simulate the behavior of available water resources for one or several watershed. The model integrates surface flow, streamflow, flow in the unsaturated zone, groundwater flow and the interactions between rivers and water tables. Its formulation and its structure, especially its nested square meshes of variable sizes, give a great deal of flexibility to the model; this facilitates adaptation to variable modeling scales and to a wide range of geological, geographical and climatological conditions. An application of the MC model on the Caramy watershed (France) is presented.

INTRODUCTION

One of the earliest and simplest hydrological models is the quantitative expression of flood magnitudes in relation to rainfall and watershed area, known as the rational formula (Mulvaney, 1851). Since then, further progress in basic and applied hydrology has contributed to a better understanding of the terrestrial components of the hydrological cycle. This, in turn, supported by an increase in computation capabilities, has permitted the development of more realistic hydrological models.

Today, many types of deterministic physically based watershed models are reported in the literature. These models can be divided into two main categories: streamflow-overland flow models and groundwater flow models. In the surface flow models, the groundwater flow is treated only in part and often taken into account with a lumped parameter. This category is valid where groundwater does not constitute an important part of the overall flow domain. The Stanford Watershed Model (Crawford and Linsley, 1966), the SSARR model (US Army Corps of Engineers, 1975), the CEQUEAU model (Morin et al., 1981) and MDOR (Villeneuve et al., 1984) are a few examples of this type of model. Fleming (1979) presents a good review of many surface models.
The models of the second category are used where groundwater resources dominate. In groundwater models, surface and stream flows are treated as boundary conditions and may even be completely disregarded. There are a great many widely used groundwater models (Bachmat et al., 1980), e.g. : the Prickett and Lonquist model (1971), the model by Trescott et al. (1976) and Newsam (Ledoux and Tillie, 1980, Ledoux, 1975).

However, there is a type of watershed where surface and groundwater flows are closely linked. Here, both the surface and the groundwater and their interactions play a significant part and if they are to be managed efficiently, they must be studied together. It is therefore necessary to use a hydrological model that realistically simulates the combined use of the surface water and the groundwater and how they interact. Such a model has the advantage of taking into account all recharge to the hydrological basin as well as the possible interactions between the various terrestrial components of the water cycle. This type of model is an efficient tool for representing the different components of the water budget and has proved very useful in dealing with regional water resource problems related to surface and groundwater (Hansen and Dyhr-Nielsen, 1983, Morel-Seytoux et al., 1980, Morel-Seytoux et al. 1981). It can for example, make it possible to study the effects on surface water flow conditions of withdrawal in aquifers, particularly during periods of low water (Miles and Rushton, 1983, Refsgaard and Hansen, 1982b, Besbes et al., 1981, Morel-Seytoux et al., 1980, 1981).

This article discusses the joint modeling of surface and groundwater flow by presenting the MC model. First, we examine the general characteristics of this type of model and then, we describe the structure and formulation of the MC model. The letters MC stand for "Modèle Couplé", coupled model, which is its name in French.

1. INTEGRATED FLOW MODELS

1.1. Characteristics

Obviously, the model cannot represent all the mechanisms involved in the hydrological cycle and, to avoid undue complexity, must simplify reality by integrating only its principal components. The aim of the modeling is to estimate the total flow at the outlet of the watershed. It is recognized that total flow is a combination of three processes : surface flow, interflow and base flow (fig. 1). We are also interested in the possible interactions between these hydrological processes and the system's environment (fig. 2), exchanges with the atmosphere, surface outflows, lateral contribution by surface water, exchanges between aquifers and exchanges between the non-modelled surface areas and aquifers.

However, in addition to the integration of the main processes and relations, the model should, for economic and operational reasons, satisfy particular requirements (Freeze and Harlan, 1969, Jacquet, 1971). First, the model must take into account the system's physical properties. The model's representation of the system must be based on a maximum amount of geological, geomorphological, topographical and physiographical infor-