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AFFDEF: A spatially distributed grid based rainfall–runoff model for continuous time simulations of river discharge

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Abstract

This paper aims to present a rainfall-runoff model that was recently released into the public domain via the World Wide Web. The model, AFFDEF, is spatially distributed (grid based) and performs continuous time simulations of river flows at any time step and at any location in the catchment. It does not, however, account for snowmelt. Conceptual and physically based schemes are employed for simulating the rainfall–runoff transformation. AFFDEF's main strength is its computational efficiency, which allows the model to perform long simulation runs (e.g. thousands of years at hourly time step). Furthermore, AFFDEF does not require extensive information in terms of historical hydrological data or geomorphology of the contributing area. It may, therefore, represent a powerful tool for performing hydrological simulation studies. The model code, written in FORTRAN programming language, provides a user friendly and ready to use tool that runs on personal computers, as well as UNIX systems. We believe that AFFDEF may represent an easy model to use and attractive instrument for hydrological applications where long simulation runs of river flows are needed at different locations of the catchment. Of particular interest is the possibility to generate river flows data in ungauged cross-sections of the watershed.

Keywords: Rainfall–runoff model; Continuous simulation; Grid based model; River flow; Calibration

Software availability

Name of the software: AFFDEF
Developer and contact address: Greta Moretti, Ingenieurbüro Winkler und Partner GmbH, Schlossstrasse 59a, D-70176 Stuttgart, Germany, Tel.: +49 711 6698727, fax: +49 711 6698720, E-mail address: moretti@iwp-online.de. Alberto Montanari, Faculty of Engineering, University of Bologna, Via del Risorgimento, 2, I-40136 Bologna, Italy, Tel.: +39 051 2093356, fax: +39 051 331446, E-mail address: alberto.montanari@mail.ing.unibo.it
Year first available: 2004
Hardware required: IBM compatible personal computer
Software required: FORTRAN compiler
Program language: FORTRAN
Program size: depending on the dimension of the investigated catchment and the length of the simulation (for instance: the executable file is 760 kb considering a matrix for the Digital Elevation Model of 84 rows × 118 columns and a length of simulation of 20 000 temporal steps)
Availability and cost: Software available at http://www.costruzioni-idrauliche.ing.unibo.it/people/alberto/affdef.html, download free of charge

1. Introduction

Spatially distributed physically based rainfall–runoff models are nowadays increasingly used for scientific and technical purposes, impact assessment studies, prediction in

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ungauged catchments and investigation of the spatial variability of hydrological state variables. In fact, the application of this type of model, is made easier by the increasing availability of computer power and the steadily development of geographic information systems and remote sensing techniques, which help to handle the bulk of data needed as model input. Nevertheless, the application of spatially distributed, physically based models, such as SHETRAN (Ewen et al., 2000), MIKE SHE (Refsgaard and Storm, 1995) or CASC2D (Ogden, 1997), to large catchments, is restricted by the vast amount of high quality and fine resolution data needed, in order to reliably model the physical processes taking place in the catchment (Beven, 1989).

Alternative approaches to the rainfall–runoff modelisation have, therefore, been developed, which represent physical processes with far less detail but still give a spatial distributed representation of the catchment. These models were developed to simplify the simulations of practical case studies where a detailed representation of the processes involved in the catchment is not necessary. They are distributed models where some (or all) of the hydrological processes are modelled using conceptual schemes.

Examples of these alternative models, include the SLURP (Simple LUmped Reservoir Parametric) model (Kite, 1978), which subdivides the catchment into units of different land cover and other sub-units (Grouped Response Units). It is a distributed conceptual model, which has been primarily designed in order to make use of remotely sensed data. It has been applied in climate change studies.

Another alternative model, TAC^D (Uhlenbrook and Sieber, 2005), is an example of a raster based conceptual model. The core of the model is a process-oriented runoff generation routine based on experimental findings, including tracer studies (Uhlenbrook et al., 2002).

Further attempts to simplify the rainfall–runoff modelling approach while maintaining a spatial description of the catchment have produced a class of semi-distributed models that make use of a distribution function to represent the spatial variability of runoff generation (Croke et al., 2006).

TOPMODEL (Beven and Kirkby, 1979) is one such model. It predicts the dynamics of the contributing areas based on the pattern of the soil topographic index. It has been applied in many practical hydrological studies such as estimation of flood frequency distribution, by continuous simulation, in ungauged catchments (Blazkova and Beven, 1997, 2002, 2004).

The HBV model of Lindström et al. (1997), whose early applications date back to the 1970s (Bergström and Forsman, 1973), belongs to the class of semi-lumped models. The authors tried to develop a model that covered the most important runoff generating processes by using the most simple and robust structure possible (Bergström, 1995). The HBV model has been applied, in several countries, for studies concerning real time forecasting, climate change impact assessment and simulations in ungauged basins.

One of the most widely used rainfall–runoff models in Australia is the Australian Water Balance Model (AWBM, Boughton, 2004; Boughton, 2006). It consists of a conceptual model that simulates the spatial variability of the saturation overland flow by means of the conceptual basis of the Antecedent Precipitation Index (API) model. In detail, a bucket with a particular storage capacity is assigned to each portion of the catchment with different storage capacity. The rainfall is abstracted until the bucket is filled, and then all rainfall becomes runoff.

The above examples show that distributed conceptual (or mixed conceptual physically based) models can be a useful tool for the solution of several practical problems related to water resources, since hydrological analyses can be performed that would not be possible by using "pure" lumped models. Lumped models are not capable of evaluating the effects of local land use changes (such the reduction of the permeability of urbanised areas, or the deforestation of skiing resorts) and cannot simulate river flows in internal river sections. Distributed models have the advantage, once they are calibrated by using river flow data observed at a selected site, of being able to simulate the flows in any location of the river network. Moreover, the use of conceptual schemes allows simulations that would be demanding, in terms of data requirement and computational resources, if fully physically based models were utilised.

The purpose of this article is to present the continuous simulation, spatially distributed (grid based), rainfall–runoff AFFDEF model that was developed at the University of Bologna and has recently been made available on the World Wide Web. It may be downloaded at the web site http://www.costruzioni-idrauliche.ing.unibo.it/people/alberto/affdef.html. The code is written in the FORTRAN programming language and is fully commented; it can run on a personal computer as well as a UNIX system, with a user-friendly interface.

The following requirements were determined: (a) the model simulations should be reliable in making predictions for ungauged or scarcely gauged catchments or where little information about the contributing area is available; (b) the model should allow a spatially distributed description of the geomorphological characteristics of the catchment in order to generate river flow data at any cross-section of the river network; (c) the model should perform reliable simulations of the river flows even when only short records of historical data are available; (d) the model should have some physical basis in order to constrain the range of values of some parameters by means of in situ measurements or physical reasoning and in order to decrease parameter uncertainty; (e) the model should be computationally inexpensive in such a way that long simulation runs could be performed at short time steps in a reasonably limited time, even for medium size basins.

The proposed rainfall–runoff model belongs to the class of distributed conceptual models because it allows a spatially distributed description of the catchment combined with the use of conceptual and physically based schemes for modelling hydrological processes at the grid scale. As the listed requirements show, the model has been conceived to be used for practical purposes and to be applicable to a wide spectrum of real world case studies.

The description of the model is given in the following section together with the description of the data needed to