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Experience with Field Testings of SHE on Research Catchments

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The development of the European Hydrologic System (SHE) has now reached such a stage, that it is ready for practical applications. Extensive field testings and associated developments have been carried out in recent years. The testings have included the complete system as well as the individual components. Particular emphasis has been given to the development and testing of the soil water flow model.

The paper demonstrates results from a field testing of SHE on the Wye Catchment in Britain, as well as examples of applications on small experimental catchments in Germany and New Zealand.

Introduction

The SHE is developed from the non-linear partial differential equations for the processes of overland and channel flow, unsaturated and saturated subsurface flow. These equations are solved by finite differences techniques. The system is completed by descriptions of snow melt, interception and evapotranspiration.

Since it is not yet economically viable to develop a system fully three-dimensional in space which allows the required accuracy of discretization in both horizontal and vertical planes, the SHE has been rationally simplified by assuming that in the unsaturated zone vertical flow is, on most slopes, far more important than lateral flow. This results in a model structure in which independent one-dimensional

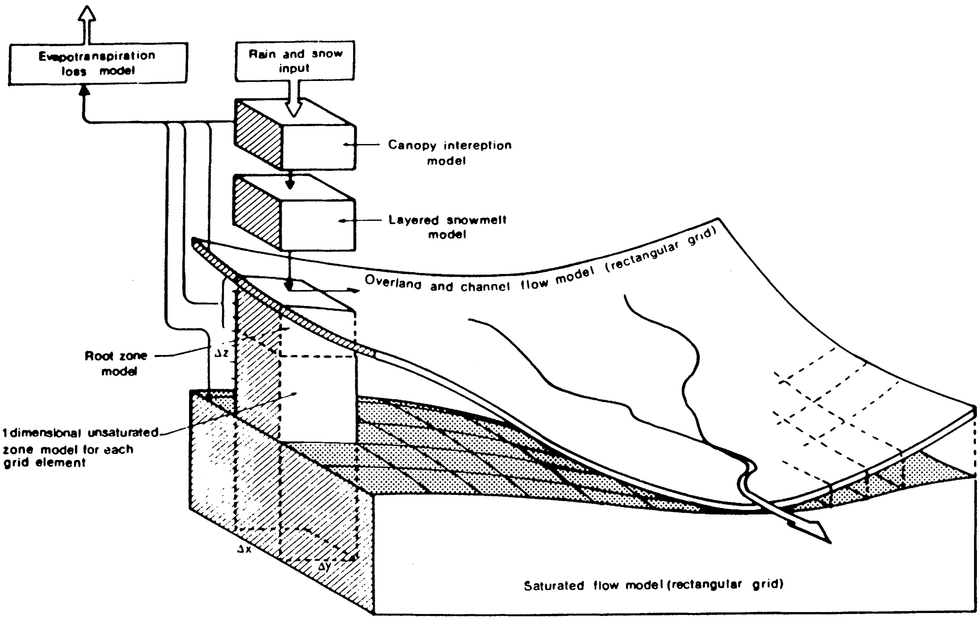

Fig. 1. Structure of the European Hydrologic System.

unsaturated flow components of variable depths are used to link a two-dimensional surface flow component with a two-dimensional groundwater flow component. The horizontal plane is divided into rectangular grid squares, and an independent discretized unsaturated component is associated with each grid square. The river system is supposed to run along the boundaries of grid squares. For a more comprehensive description of SHE, reference is made to Jensen and Jønch-Clausen (1982).

The model structure is illustrated in Fig. 1.

SHE is structured with a Frame, which coordinates and controls the operation of the individual components. This feature in combination with the modular form of structure of the SHE provides a considerable flexibility by allowing the components to assume different levels of complexity or to be omitted in any given application, depending on the purpose of the application and the availability of data.

Further, the individual components are structured as separate units which can be used independently. Since SHE is intended as a general hydrologic modelling system, this flexibility is considered of vital importance.

By accounting directly for the spatial variations in hydrologic inputs and catchment characteristics through the physically based parameters, SHE makes it possible among other things, to predict the effect of human interference on the hydrologic regime in a river basin or in a subbasin. Such interference may consist of changes in land use (deforestation), changes in land management (land reclamation and soil conservation) and changes in water management (drainage and irrigation, ground-water abstraction and channel improvement). This applicability is of great practical significance since so far no physically based methods have been presented by which reliable predictions can be made.

Several research organizations have been contacted in order to locate well-equipped catchments, where comprehensive and reliable data bases could provide thorough field testings of SHE. The ideal testing, of course, would be a catchment where quantitative predictions of the effects of human activities could be compared with measurements. However, no suitable catchment with measurements available both before and after the changes has been found yet.

Field Tests

The field testing carried out so far has mainly been confined to simulations of the existing hydrological conditions. An exception in this respect is the testing of the individual soil water flow model, which has been applied for predicting the effects of irrigation (Jensen 1983). On catchment scale SHE has been applied to the River Wye catchment in Wales. This study has focused on the simulation of selected storm flow events, with particular attention to the spatial variation of runoff within the catchment. Other field applications have been carried out in cooperation with research organizations in Germany and New Zealand. Examples of results from these studies are shown below.

Wye Catchment (Plynlimon), Wales

The Wye Catchment is a small upland catchment in Mid-Wales (Fig. 2), heavily instrumented by Institute of Hydrology in Wallingford. The catchment covers an area of 10.5 km^2, and is characterized by rather steep slopes and altitudes between 340 m and 740 m. On the high plateau, the predominant vegetations are grassland and heath, whereas mires are dominating in the valley floors. Rather shallow soils (thickness generally smaller than 1 m) of peat, peaty peazols and peaty gleys are overlying shales and mudstone.

The distributed model description of the catchment is provided on a 250m × 250m grid. Each grid square has specifications of:

- ground- and impermeable bed level
- vegetation type
- soil type
- flow resistance coefficients for surface flow
- rainfall and other meteorologic data.

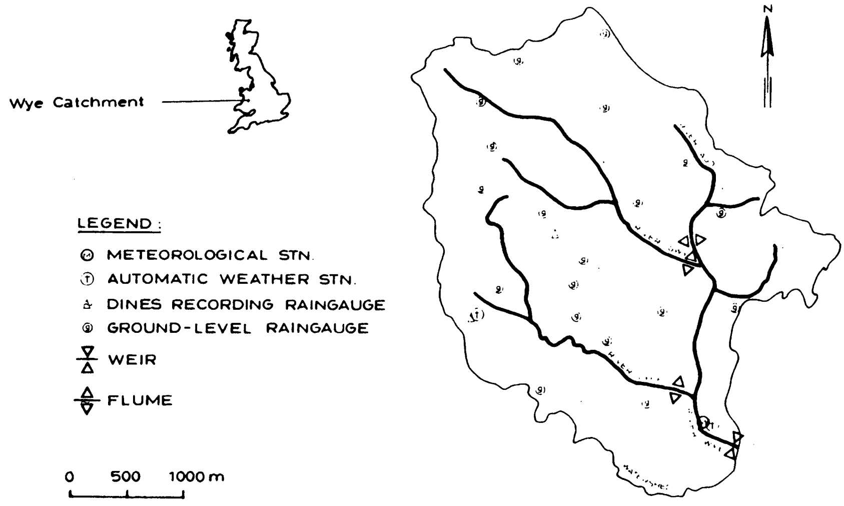

Fig. 2. The Wye catchment used for a fixed testing of SHE.

The above information is provided in matrix form to SHE as illustrated in Fig. 3. This figure shows input matrices of vegetation, soil, topography and rainfall.

Calibration and Validation – The field test has focused on the simulation of two individual flood events selected from the stream flow record. The first flood event, beginning Oct. 3, 1976, covers a 40-hour period with a measured peak flow of 1 m^3/s. The second one, beginning Oct. 13, 1976 involves much higher stream flows with a maximum peak of 7.5 m^3/s within a period of 80 hours.

The test is divided into a calibration and a validation part. The calibration process has shown that soil properties and initial soil moisture conditions are the most important parameters governing infiltration and hence surface runoff. However, in the calibration process the soil parameters are varied only little from the originally measured values and the calibration relies therefore primarily on estimates of initial moisture contents in the unsaturated zone in the various parts of the catchment. These values are estimated on the basis of soil types and antecedent rainfall.

Fig. 4 shows the simulated and observed outflow hydrographs from the catchment. All calibration runs have produced hydrographs within a limited range (the dotted curves). Actually, the upper 'boundary' curve in Fig. 4 represents the initial calibration run. Produced on the basis of measured and estimated quantities only, this run is seen to produce a response in the correct order of magnitude and is thus a good basis for calibration. By modifying the initial moisture contents in the valley soils and by changing soil parameters slightly the final simulation is obtained.

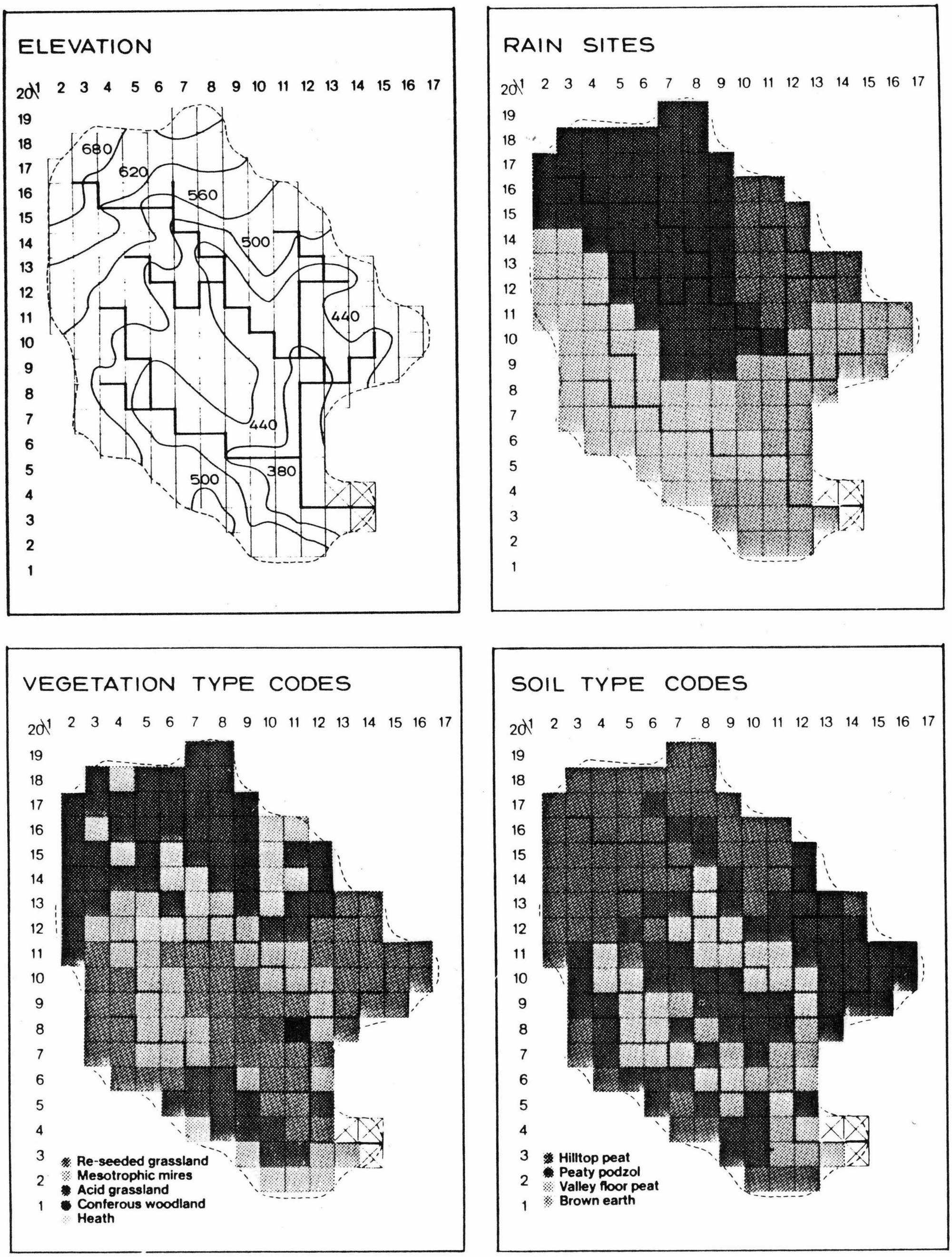

Fig. 3. Examples of input matrices for the SHE model.

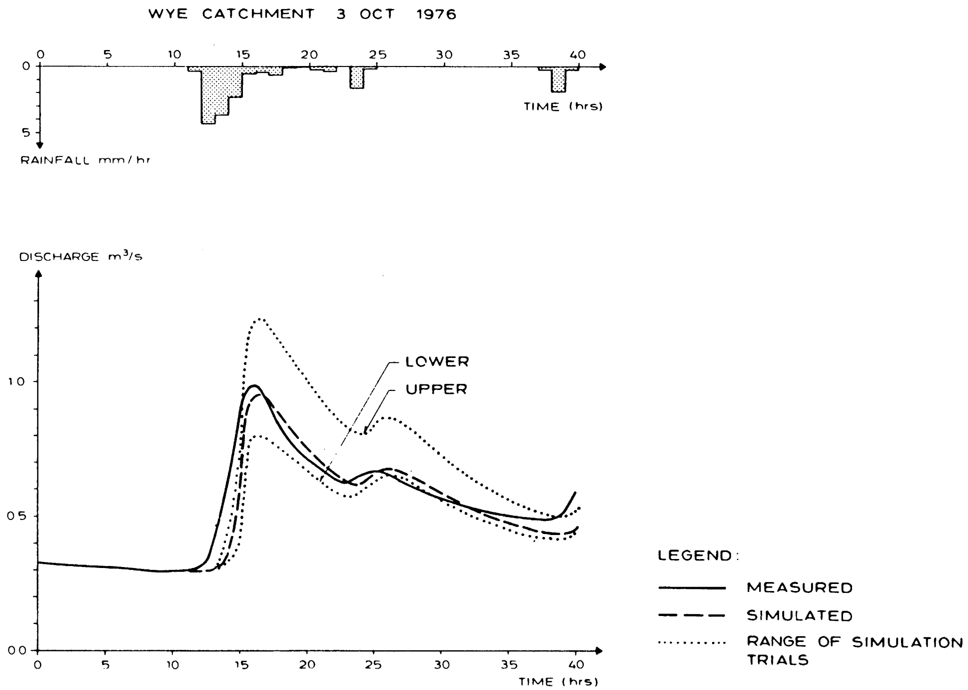

Fig. 4. Calibration, Wye catchment.

Using the calibrated model and estimated initial soil moisture conditions the second more severe flood event is simulated, see Fig. 5. It is significant that a peak flow of 7.5 m^3/s in this case is predicted rather accurately using a model which has been calibrated on an event with a much smaller peak flow. This is possible because of the distributed physically based nature of SHE. By basing the model description on the physical laws governing the hydrologic processes, extrapolation beyond the calibrated range can be made with higher reliability than is possible with traditional conceptual models.

Fig. 5 also shows the simulated streamflow in upstream tributaries. The distributed structure of SHE makes it possible to obtain hydrographs at all computation points in the river system.

As shown by the figure the simulated and measured hydrographs for the two upland tributaries compare well. This, together with the accurate simulation of the total catchment outflow demonstrates the capability of SHE to provide an accurate representation of the flow distribution within the catchment.

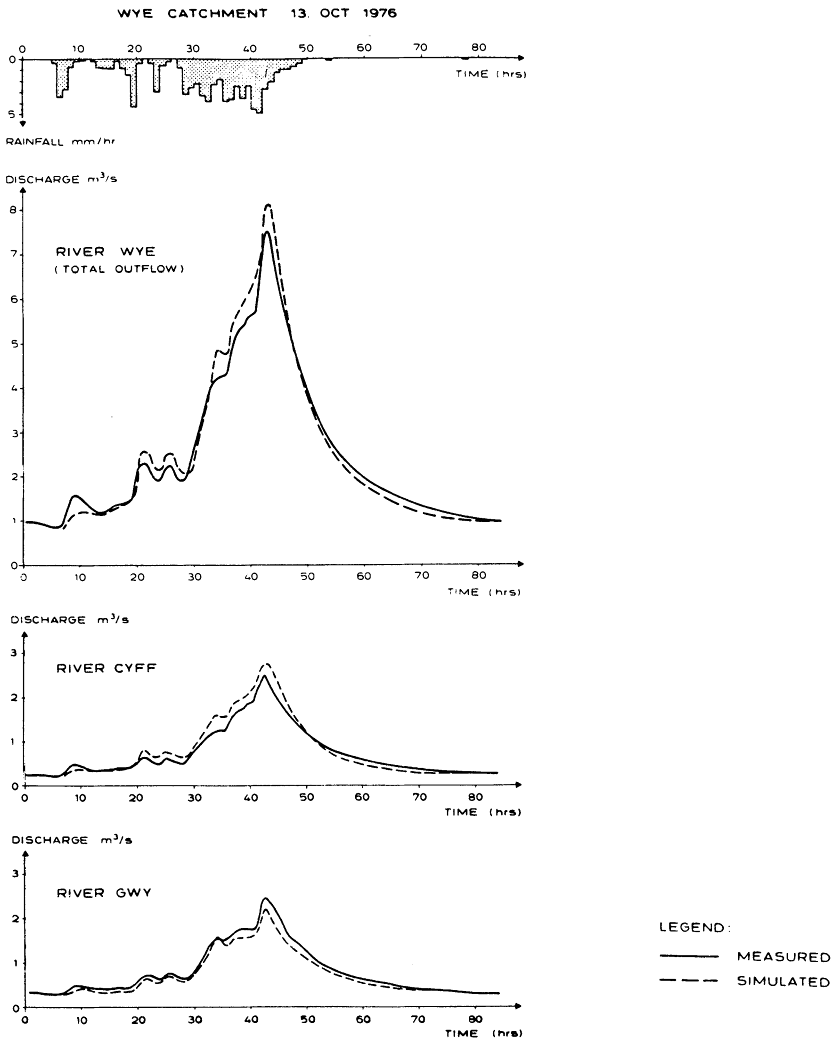

Fig. 5. Validification, Wye catchment.

Research Catchment in Neuenkirchen, West Germany

The Neuenkirchen Catchment is a heavily instrumented catchment near Braunschweig in Germany. A comprehensive programme including field and laboratory investigations has been initiated by the University of Braunschweig with a view to identifying and describing surface and sub-surface water flow, solute transport and soil erosion. One of the main objectives of the programme is

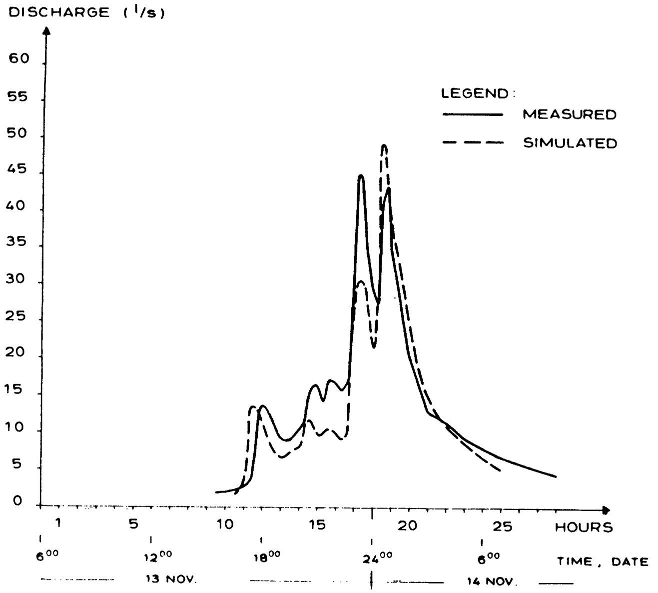

Fig. 6. Simulated and observed hydrographs, Neuenkirchen catchment.

to apply and validate a distributed and physically based catchment model like SHE on the field data. The data collection programme is very comprehensive and will provide detailed information on several processes with a refined resolution in time and space. Hence, this catchment will provide a unique basis for a thorough testing of the SHE.

At the present early stage of the cooperation, SHE has been tested on a small 0.25 km^2 subcatchment. A grid setup of 119 grid squares with a horizontal discretization of 50×50 m and 25×50 m, respectively has been used.

The simulation is performed with time steps of six minutes. This small time resolution is required in order to accurately describe the rapid fluctuations in the observed outflow hydrograph, which are due to the small time of concentration of the catchment.

All the required input data are available except for the surface resistance coefficients. Hence, these have to be estimated on the basis of experience and calibration. Similar to the previously described field test, a short flood event has been extracted from the stream-flow record. In Fig. 6 the simulated and observed runoffs are shown for a 25-hour period starting Nov. 13, 1983. A characteristic behaviour of this catchment is the rapid changes in the outflow hydrograph in response to changes in the rainfall input. These fluctuations are described accurately in the simulation.

In the previous field study it has been demonstrated that hydrographs can be

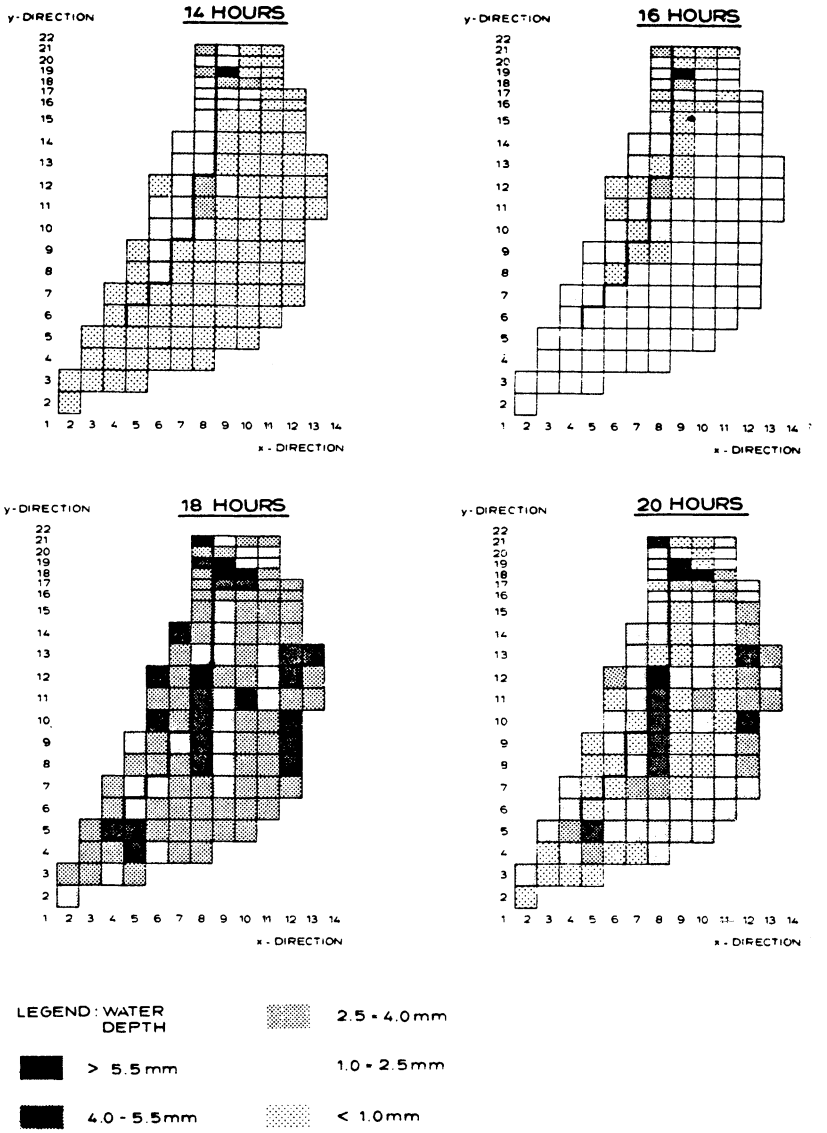

Fig. 7. The spatial distribution of the overland water depth to selected times.

extracted from the SHE simulation anywhere in the river flow calculation network. Another example of the capability of SHE to simulate the spatial variation in catchment processes is illustrated in Fig. 7. Here the simulated spatial variation in overland flow depth is shown for four consecutive times. Such information is crucial in relation to soil erosion studies.

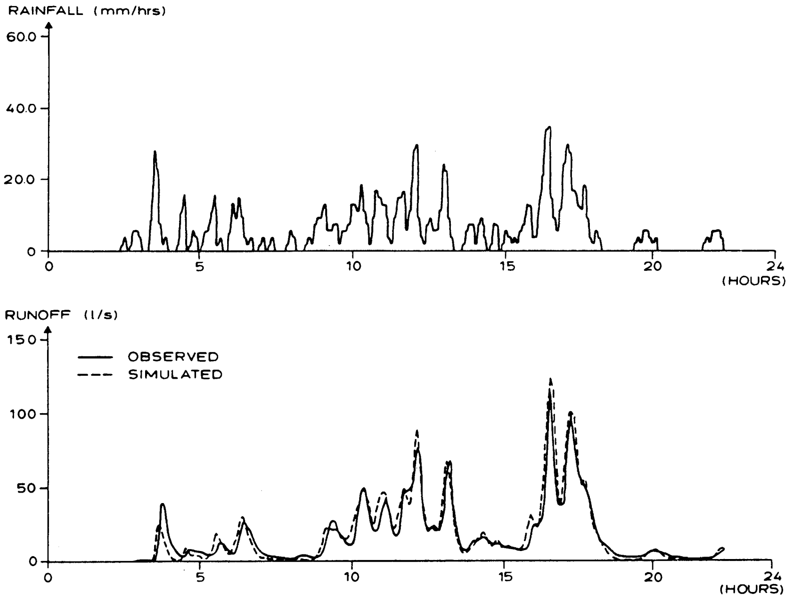

Fig. 8. Simulated and observed hydrographs, April 1974, Pukeiti subcatchment.

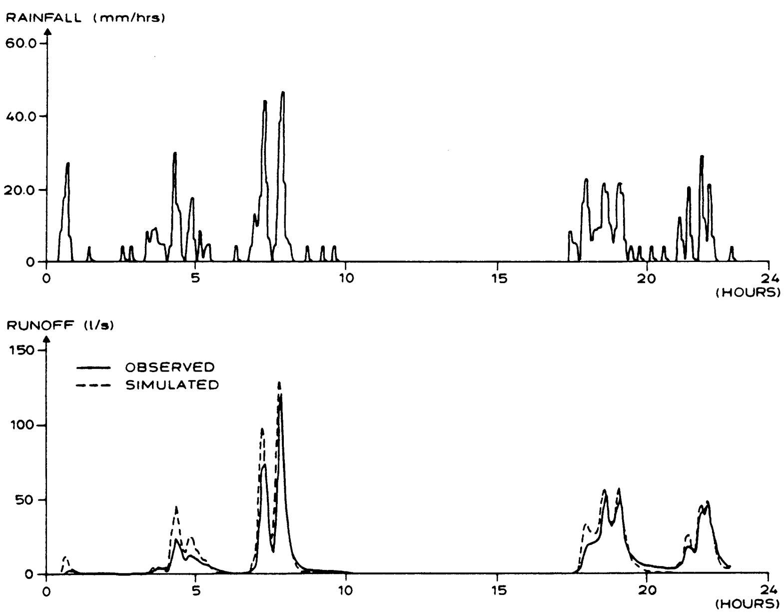

Fig. 9. Simulated and observed hydrographs, January 1976, Pukeiti subcatchment.

Puketurua Catchment, New Zealand

The SHE has been applied to two IHD representative basins in New Zealand. The objective was to demonstrate the ability of SHE to simulate the particular hydrological conditions which exists in New Zealand. Below is presented two examples from a validation of SHE on the Puketurua basin. Figs. 8 and 9 show comparisons between measured and simulated runoff from a small subcatchment Punkeiti in the basin. This subcatchment is approximately 1.5 hectares. The catchment is gently sloping and is used as grazing areas for sheep and cattle.

The predominant soil is a low permeable salty loam, and during heavy storms approximately 65-75% of the rainfall contributes to surface flow. The infiltrating water is not recorded since all groundwater bypasses the runoff gauging station.

SHE has been calibrated on one storm event and Figs. 8 and 9 show two validation runs on two other storms. It is evident from the figures that the recorded hydrographs are simulated very accurately. This applies both to the timing and magnitude of the individual runoff fluctuations, and to the general water balance. Of particular importance is the validation of the updating of the soil moisture conditions between the storms in Fig. 9.

Conclusions and Further Developments

The field tests carried out so far with the SHE system have shown promising results. This applies both to the complete system and the individual components. These tests have supported the principle behind the model development.

The SHE is a new approach to hydrological modelling by providing a distributed description of the hydrological processes which is physically sound. This implies that almost all information (data, physical parameters etc.) of relevance for the physical processes can be introduced in the system. This is in contrast to traditional lumped and conceptional models which cannot make sensible use of data like topography, soil characteristics, vegetation maps etc. By accounting for the spatial variations in hydrological inputs and catchment characteristics, SHE is particularly suitable for predicting the hydrological effects of physical local changes in a catchment such as deforestation. For such applications no other methods being physically based have been presented so far.

More testing of the SHE is required to demonstrate the capabilities of the system and to identify refinements and new developments. A few changes are already planned. As part of the coorporation with the University of Braunschweig interflow and tile drainage components will be introduced. These processes are of particular importance under many climatic conditions and their inclusion in the system will increase its general applicability.

Acknowledgements

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The model test on data from New Zealand has been a joint effort between Danish Hydraulic Institute and the Hydrology Centre in Christchurch.

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