Validating Hydrological Models Using Process Studies and Internal Data from Research Basins: Tools for Assessing Hydrological Impacts of Environmental Change (VAHMPIRE)

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Abstract The VAHMPIRE project is a novel approach to testing and improving capabilities of hydrological models, with the ultimate aim of increasing t potential for water resource assessment under changing environmental conditions. The project brings together experienced modellers with fielc groups in order to improve our understanding of hydrological functionin to provide detailed within catchment data for model validation. The proc is iterative in that models define the requirements for field measuremen which provide data to a further stage of modelling. New techniques for ı and extensive, but detailed, field measurements are also being tested v the project, thus offering new tools for model parameterization in the fu A range of experimental catchments with existing data bases across Eu are used within the project for testing various model components and fc comparison between modelling approaches. In all sites measurements being augmented to reinforce model validations.

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Introduction The VAHMPIRE project aims to improve hydrological modelling approa through identifying model weaknesses in reproducing actual internal catchment processes as well as investigating parameter variability, and progress in understanding hydrological processes, through improved fi observation and issues arising from modelling queries and outputs. The remote objective is to provide reliable tools for assessing the hydrologic consequences of environmental change and defining the land and wate management strategies necessary to preserve water quantity and quali

A physically-based hydrological model (SHETRAN) and a parsimoniou model (TOPMODEL) are being validated and improved using data from experimental catchments, including work to ensure that the internal dyn and processes of the catchments are properly represented. Submodels handle with forest interception and snow melting are being specially ch and developed.

A new generation of field techniques including TDR (Time Domain Reflectometry), GPR (Ground Probing Radar) and GPS (Global Positio System) have been tested and used together with other field experimer obtain data for internal validation of subsurface hydrology of small rese catchments. The methodology for hydrological use of GPR at the hillslo and small catchment scales (soil water content, soil water reserve and table delineation) is being developed through validation in a range of fi conditions

Joint field campaigns were carried out in the Vallcebre catchments

(Southeast Pyrenees), an area with strong spatial and temporal heterogeneities. The purpose of these campaigns has been not only to gather field data but also to create the best conditions for exchanging experience between researchers concerned with modelling or to field observations. Identifying model deficiencies and guiding field observati from model outputs have been best performed during these campaigns Other field campaigns in a range of experimental sites in Spain and Switzerland took place for specific purposes (consequences of land us and changes, erosion processes, flow generation and partitioning, sno melting). Data from Experimental Catchments in Germany have been u test models in other environmental conditions.

Both downscaling and upscaling investigations are being performed. Th role of increasing DTM resolution and information with the help of GPS been studied within the TOPMODEL approach. A new TOPKAPI model being developed and tested allowing the application of models calibrat and validated in small basins to wider areas. Finally, comparisons with common water management models SACRAMENTO and BROOK have performed.

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Methodological Approach

The development of more sophisticated hydrological models in recent y has been a cause of a mixture of optimism and debate amongst hydrol Models have developed from those of the lumped, conceptual type, thr distributed models to the latest generation of physically-based distribut and parsimonious physically-based models. In order to model changed conditions models must have the capability to reproduce hydrological processes within a basin, rather than relying on empirical or statistical relationships. This requires that the models have a as a basis for physi basis.

Dramatic land-use changes are already happening in large areas of Eu and their hydrological impacts are expected to be of major importance. Although the importance of climate change is recognised by the Project Partners, the difficulties of production of reasonable quality future rainf and temperature scenarios, which are themselves the subject of EU Research Projects, means that climate change will not be directly addre in this Project. However, the high seasonality and interannual variation climate at Vallcebre, that drive several runoff generation mechanisms, means that the models are being validated against a wide range of clim conditions. On the other hand, the ability of the models to represent the modified processes arising from land-use change indicates that they wi be able to represent the processes resulting from changed climate conditions. Therefore, this project can be viewed as an attempt to prod more robust tools for the hydrological modelling of any environmental change.

The representation of hydrological processes by models has been a fr area for discussion in recent years. A criticism of physically-based mod like SHE (Systeme Hydrologique Europeen) (Abbott et al., 1986a, 198 physically-conceived models such as TOPMODEL (Beven and Kirkby, Beven et al., 1994) is that similar model results, in terms of prediction o discharge at the catchment hydrograph, may be obtained by the use of number of different parameter combinations (ea. Beven, 1989; Abrahar 1994). This indicates that hydrological processes within the catchment not be being represented correctly, or have been incorrectly parameteri even if the overall effect is reproduced. If this is the case, then any predictions of what may occur in the future following land-use or climate change would be in error.

Validation of the within catchment process representation is therefore necessary to improve the predictive capacity of these models. This is possible because distributed (like SHETRAN) and semi distributed (like TOPMODEL) hydrological models yield distributed results such as instantaneous soil water conditions, in the form of water tension or defi levels that can be compared with measured data. The most appropriate approach to model validation is therefore a modelling exercise coupled an intensive programme of field measurements in catchments including use of updated measurement techniques.

Catchments

Upland and mountain areas are of key importance to water supply in m areas of the European Union. Current land management policies, both member states and EU level (including the Common Agriculture Policy) based mainly on economic grounds but their hydrological soundness is very poor, or is based on precarious hydrological grounds. This project therefore focuses on mountain areas.

The VAHMPIRE project is highly dependent on the use of internal data a series of research basins throughout Europe. The Vallcebre (Cal Roc Can Vila, Ca l'Isard, Santa Magdalena and Cal Parisa) catchments in th eastern Pyrenees provided the focus for Joint Field Campaigns and modelling work. Basin areas range from 14 ha to 4 km^2, and include for hillslopes, areas of terracing (cultivated, abandoned or reforested), lime outcrops and very active badland areas. The hydrological functioning alternates between the usual processes of dry areas (intense rainstorm over thin soils) and those characteristic of humid areas (temporary satu areas). Thus many of the most difficult issues for modelling (Gallart et a 1994) are included within at least one of the sub-basins which are, individually, relatively homogeneous.

Other catchments are used either for specific field objectives, or the application and validation of models, or both. In the Central Pyrenees, t Izas, Loma de Arnas and San Salvador catchments are being used to analyse the hydrological roles of snow melt, grass-matorral and forest c respectively, whereas the larger Alto Aragon catchment will be used for application of models adequate for larger basins. A series of experimer plots at Aisa also provide information on runoff and erosion from typical uses and management systems. The Torre Marimon experimental farm Barcelona, will be used to analyse soil moisture, runoff and erosion consequences of alternative farming strategies. The Haute Mentue catchments in Switzerland are being used for identifying the different components of runoff using tracers. The Lange Bramke, Große Schach Großes Mollental and Alte Riefensbeek catchments in the Harz Mounta and Lainbach in the Bavarian Alps (Germany) will be used primarily to compare the traditional conceptually-based models and the physically-l ones.

Models

SHETRAN is a physically-based distributed modelling system designec simulate simultaneous water flow, sediment transport and contaminant migration at the catchment scale. It has been developed at the Universi Newcastle upon Tyne by upgrading the SHE (Systeme Hydrologique Europeen) water flow modelling system (Abbott et al., 1986a, b). Its phy basis and distributed structure allows detailed examination of the hydrological processes operating within catchments. In addition, SHETI physical basis means that, if changes in physical parameters can be predicted, it can be a powerful tool for quantifying the hydrological effe land-use and climate change.

TOPMODEL is a parsimonious physically-conceived semi-distributed hydrological model, in which topographic structure is considered as the driving force. Outputs of a distributed nature can be obtained and will b validated against field data. Such validation, and the representation of internal catchment variability form the two main areas of research in thi Task. TOPMODEL and topographic analysis studies mainly focus on th Vallcebre basins in the Spanish Pyrenees.

However, other applications of TOPMODEL to the Haute-Mentue catch have also been carried out.

TOPKAPI. As a means of uspscaling model applications, the basic hypotheses embedded in two widely applied hydrological models (the A model and TOPMODEL) have been reviewed together with a considera of their pitfalls, in order to underline the main aspects to be defined in a model formulation. In order to substantiate the basic concepts used to a lumping from hillslopes to catchments and ultimately to GCM's, a numb tentative experiments have been performed and briefly reported (Todin 1995). This resulted in the early stage of a new model formulation TOP (TOPographic Kinematic APproximation and Integration), as a logical consequence of the defined model requirements and the underlying hypotheses. In synthesis the conclusions of this preliminary work are:

a. It is possible to lump horizontal flow properties in the vertical dimens without a significant loss of accuracy in representing the horizontal component of flow.

b. It is possible to represent the horizontal movement of flow on the hill and in the unsaturated zone by means of kinematic models; this allows of non-linear reservoir type models when integrating the effects at large larger scales, with parameters that can be determined on the basis of topography, physical properties and geomorphology.

c. A succession of hillslopes can be incorporated in a rainfall-runoff mo means of a probability distribution.

d. The soil moisture availability can be considered as an average lump quantity within a subcatchment unit, as in the ARNO model, thus driving actual evapotranspiration and percolation.

This has led to the definition of a new parameterization of the TOPKAP model, which must now be developed and tested with field data.

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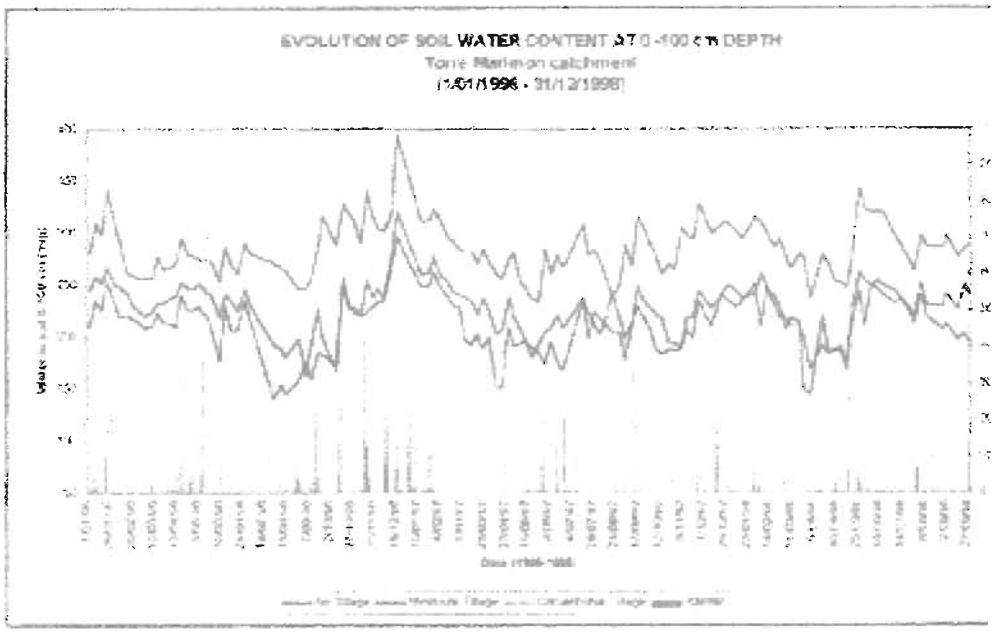
Results Data

Soil moisture monitoring

Soil moisture monitoring systems based on TDR method have been ins and exploited in the Vallcebre, Loma de Arnás Torre Marimon and Haute-Mentue catchments. This enables periodic determination of soil balances of the catchments as well as the analysis of the role of topogr and vegetation cover on spatial distribution of soil water content that is used for validation of hydrological modelling. In the Vallcebre catchmer networks of piezometers and soil tensiometers have been set up and exploited in order to improve the knowledge of the hydrological behavic the catchments, as well as to validate the models.



Interception and evapotranspiration

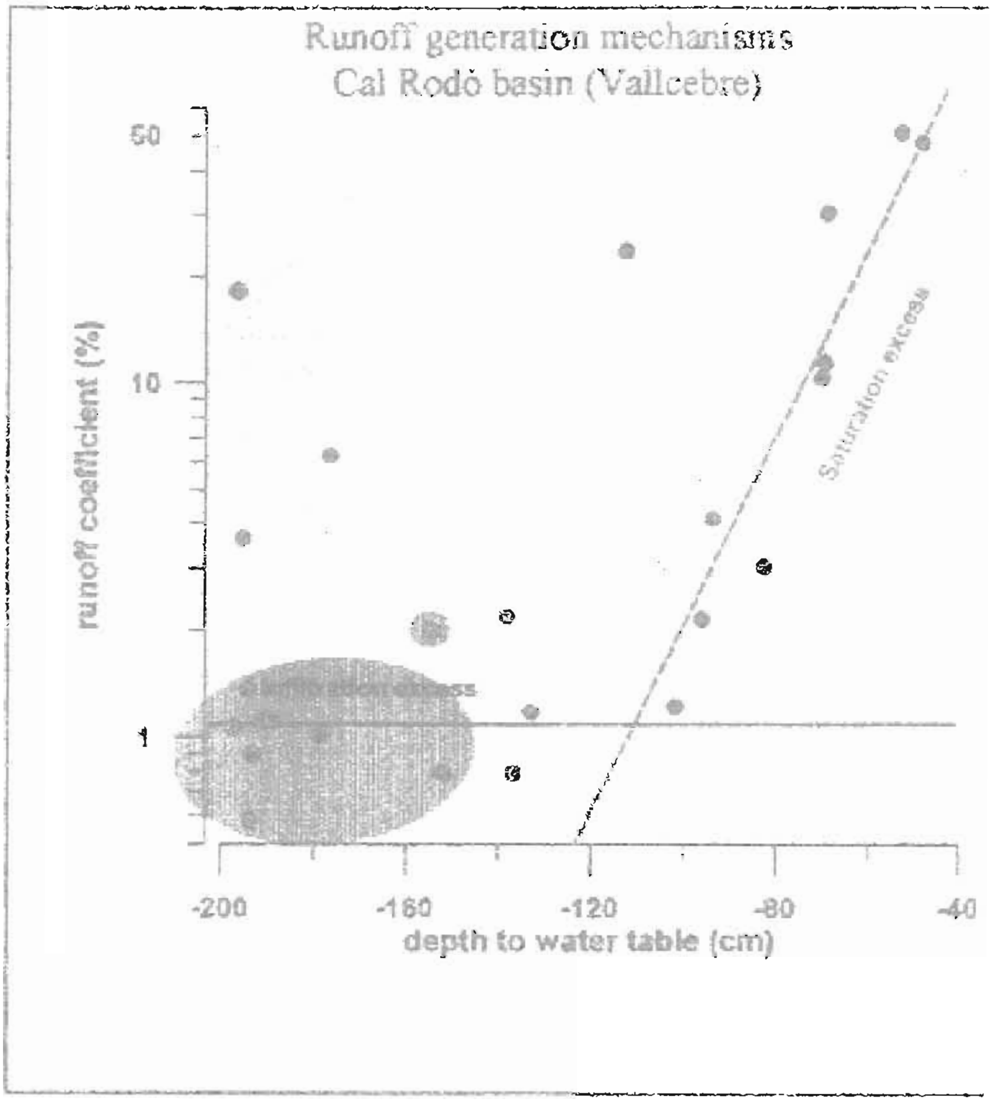
Data on actual evapotranspiration has been obtained for *Pinus sylvestr* patches and permanent grasslands in the Vallcebre catchments using f interception plots, sapflow monitoring and Bowen Ratio Energy Balance stations, and for *Pinus halepensis* in the Torre Marimon experimental fa using forest interception plots.

This information enables the analysis of the dependence of interceptior transpiration on weather, physiographic and stand characteristics, as w made possible the Validation of modules adequate for describing the fc water balance, useful for different types of hydrological models.

Flow partitioning /runoff generation

Detailed data for the evolution of snow cover at the Izas catchment for t season 1996-97 has been obtained through the improvement of autom sensors and intensive field campaigns.

Short intensive field campaigns to collect water samples for environme tracing have been performed at the Haute-Mentue catchments. Methodological issues related to environmental tracing have been furth explored through the development of a specific software package (see below).

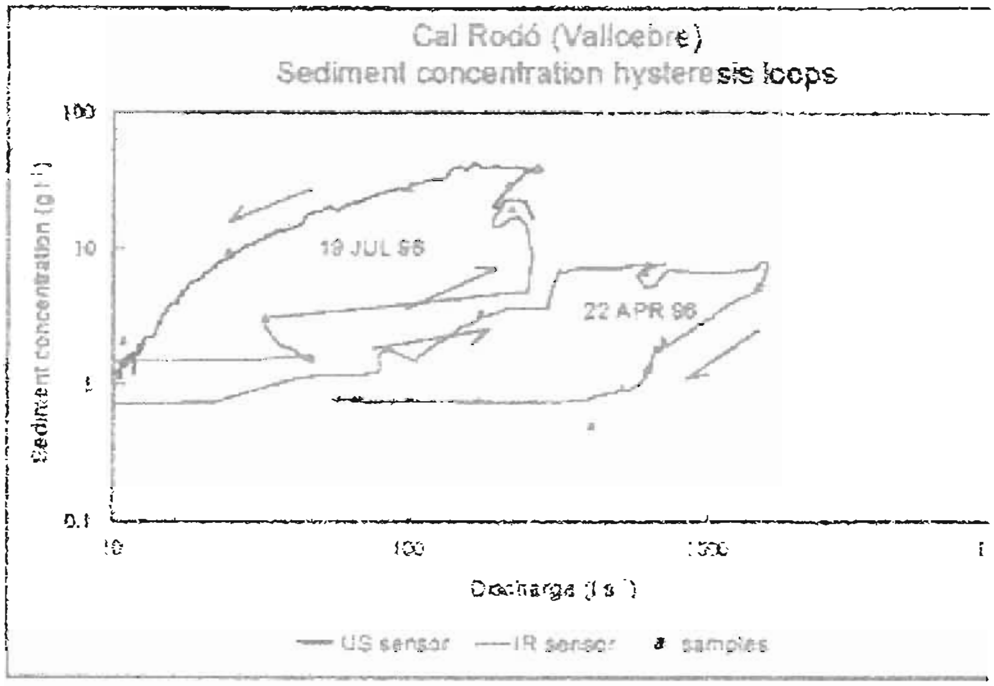


Environmental tracer studies are also being carried out on the Vallcebr basins to investigate the inhomogeneity of the 'old' water reservoirs in a Mediterranean catchment, to identify appropriate chemical tracers and mixing models for the Vallcebre basin geochemical setting and hydrolo processes, and to assess the residence time of underground waters.

At Vallcebre the several sources of information has been used to identi runoff generation mechanisms in areas where a wide temporal range of water reserve and spatial variation of soil thickness and properties mak use of current physically-based models difficult.

By means of fieldwork and geomorphological mapping the sediment so
in the Alto Aragon catchments have been identified, together with the pathways which sediments follow to the channels, and the areas of temporary sediment storage. Soil erosion and redistribution is also beir
studied by means of caesium-137.

Sediment monitoring at the Vallcebre catchments has been made with t
help of both an Infra-Red backscattering sensor (JR) and an Ultra-Soni
beam attenuation sensor (US) continuous recording systems.



This information together with the results of former studies on the beha
of badland surfaces are being used to perform a perceptual sediment n
adequate for catchments with badland areas, with regard to runoff gene
mechanisms, weathering rates and sediment conveyance discontinuitie

An assessment of sediment losses at the small catchment scale is bein
carried out by ESAB at the Torre Marimon site, together with a relative
assessment of sediment production from different dry-farming techniqu
This will include a validation of the EUROSEM model at the small catch
scale.

Models and methods

A Snow Processes Model (SPM) is being designed, for a wide range of applications and able to be used within SHETRAN or as a stand alone model. The SPM is distributed in space by implementing an individual c
dimensional model of vertical energy and mass balance for the snowpa
each grid cell of a raster representation of the catchment being modelle
full surface energy balance model has been incorporated to the SPM,

although the option for the use of simple degree-day index is being retɛ for situations where detailed meteorological data are not available, or w speed and simplicity of approach are preferred to detailed physical processes.

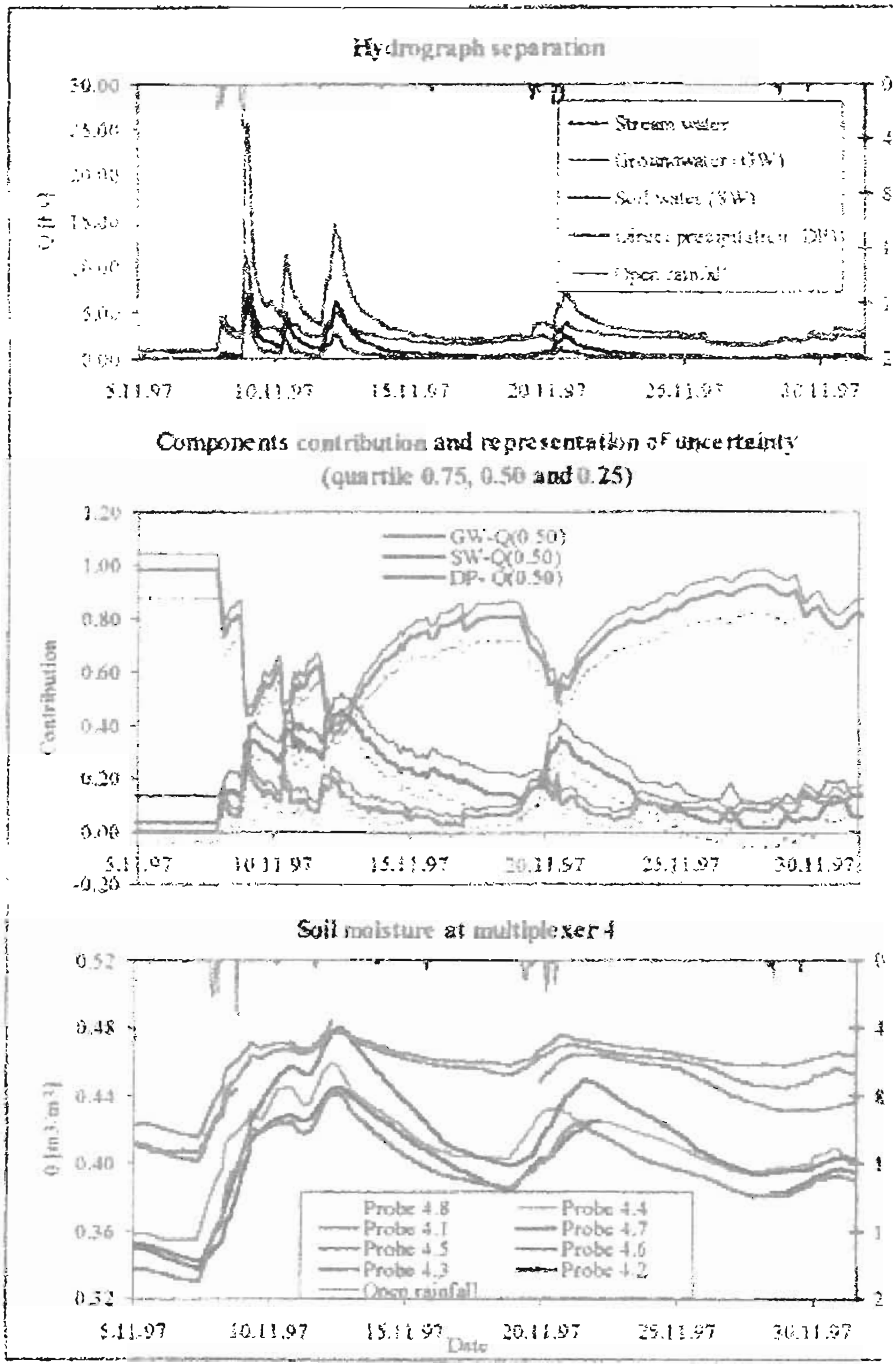
Validated examples of SHETRAN model to a range of climatic and environmental conditions have been obtained, with additional informati the degree of reproduction of internal catchment processes and state variables.

A new TOPCAT model that is a simplification of the TOPMODEL appro has been designed to be used within a standard spreadsheet. It is base an exponential law for baseflow, plus a quickflow component. This mod been developed as a part of an exercise to study the relationships betw small-scale features and the resolution of the Digital Elevation Models, provides the catchment-scale framework for the development of a new called TOP Terrace, that handles specific sub-grid features (agricultura terraces).

Two new generalisations of TOPMODEL have been developed. The fir proposes a power law for vertical hydraulic conductivity at saturation (Iorgulescu and Musy, 1997), the exponential profile of the initial TOPMODEL formulation being a limit case of this general form. The se one is a trial to improve model consistency and physical basis, and con the role of saturated areas in runoff generation, by avoiding the occurre of negative deficits through splitting the catchment into two dynamically varying zones, the one contributing to overland flow, and the other to infiltration.

A new TOPKAPI model, based on the coupling of kinematic approach ɛ the topography and physical properties of the catchment is being elabo During its development, the need for a distributed version raised, to est the possible sources of errors and to verify the effectiveness of the pro approach. This distributed version has already been set up and validat with data from the Vallcebre and Reno catchments, the area of the last being twenty times wider than the area of the first one.

An operational guide for hydrological applications of Ground Penetratin Radar is being prepared from the experience obtained at the Vallcebre, Torre Marimon and Haute Mentue experimental areas, where comparis with TDR measurements have been performed



A new software package AIDH (Analyse d'Incertitude des Décompositic d'Hydrogramme) has been developed to perform an uncertainty analysi hydrograph separation and allows for parametric and non parametric probability distribution functions for the geochemical signatures of mixir model components.

This method has been developed and applied to the Haute Mentue catchments, and the results have been compared with the continuous records of soil moisture.

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Acknowledgements This research was supported by the "Environment and Climate Progran under contract ENV4CT95-0134 and the Swiss Government under Grai OFES#95.00449.

The development of the project could not be made without the contribut a number of researchers. Thanks are especially given to S. White for h help in project organisation, and to L Dalmau, Ch. Joerin and J. Latron providing graphs with original information on soil moisture; hydrograph separation and runoff generation mechanisms respectively.

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