Recent developments of the Système Hydrologique Européen (SHE) towards the MIKE SHE

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Abstract The development of the Système Hydrologique Européen (SHE) started in 1977 as a joint effort by three European organizations: Institute of Hydrology (UK), the French consulting firm SOGREAH and the Danish Hydraulic Institute. The SHE is often quoted in the literature as a prototype of the distributed, physically based group of models. In this paper the comprehensive results of further developments of the MIKE SHE version, which have taken place during the last five years, are summarized. MIKE SHE simulates water flow, water quality and soil erosion processes for the entire land phase of the hydrological cycle. It is intended for scientific and engineering hydrology. MIKE SHE is a fourth generation, user-friendly modelling package comprising a number of comprehensive pre- and post-processors including digitizing, graphical editing, contouring, grid-averaging and graphical presentation with options for display of animations.

INTRODUCTION

The European Hydrological System, SHE, was developed as a joint effort by the Institute of Hydrology (UK), SOGREAH (France) and the Danish Hydraulic Institute (DHI). It is a deterministic, distributed and physically-based modelling system for describing the major flow processes of the entire land phase of the hydrological cycle. A description of SHE is given in Abbott et al. (1986a; 1986b). Further presentations of the joint experience and methodology of model application are given in Refsgaard et al. (1992), Jain et al. (1992) and Lohani et al. (1993). Since 1987 SHE has been further developed independently by three organizations which are the University of Newcastle (UK), the Laboratoire d'Hydraulique de France (LHF) and the DHI. The University of Newcastle's version, denoted SHETRANS, has been further developed and is presently used in Newcastle for research purposes. DHI's version of SHE, known as MIKE SHE, represents significant new developments with respect to user interface, computational efficiency and process descriptions. LHF has made an agreement with DHI on marketing and application of MIKE SHE in France and a few other countries.

MIKE SHE

Integrated modular structure

The core of MIKE SHE is the module that describes the water movement in the area...
under consideration — MIKE SHE WM. A number of add-on modules are available and can be applied according to the specific problems in the study area.

The following add-on modules are already available, or are under development, for water quality, soil erosion and irrigation studies:
(a) MIKE SHE AD — advection and dispersion of solutes;
(b) MIKE SHE GC — geochemical processes;
(c) MIKE SHE CN — crop growth and nitrogen processes in the root zone;
(d) MIKE SHE SE — soil erosion;
(e) MIKE SHE DP — dual porosity; and
(f) MIKE SHE IR — irrigation.

Below, a brief introduction to the WM module is given. For a further up-to-date description of the various modules, references are made to DHI (1993a), DHI (1995) and VKI (1995).

Water movement module (MIKE SHE WM)

The overall model structure is illustrated in Fig 1. MIKE SHE WM comprises six process-oriented components, each describing the major physical processes in individual parts of the hydrological cycle and, in combination, describing the entire hydrological cycle:
(a) interception/evapotranspiration (ET);
(b) overland and channel flow (OC);

![Fig. 1 Schematic representation of the components of MIKE SHE.](image)
Recent developments of the SHE towards the MIKE SHE

(c) unsaturated zone (UZ);
(d) saturated zone (SZ);
(e) snowmelt (SM); and
(f) exchange between aquifer and rivers (EX).

The modular form of system structure, or architecture, ensures great flexibility in the description of the individual physical processes. Thus, some of the components already include alternative options for describing the processes. Data availability or specific hydrological conditions may favour one model description as compared to another. By ensuring that the data flow between components is unchanged, alternative methods which are generally accepted in a certain geographical region or a country, can be included in the MIKE SHE WM system, if required. The user can produce his own model configuration, e.g. starting with simple process descriptions and gradually changing to more complex descriptions, as and when required.

The governing partial differential equations for the flow processes are solved numerically by efficient and stable finite difference methods in separate process components. All process descriptions operate at time steps consistent with their own most appropriate temporal scales. Hence the processes may be simulated using different time steps which are automatically updated during the simulation and coupled with the adjoining processes as and when their time steps coincide. The facility allows for a very efficient operation, making it possible to carry out simulations for long time periods.

Individual components can also be operated separately to investigate a single process. This may be relevant in a range of applications, where only rough estimates of data exchange from other parts of the hydrological cycle are required. An example could be a groundwater study where only approximate recharge estimates may be required and a full coupling to the unsaturated zone above the groundwater table is unimportant.

The ability to provide an integrated description of the various processes, despite different time scales, is the most important feature of MIKE SHE WM. This integration has probably been the largest problem encountered during its development and provides a unique feature. Perhaps the most difficult coupling is the one between the unsaturated zone and the groundwater components, which is described in Storm (1991).

Pre- and post-processor

The user interface of the MIKE SHE module includes powerful pre- and post-processing facilities with particularly strong GIS capabilities. The software can be applied to the input data and results of all the MIKE SHE modules.

Some examples of the software capabilities are:
(a) digitization of contours from maps such as those of the ground surface and geological layers;
(b) digitization of the river system layout;
(c) digitization of aerially-distributed information, such as land use, soil types, etc.;
(d) transformation of vectorized information to grid information, e.g. interpolation of contour or point information;
(e) graphical editing of 2-D data and river data;
(f) very flexible transformation of geological/hydrogeological vectorized data into 2-D or 3-D grids;
(g) double mass plots;
(h) water and solute mass balance calculations for any sub-area;
(i) arithmetic operations on matrices and time series;
(j) isoline plots, vector plots;
(k) plots of the variations in space of a variable in any layer or along any line through the model; and
(l) plots of time series of any variable.

All graphical presentations can be in colour and are produced with a UNIRAS graphical package.

The user can easily design, produce and display animation of any variable. This provides a unique opportunity to present the dynamic behaviour of the simulated system and adds a new dimension to error handling and interpretation of results.

APPLICATION EXPERIENCE

MIKE SHE is today being used operationally by a large number of organizations in different countries, ranging from university and research organizations to consulting engineering companies.

The original SHE version has been tested on a number of research catchments and applied to a few other projects, see e.g. Bathurst (1986), Storm et al. (1987), Refsgaard et al. (1991) and Refsgaard et al. (1992) for further details.

MIKE SHE is an extended version of SHE and has been applied to a large number of projects during the past few years. A list of applications in which DHI has been directly involved are shown in Tables 1 and 2 for research and consulting projects, respectively. These applications illustrate the very wide range of water resources problems for which MIKE SHE is a suitable tool.

In addition to the applications listed in the two tables MIKE SHE is used by other organizations in a large number of projects which are not known to the authors.

SHE was originally developed with a view to describing the entire land phase of the hydrological cycle in a given catchment with a level of detail sufficiently fine to be able to claim a physically-based concept (Abbott et al. 1986a; 1986b). The equations used in the model are, with few exceptions, non-empirical and well-known to represent the physical processes at the appropriate scales in the different parts of the hydrological cycle. The parameters in these equations can be obtained from measurements as long as they are compatible with the representative volumes for which the equations are derived.

In most regional catchment studies carried out so far, it has not been possible to represent the spatial variations in catchment characteristics with such a detail that the model could be considered physically-based. In fact, this was realized at an early stage when the applications changed from testing against analytical solutions and small-scale research areas to applications on medium sized catchment areas.

However, experience shows that the spatial resolutions and variations in properties used provide a very good representation of the conditions in the areas modelled. In practice the spatial variations are derived from maps describing topography, soil and land use patterns and interpreted geological conditions, combined with information about the general properties of the different map units. The model's parameter values are then modified during calibration to match observed conditions at discrete points.
Table 1 List of MIKE SHE applications on externally funded research projects.

<table>
<thead>
<tr>
<th>Location</th>
<th>Project Title</th>
<th>Period</th>
<th>Topics and references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>The quantitative and qualitative impacts of real-time control on surface waters and storm water drainage and infiltration for water supply in Berlin Friedrichshagen</td>
<td>1994-1996</td>
<td>Groundwater pollution from river and sewer system. Demonstration of real-time control possibilities. Coupling with MIKE 11 river modelling system and MOUSE urban drainage modelling system</td>
</tr>
<tr>
<td>UK</td>
<td>Modelling of the impact of contaminated land on water quality using the MIKE SHE model</td>
<td>1994-1995</td>
<td>Groundwater pollution, geochemical modelling</td>
</tr>
<tr>
<td>Denmark</td>
<td>Strategic environmental research programme</td>
<td>1993-1996</td>
<td>Groundwater pollution</td>
</tr>
<tr>
<td>Denmark</td>
<td>Validation of pesticide models</td>
<td>1994-1996</td>
<td>Leaching of pesticides in clayey soils with preferential flow paths</td>
</tr>
</tbody>
</table>

There are a number of fundamental scale problems which need to be carefully considered in the model applications. This is particularly important when describing the interaction between the surface flow and the subsurface flows. A few areas where scale problems are encountered include:

(a) The interaction between groundwater and river. Since the flow is based on Darcy's law using the gradient between the river water level and the groundwater heads in the adjacent grid squares, the flow rates and the resultant head changes will depend on the spatial resolution used. This is an important aspect in, e.g. simulating the hydrograph recessions correctly.

(b) In catchments with a dense drainage network it is often not possible to represent the entire drainage system (many streams are of ephemeral nature). For such situations sub-grid variations in the topography need to be accounted for in order to simulate the hydrograph response in the main streams correctly.

(c) For modelling of infiltration and vertical unsaturated flow in the soil, the hydraulic parameters used in Richards' equation can be obtained from laboratory measurements on small undisturbed soil samples. However, for grid squares covering large areas (e.g. 25 ha) these are seldom representative unless completely homogeneous
conditions exist in the horizontal directions. Therefore effective or representative parameters are used, which means that the simulated soil moisture conditions cannot be verified directly.

In fact much of the criticism against MIKE SHE often arises from the way the unsaturated flow is simulated and very seldom from how the groundwater conditions are treated.

For most catchment simulations, the use of Richards' equation becomes conceptual rather than physically based and simpler approaches could be chosen. Nevertheless, this equation provides a good routing description, and the capability to simulate capillary rise under shallow water table conditions is an important option for studies where, e.g. wetland areas are included. For situations where Darcy's law does not apply, a simple macro-pore option is included in the solution.

Because representative parameter values are used, the reliability of the results depends very much on the data available for comparison of the simulated spatial and temporal variations with observations. This is well-known from groundwater applications, where the aquifer properties (conductivities or transmissivities) are derived based on calibration against observed head variations in discrete points. For regional catchment studies, the model performance is usually evaluated based on comparisons against river discharges and groundwater heads. Very seldom are measured soil moisture data available, and if they are, such comparisons require that site specific properties are

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<tr>
<td>Estonia</td>
<td>Tapa Airbase - groundwater model</td>
<td>1993</td>
<td>Groundwater pollution</td>
</tr>
<tr>
<td>Slovakia</td>
<td>Danubian lowland — groundwater model</td>
<td>1992-1995</td>
<td>Surface water quality, river and reservoir erosion and sedimentation, groundwater quality and geochemistry (redox), wetland ecology coupling with ARC/INFO and Informix</td>
</tr>
<tr>
<td>Denmark</td>
<td>Six projects on optimization of remedial measures for safeguarding groundwater resources from pollution from waste disposal sites</td>
<td>1992-1994</td>
<td>Groundwater pollution</td>
</tr>
<tr>
<td>UK</td>
<td>River management study, River Avon, Wessex</td>
<td>1992-1993</td>
<td>Effects of groundwater abstraction and augmentation schemes on streamflow</td>
</tr>
<tr>
<td>Denmark</td>
<td>Environmental impact assessment of a highway construction</td>
<td>1992-1993</td>
<td>Effects of groundwater drawdown due to tunnel construction</td>
</tr>
<tr>
<td>Australia</td>
<td>Irrigation salinity</td>
<td>1991-1993</td>
<td>Process simulation of an irrigation district with focus on flow and salinity transport</td>
</tr>
<tr>
<td>Denmark</td>
<td>Two projects on identification of new well field for water supply</td>
<td>1991-1994</td>
<td>Groundwater, effects of abstraction on streamflows and wetlands</td>
</tr>
<tr>
<td>Hungary</td>
<td>Assessment of pollution hazards in groundwater supplies</td>
<td>1991</td>
<td>Groundwater pollution</td>
</tr>
<tr>
<td>Denmark</td>
<td>Water supply planning in Aarhus county</td>
<td>1988-1990</td>
<td>Groundwater resources, effects of abstractions on hydraulic heads and streamflows</td>
</tr>
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known.

It is often stated that distributed models require a large amount of data and are therefore very time consuming and complicated to set up and calibrate. In fact, a number of short-term screening evaluation projects have been carried out with MIKE SHE, e.g. in connection with studying the contamination risks from waste disposals. In these studies only sparse existing information about the hydrogeological conditions was available. The model was used to obtain an improved knowledge about the possible flow patterns around the waste disposal site based on the existing geological interpretations. These applications could also be used to identify where existing knowledge is lacking and assist in defining an appropriate monitoring programme.

Another common argument against distributed models is the risk of over-parameterization. This risk is, of course, always there. However, the general experience is that if the data to describe the spatial variations in the catchment are lacking, it is too time-consuming and not worthwhile to modify a large number of parameter values in order to improve, e.g. hydrograph predictions. In such cases very few parameters are used in the calibration and the reliability of the results are evaluated with this in mind.

**ONGOING RESEARCH**

From the above application records it appears that MIKE SHE has already been used comprehensively both for research studies and for practical routine applications. These applications reflect that for certain types of studies there is no adequate alternative to an integrated, distributed, physically based modelling approach like MIKE SHE. Nevertheless, it is realized that MIKE SHE, in its present form, is far from being complete as a tool for advanced hydrological analyses. Many problems, both practical and fundamental, need to be solved through future research activities. A very significant part of the research carried out recently in the international scientific community is, in fact, of direct relevance and most valuable in this context.

At DHI research and developments related to MIKE SHE is carried out in the following fields:

(a) Improvement of process descriptions. Research work on macro-pore flow and solute transport is presently being undertaken. Other activities such as inclusion of density effects in the groundwater component and description of hysteresis phenomena in the unsaturated zone are planned in the coming years.

(b) Improvements in numerical efficiency are taking place continuously.

(c) An interface to geographic information systems (ARC/INFO) is being developed.

(d) Coupling with DHI’s generalized river modelling system MIKE 11 (DHI, 1994) is on-going. A coupled MIKE SHE/MIKE 11 enables description of sediment transport and water quality processes in the river system, as well as description of complex river and canal systems with hydraulic control structures. A typical area of application is irrigation command areas, where networks of both irrigation and drainage canals exist together with a large number of different hydraulic regulating structures.

(e) Fundamental research on the establishment of rigorous methodology on parameterization, calibration and validation is urgently needed. Some first, small steps have been taken, as described in Refsgaard et al. (1992), Jain et al. (1992) and DHI
(f) Fundamental research on scale problems related to spatial variability of hydrological parameters is urgently needed. In particular, problems related to different scales used for data sampling, process description and model discretization need to be addressed. Although comprehensive international research is carried out in these years no operational results and conclusions are evident.

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