COUPLING BETWEEN THE RIVER BASIN MANAGEMENT MODEL (MIKE BASIN) AND THE 3D HYDROLOGICAL MODEL (MIKE SHE) WITH USE OF THE OPENMI SYSTEM

FLEMMING DAMGAARD CHRISTENSEN[1,2]

[1]*Geological Survey of Denmark and Greenland (GEUS), Ø. Voldgade 10*
1350 Copenhagen K, Denmark
[2]*DHI Water & Environment Agern Allé 11*
2970 Hørsholm, Denmark

In this study the integrated hydrological model MIKE SHE is coupled with the river management model MIKE BASIN with use of the OpenMI system. The OpenMI is an Open Modeling Interface, which provides a framework, which simplifies linking of existing model codes and requires a minimal reengineering of these involved numerical models. The OpenMI system is under development and described in a number of reports and conference papers see for example Gijsbers [1].

INTRODUCTION

Integrated water resources management may require numerical models, which can handle water flow and quality interaction between different domains, such as groundwater, unsaturated flow, overland flow, river, urban sewers systems etc. Most numerical models only apply to one or two of these domains and there is a need for coupling the existing models into an integrated model, which also could include economical models. This can be done by using the OpenMI system, which is under development, see the webpage for the harmonIT project at www.harmonIT.org.

The focus in this paper is on the two models MIKE SHE and MIKE BASIN and how they are linked through the OpenMI system. Two different types of linking are used; The first is a simple weak uni-direction link, where MIKE SHE supplies MIKE BASIN with data and the second link is a bi-directional link, where leakage from the river is calculated based on water level in both river and groundwater.

THE TWO LINKED NUMERICAL MODELS

In the following the two models are described with the purpose to show the domains that the models covers and therefore which type of data they could be provide or accept in a link.

The integrated hydrological model MIKE SHE

MIKE SHE is an integrated hydrological model which can simulate both water flow and water quality (See Refsgaard and Storm [2]), but focus here will only be on the water movement and not the solute transport and reactions. The model is written in FORTRAN

90 and FORTRAN 77 and is well-organized into modules and subroutines. The following processes of the hydrologic cycle are included:

- Precipitation (rain or snow)
- Evapotranspiration, including canopy interception
- Overland sheet flow (OL)
- River flow (Included through the river model MIKE 11)
- Unsaturated subsurface flow (UZ)
- Saturated groundwater flow (SZ)

Within each of these processes, MIKE SHE offers several different approaches ranging from simple, lumped and conceptual approaches to advanced, distributed and physically-based approaches. Simple and advanced approaches may be combined which leads to an unparalleled flexibility that truly enables tailoring the model to the hydrological problem rather than the opposite. The MIKE SHE model is under continues development, thus the number of approaches for the different processes of the hydrologic cycle are increasing and refined.

Table 1: The different approaches implemented in the MIKE SHE system for the hydrological cycle.

Domain	Complex	towards	less complexity
ET	K&J	...	Net Rainfall
OL	2D Distributed	Lumped (C&L)	...
UZ	Full Richards	Gravity	2-layer
SZ	3D and 2D distributed flow		Linear Reservoir
River flow	MIKE11 includes: simple Muskingum routing, kinematic wave and diffusive wave for the coupled version.		

Precipitation, Evapotranspiration or Recharge (ET)

If a model setup includes the unsaturated zone, MIKE SHE will calculate infiltration, actual evapotranspiration and recharge. If the unsaturated zone is not included, the groundwater recharge is directly specified instead of rainfall and evapotranspiration. For the current version MIKE SHE (version 2003) there are two evapotranspiration models: 1) A Kristensen and Jensen model (K&J) which is an empirically method proposed by Kristensen and Jensen [4], and 2) A simplified model based on a Two-layer Water balance method based on the findings of Yan and Smith [5].

Unsaturated Zone

The unsaturated zone model in MIKE SHE is a vertical soil profile model that interacts with both the overland flow and the groundwater, where the groundwater table is the lower boundary condition for the unsaturated zone. MIKE SHE offers three different approaches including full Richards equation model, a gravity flow model and a simple 2-layer root-zone mass balance approach. All three approaches require specification of certain soil-properties. The unsaturated zone model interacts with MIKE SHE's evapotranspiration model which calculates actual evapotranspiration as a function of reference ET, soil moisture and crop characteristics.

Groundwater Flow

MIKE SHE includes a traditional finite-difference of 2-D and 3-D Boussinesq equations for groundwater flow. Instead of the 2D or 3D finite-difference model a simple lumped conceptual approach can be used where a cascade of linear reservoirs account for the interflow and baseflow components to the river.

River Flow

MIKE SHE's river modeling component is the MIKE 11 modeling system for river hydraulics. MIKE 11 is a dynamic, 1-D modeling tool for the design, management and operation of river and channel systems, see Havnø et al. [3]. MIKE 11 supports any level of complexity and offers a simulation engine that covers the entire range from simple Muskingum routing to the Higher Order Dynamic Wave formulation of the Saint-Venant equations.

Overland Flow

MIKE SHE's overland-flow component includes a 2D finite difference diffusive wave approach. Instead of the 2D of diffusion model, it is possible to use a lumped overland flow based on a Crawford and Linsley empirical relation between flow depth and surface detention together with the Manning equation for discharge. The model is described in details in Fleming [6] and Crawford and Linsley [7].

OpenMI for MIKE SHE

OpenMI is for MIKE SHE used to make the model to an open-ended software system, which can link up to 3rd party software and technologies. Furthermore it would be easier to add/or shift approaches used for different water domains. For instance another evapotranspiration model could easily be added to MIKE SHE due to the open-ended nature of OpenMI and thereby enhancing the flexibility and applicability of MIKE SHE

The river management model MIKE BASIN

The MIKE BASIN model is a river management model addressing water allocation, conjunctive use, reservoir operation, or water quality issues. The model builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. In situations of water shortage, a conflict arises of how to distribute the water available in river among the stakeholders (users of water). MIKE BASIN solves this distribution problem by setting up priorities rules on a local or global scale and with different priority levels.

The overall modeling concept in MIKE BASIN is to find a stationary solution for each time step, and due to this stationary assumption, MIKE BASIN is good to find "typical" value for water quantity for slowly changing system. Thus the philosophy of MIKE BASIN is to keep modeling simple and intuitive, yet provide in-depth insight for planning and management. For detailed description, see DHI Water & Environment [8].
MIKE BASIN includes a very simple groundwater model, which is just one linear reservoir and with this groundwater model is not possible to quantify pumping effects as a function of distance to a river or include variability in the spatial net-recharge to the groundwater. These issues can be achieved by coupling MIKE BASIN and MIKE SHE through OpenMI.

THE OPENMI ARACHITECTURE

The core of the OpenMI architecture describes a small and standardized set of interfaces and classes that accommodate linkages between models. The OpenMI is in detailed described in *"Update on the HarmonIT Project. The OpenMI Standard for Model linking"* by Moore et al. [9], *"OpenMI – New Opportunities for Model developers"* by Westen et al. [10] and *"Catchment Decision Support Systems Using OpenMI"* by Fortune et al. [11], which all are papers in the current proceedings. The OpenMI system provides the standard of the data and link structure and the demands for the wrapper, see Moore et al [9] and Westen et al. [10]. The focus here will be on the MIKE BASIN and MIKE SHE coupling using OpenMI and not the OpenMI itself.

MIKE SHE and MIKE BASIN as an OpenMI-compliant model.

Figure 1 shows on the left side, the MIKE BASIN model and on the right side the MIKE SHE, where the setups of the two models are created in their respective Graphically User Interface (GUI). From this, a number of input files are created and the models read in the setups and during simulation create output files which can be viewed in the GUI. This is the normal execution of the models. The OpenMI configuration editor is used to setup the link between MIKE SHE and MIKE BASIN while the communication between the models during runtime is done through the wrapper with "GetValues" calls to the model engines. Thus each model still has it own setup and the results are viewed in their respective GUI's.

The first task for making the two models an OpenMI-compliant model is to convert the model engine into a component which easily can be wrapped into an OpenMI "LinkableComponent". For the FORTRAN model, MIKE SHE, it is just to create a win32 library instead of a executable application and export a number of entries to the model engine, for instance the main methods such as Initialize(), PerformTimeStep(), SetValues() and GetValues(). The C^{++} model, MIKE BASIN, it is already a component and the access to model engine is easily connected through managed C^{++} code. In this way all the necessary methods in the MIKE BASIN are accessible. Thus the reengineering for MIKE BASIN is very small, while for MIKE SHE a few hundreds lines of new code had to be written.

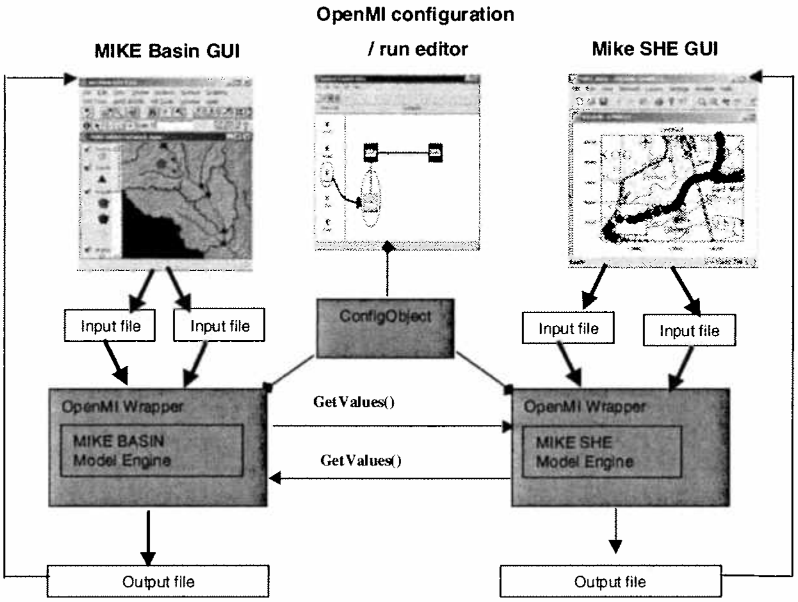

Figure 1. MIKE BASIN and MIKE SHE linked through the OpenMI system.

The next step is to create a model specified wrapper for each model, which takes care of the implementation of methods for LinkableComponent class, link handling, and the interface to the model engines. This process is easily done by creating a specific wrapper class inhered from the OpenMI Utility wrapper. Only a few adjustments and implementations are necessary to the inherited wrapper class in order to access the model engine core. Finally the system in Figure 1 is created.

Before runtime, the links between the models need to be configured and this is done with the OpenMI configuration tools, which read in XML files that contains information on the model components (textual description, version number, company etc.)[1] and the exchangeable data[2]. Information on the exchangeable data includes accepting and providing quantities (e.g. water table, fluxes, flow and etc.) and where it can provide or accept these quantities.

Use of the linked models

The coupling between MIKE SHE and MIKE BASIN is used for two cases for which the results will be shown at the conference. The first case is a large setup, but less detailed thus the computing time is reasonable. It includes for MIKE SHE: 1) the simple 2-layer model for the unsaturated zone, 2) the Crawford and Linsley model for overland flow and 3) for the saturated zone linear reservoirs model is applied. MIKE SHE provides then

[1] Called Component descriptor in OpenMI terms
[2] Called Exchange model in OpenMI terms

overland flow, baseflow and interflow for each predefined subcatchment (polygon) to the MIKE BASIN river nodes. This link is created in the OpenMI configuration editor and the initialization phase is ready to start.

Initialization phase

Figure 2 shows a sequence diagram for the initialization phase where the setups of MIKE SHE and MIKE BASIN are constructed based on their input files. The link, between the linkable components is established based on the configuration information. The link (see the figure) has an ID and contains information on input and output quantities and elements and data operations (dataOps in the figure). Data operations are set when the results are mapped from one element set to another element set. For the current case the "input-quantity" is inflow to an "input-elements", which contains of MIKE BASIN river nodes located in an XY-coordinate system. The "output-quantity" is subcatchment outflow, which consist of overland flow, interflow and base flow and the "output-elements", is the MIKE SHE subcatchment-polygons defined in an XY-coordinate system. Due to the different element type, results from the polygons have to be mapped to river nodes and this is done by using the OpenMI spatial utility. The method that equally distributes the subcatchment flow among the river nodes inside a polygon is picked. The link is then added to the two model engines through their wrappers.

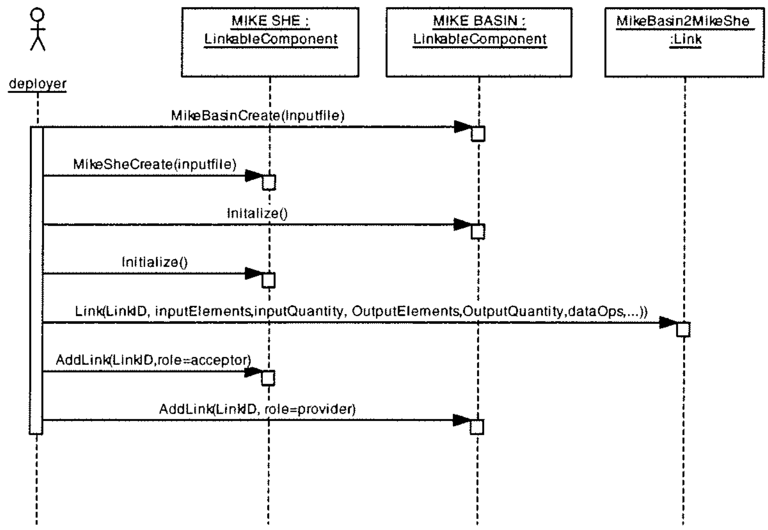

Figure 2. The initialization phase, where the actual models are constructed and the link is established

Execution of the linked models

The computation starts with the "deployer" performs at GetValues() call to MIKE BASIN linkable component at a specified timestamp. As seen on figure 3, the MIKE

BASIN starts to simulate, but it requires data from MIKE SHE and therefore calls GetValues() to the MIKE SHE linkable component. MIKE SHE starts now to compute and returns the results.

In this setup the MIKE SHE model general uses a smaller time step than MIKE BASIN and when MIKE SHE is done with one time step, it save the required results in an OpenMI utility buffer. After MIKE SHE have reached the end of the requested time interval, sum of the subcatchment flow within the requested time interval is calculated in the buffer and the results are return to MIKE BASIN. Now MIKE BASIN can start on it's next timestep and so it continues till MIKE BASIN can return the results to the deployer. The simulation results from MIKE SHE and BASIN will then be viewed in their respective GUI's.

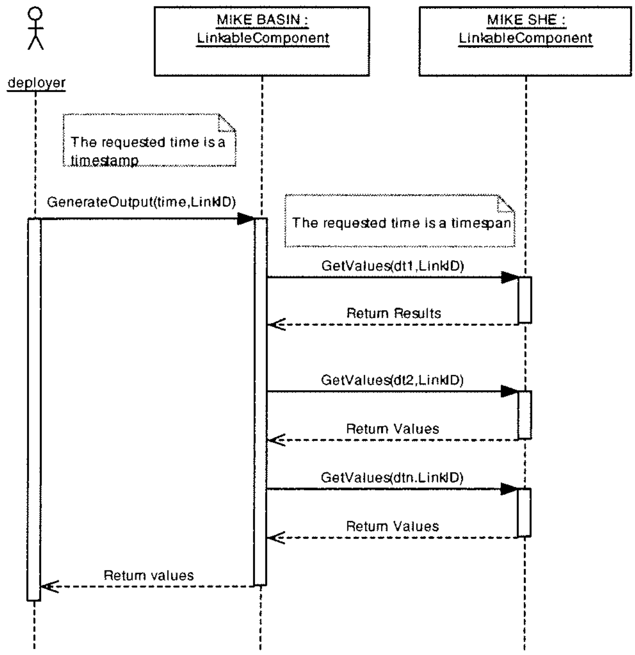

Figure 3. Simulation process for the uni-linked models.

This first case with a large model area has been tested with some preliminary simulations, but at the conference the real setup¸ with "measured" landuse data, precipitation data etc. will be shown. The next case, where the linked models are used, is for a smaller but more detailed setup for the groundwater. Here a net-recharge is used for input to the 3D finite groundwater model and the link to river model is a bi-directional link where the leakage between the river and groundwater is calculated based on the difference in water levels between river and groundwater. Furthermore the MIKE BASIN will control the pumping rate in groundwater in the MIKE SHE model for addressing the water allocation. Preliminary simulations from this second case will also be shown at the conference.

CONCLUSION

The OpenMI simplifies linking of MIKE SHE with MIKE BASIN codes and have only required a relatively small reengineering of up to a couple of hundreds lines of code compared to the thousand lines of codes in these involved models. Through the OpenMI the flexibility and applicability of the models are enhanced, however performance issues have not yet been investigated by comparing a tailor link with a link through OpenMI.

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