DAISY – MIKE SHE coupling using OpenMI

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The NiCA project is led by GEUS (contact: Jens Christian Refsgaard, mail: jcr@geus.dk) and comprise the following partners:

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- Department of Earth Sciences, Aarhus University
- Knowledge Centre for Agriculture
- Laval University, Quebec, Canada
- Aarhus Geophysics
- Alectia A/S
- DHI
- SkyTEM
- Municipality of Aarhus
- Municipality of Odder

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1. Introduction

1.1 Motivation and purpose

Nitrate leaching can be estimated by different methods. The simplest method is to assume a balance between N inputs and outputs on an annual basis, i.e. the leaching equals the inputs from fertilisation plus aerial deposition minus outputs to crop yield and denitrification. This assumes that the pools of organic N in the soil do not change over time. A more comprehensive description can be provided by the mechanistic soil-plant-atmosphere DAISY code (Hansen et al., 1991; Abrahamsen and Hansen, 2007) that considers dynamic aspects, including changes in soil organic carbon storages. DAISY has traditionally been used in catchment based nitrate modelling in Denmark (Styczen and Storm, 1993 a,b; Refsgaard et al., 1999, Hansen et al., 2009) coupled to the hydrological modelling system MIKE SHE (Abbott et al., 1986; Graham and Butts, 2005; Refsgaard et al., 2010). The traditional DAISY – MIKE SHE coupling has been sequential with DAISY providing inputs to MIKE SHE in terms of N-leaching from the root zone without any feedback from the groundwater system (MIKE SHE) to the root zone (DAISY). This lack of feedback has long been considered a weakness that could potentially bias the simulation results, because the groundwater table in large parts of the country is so close to the terrain that it influences the root zone conditions and hence the N-leaching.

According to the NiCA project description from 2009, three alternative tool for simulating the nitrate leaching from the root zone should be used and compared: (a) a fully coupled DAISY-MIKE SHE code developed by use of OpenMI techniques (Gregersen et al., 2007) and made operational as part of the NICA project; (b) the standard use of DAISY and MIKE SHE as two separate codes used sequentially without feedback from the groundwater table in MIKE SHE to the lower boundary condition (groundwater table) in DAISY (Abrahamsen and Hansen, 2000); and (c) a simpler N-balance method, where the annual N leaching is based on existing agricultural management data reported from farmers to the authorities and the annual values subsequently converted to daily concentrations by use of DAISY.

The work on the N-balance method and the comparison to the standard use of DAISY has been reported in another NiCA Technical Note (Thirup, 2013). The purpose of the present note is to report the work carried out on coupling of the DAISY and MIKE SHE codes.

A comprehensive description of the whole NiCA project model, including the nitrate leaching is given in Refsgaard et al. (2014).

1.2 Previous work on DAISY – MIKE SHE couplings

Initial attempts to couple the DAISY and MIKE SHE codes were started in 1996 under an EU FP4 project (UNCERSDSS) and finalised in two Danish funded research projects (Pesticide modelling at catchment scale under the Strategic Environmental Research Programme, and RS-Model under the Earth Observation Programme) and reported in Christiansen et al. (2004) and Boegh et al. (2004). This first coupling, where DAISY was hard coded into MIKE SHE, turned out to be too difficult to maintain and was abandoned.
The primary weakness of a hard-code coupling is that the DAISY version embedded in MIKE SHE is static. Advancements in the original DAISY code must be added manually to the hard-coded coupled version. This is difficult and time consuming. The OpenMI model interface developed by the OpenMI Consortium (www.openmi.org) provides a technology that allows a more modular approach. OpenMI compliancy is analogous to the USB interface on computers, where any USB compliant device can be plugged into any USB port. OpenMI compliancy allows any external user to link any OpenMI compliant software together. The principle requirement is that both codes must maintain the support for the OpenMI programming interface.

Thus the DAISY – MIKE SHE coupling was revisited to develop a more flexible coupling that would allow the coupling to be more easily updated as the individual codes evolved. This coupling was performed within the context of the pesticide modelling project, SAFIR, funded by the European Commission within the Sixth Framework Programme between 2002 and 2006. This project established a coupling that functioned in a single setup. However, the coupling was neither fully documented nor fully tested. Thus, the coupled version could not be generally applied by users outside of the original developers.

The objective of the NiCA efforts was to test and document the existing OpenMI-based DAISY – MIKE SHE coupling. The tests were designed to confirm its applicability for nitrate modelling. The documentation would enable the coupled models to be applied operationally by the wider user community.

1.3 External developments

When the NiCA proposal was prepared, DAISY was being used extensively by the Danish authorities for water resources studies. Studies for groundwater protection and nitrate modelling of small (5-15 km²) well monitored agricultural LOOP catchments (Rasmussen, 1996) were tendered to consulting companies. They were commissioned by the Danish Counties until the Danish Counties were dissolved as part of the municipal reform in 2007. At this time, responsibility for groundwater planning was transferred to the federal Ministry of Environment. After some time, the Ministry changed its policy and reduced the number of groundwater planning and nitrate studies it commissioned. Today, the number of nitrate modelling studies being commissioned is effectively zero.

DHI is committed to make all its MIKE software products compliant with the OpenMI programming interface. OpenMI compliancy of the MIKE software is a necessary, but not sufficient, precondition for maintaining an operationally functional DAISY – MIKE SHE coupling. The other necessary requirement is that the DAISY developers maintain the compliancy of the DAISY code.

Given the more than 12 years of development history of the DAISY - MIKE SHE coupling and the invested effort by both developers, it was logically assumed during the NiCA project proposal phase that the OpenMI compliancy would be maintained for both MIKE SHE and DAISY. However, since the development of the initial OpenMI-based DAISY – MIKE SHE coupling, the DAISY developers have not maintained the OpenMI compliancy of the DAISY code. As the DAISY developers were not part of the NiCA consortium, there was no direct responsibility for compliancy to be updated.
2. The DAISY – MIKE SHE Coupling

The primary weakness of any hard-coded coupling is that one code must be embedded in the other and the embedded code becomes static – unless any changes in the original code are manually updated in the embedded version. This is difficult and time consuming. In the original DAISY – MIKE SHE coupling, the DAISY code was embedded in MIKE SHE.

However, technological advances in computing, the impetus provided by the Water Framework Directive in Europe, co-funding from the European Commission and support from the leaders of earlier attempts has now enabled the FP5 project HarmonIT to develop the Open Modelling Interface (OpenMI).

The OpenMI Association (www.openmi.org) is a not-for-profit foundation established with funding from the European Commission and support from the founding members (DHI was a founding member). The impetus was driven by the European Water Framework Directive to improve water quality across Europe – of which an important component is the interoperability of water-related numerical models.

**OpenMI Version 1.0** – The initial funding for the OpenMI Association came from the HarmonIT project; a research project supported by the European Commission under the Fifth Framework Programme and contributing to the implementation of the Key Action “Sustainable Management and Quality of Water” within the Energy, Environment and Sustainable Development. Contract no: EVK1-CT-2001-00090. The result of this project was OpenMI Version 1.0 released in 2005.

**OpenMI Version 1.4** – The second official version of the OpenMI standard was released in 2007 as part of the OpenMI Life project. The OpenMI-Life project was again supported by the European Commission under the Life Programme and contributing to the implementation of the thematic component LIFE-Environment under the policy area "Sustainable management of ground water and surface water management" Contract no: LIFE06 ENV/UK/000409.

**OpenMI Version 2.0** – The third and latest version of the OpenMI standard was released in 2010. This version improved on the versatility compared to OpenMI Version 1.4. OpenMI 1.4 was mainly restricted to models that progress in time, whereas OpenMI 2 offers a set of base interfaces that are not aware of the type of a model. These interfaces can easily be extended, to express the exchange items and their values in terms of ontologies, instead of in terms of spatial and time scale definitions.

The OpenMI Interface is a standard interface that enables OpenMI components to exchange data as they run. An OpenMI component is a piece of software that complies with the OpenMI requirements. The OpenMI standard is a flexible set of open source programming tools and model interfaces to facilitate model coupling. OpenMI compliancy is analogous to the USB interface on computers, where any USB compliant device can be plugged into any USB port. OpenMI compliancy allows any external user to link any OpenMI compliant software together. The principle requirement is that the coupled codes must maintain the support for the OpenMI programming interface. If this condition is met, then
updates in the base codes can be relatively easily integrated by simply updating the inter-
face between the codes.

The DAISY – MIKE SHE coupling for the NiCA project was based on the
- Original SAFIR pesticide version of the DAISY – MIKE SHE coupling was based on
  DAISY version 4.92 (from about 2006),
- MIKE SHE Release 2011, Service Pack 4, and
- OpenMI Version 2.0.

Technically, MIKE SHE is running both a Water Movement (WM) and a Water Quality (WQ)
model separately. Further, the river flow is calculated by MIKE 11. In a fully coupled sys-
tem, there could be up to four separate executables running, including DAISY. The WM
model calculates the groundwater level and the fluxes to and from the Saturated Zone (SZ)
boundaries. Normally, the WM also includes the Unsaturated Zone (UZ), but in a coupled
simulation, the UZ module is not active and the DAISY model provides the UZ fluxes from
the surface to the groundwater table, and MIKE SHE provides DAISY with the depth of the
groundwater table. DAISY uses the groundwater table as its lower boundary condition.
Likewise, for the WQ model, MIKE SHE takes care of the SZ solute transport and fluxes,
whereas DAISY provides the solute fluxes to the SZ, and MIKE SHE provides the solute
concentrations in the groundwater to DAISY.

An OpenMI Master program controls the running of MIKE SHE and DAISY and the ex-
change between them. This is accomplished by a series of Triggers, which calls the pro-
grams as needed and connects the output of one program to the input of the other.
3. Test of the DAISY – MIKE SHE coupling

3.1 Planned test setup

Considerations for the test scheme
To test the DAISY – MIKE SHE coupling, it was planned to compare the results from the coupled models with results from the models run separately, which is the traditional way to run the models. We found it important to test a setup that included situations both with and without expected differences in the results from the two model setups. In areas with periodically high water table, different results would be expected for some variables, while no differences would be expected in areas with a thick, steady unsaturated zone.

We planned a hillslope test based on the existing coupling described in Chapter 2. Boundary conditions, slope, soil type, drainage, etc. were adjusted to create a setup that allows comparative aspects in situations with and without expected differences in the water and N-fluxes across the model boundary between DAISY and MIKE SHE.

Outline of actual test setups
In the hillslope test the following situations were planned to be represented (lower boundary conditions in DAISY):

- Thin unsaturated zone at the bottom of the slope.
- Thick unsaturated zone at the top of the slope
- Between the top and bottom the unsaturated zone transitions from thin to thick.

In the MIKE SHE model, this is set up with a cell size of 50x50 m and covers the simulation period 1 January 1998 – 30 December 2000. It includes the saturated zone (6 layers), overland flow and river flow (MIKE 11). The SZ model has a fixed head boundary condition in the upstream (North) end and the water leaves the model via the river at the downstream end.

In the DAISY model these situations can be represented in three DAISY columns. All the DAISY setup files are identical with the exception of the lower boundary conditions. The drainage is coded in the DAISY model. DAISY is run with repeating growing spring barley year after year. The weather file is from Norsminde, which is one of the test sites in the NiCA project.

The results from running the coupled versus uncoupled DAISY and MIKE SHE were planned to be compared at the following points:

Nitrogen balance:
- N-harvest
- N-leaching from the root zone
- N-leaching in drain
- N-leaching to the stream at the bottom of the slope

Water balance:
- Evapotranspiration
- Flux out of the root zone
• Flux to drain
• Flux to the stream at the bottom of the slope
• Ground water level

Dynamic / Timing:
• Water and nitrogen in drain
• Water and nitrogen to the stream at the bottom of the slope

3.2 Test results – coupling not operationally functioning

The DAISY, MIKE SHE and OpenMI setup files were created as planned. The models run fine individually. However, when run coupled, the DAISY and MIKE SHE models do not exchange data as expected. This problem occurs because the OpenMI interface has not been maintained and updated in the newest DAISY versions. We involved the DAISY group in the troubleshooting, but we were still not able to create a DAISY model setup that runs coupled with MIKE SHE.

After a considerable effort, we now have to recognize that it is not possible to couple DAISY and MIKE SHE in the context of the NiCA project. Our analysis shows that the following software developments are required to make the coupling functional:

• The DAISY OpenMI interface must be updated to OpenMI Version 2.0
• DAISY’s OpenMI coupling interface developed in DAISY Version 4.92 (from about 2006) must be ported to the newest version of DAISY.
• The DAISY side of the DAISY – MIKE SHE coupling must be updated to account for numerical corrections made in MIKE SHE since the first coupling attempt to DAISY Version 4.92.

These three activities represent major and fundamental software efforts by the DAISY research group, who are not part of the NiCA consortium. Thus, these efforts are beyond the scope of NiCA.
4. Perspectives for the future of the coupling

Conditions for having an operational coupling
To ensure the longevity of a functional DAISY – MIKE SHE coupled framework, four conditions must be met. There must be a:

- Long term commitment to establish and maintain a coupling from the MIKE SHE developers (DHI);
- Long term commitment to establish and maintain a coupling from the DAISY developers (University of Copenhagen);
- Major effort to demonstrate the usefulness of the coupled framework, including comprehensive testing and documentation of the coupled tool; and
- Market demand for such tool.

Need for coupling
Although a market demand is required to ensure the longevity of the coupling, the coupling is of

- Considerable scientific interest, as previously documented by Christiansen et al. (2004) and Boegh et al. (2004).
- Potential practical interest. The Danish market/demand is not as promising as when the NiCA project was conceived. However, there may be international interest for such a tool.
5. Conclusions

- The MIKE SHE part of the OpenMI coupling between DAISY and MIKE SHE was developed further after the original OpenMI coupling as part of the SAFIR pesticide project. This included correcting a few numerical errors in MIKE SHE and tailoring the interface to be used also for non-pesticide applications.

- A scheme for testing the DAISY – MIKE SHE coupling on a nitrate modelling case was designed and model setups were created both for MIKE SHE and DAISY. When attempting to run the coupled code it turned out that the current versions of DAISY and MIKE SHE do not exchange data correctly. This problem occurs because the OpenMI interface and coupling in DAISY has not been maintained and updated in the newest DAISY versions.

- Re-establishing the OpenMI coupling in the most recent version of DAISY and ensuring its operability for nitrate modelling will require a major effort that is outside the scope of NiCA.

- To make the coupled model tool attractive for external users will require a long term commitment from both the MIKE SHE developers (DHI) and the DAISY developers (University of Copenhagen). Today, the DAISY group does not see sufficient interest to be able to make such commitment.

- A DAISY – MIKE SHE coupling is still scientifically interesting. However, the Danish market for DAISY related studies among consulting companies has almost disappeared during the past five years. Thus, the interest among practitioners is probably quite limited at present.
6. References


