Advances in integrated hydrological modelling with the LIQUID framework

F. Branger

S. Debionne

P. Viallet

I. Braud

S. Jankowfsky

See next page for additional authors

Presenter/Author Information
F. Branger, S. Debionne, P. Viallet, I. Braud, S. Jankowfsky, O. Vannier, F. Rodriguez, and S. Anquetin

International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Advances in integrated hydrological modelling with the LIQUID® framework

F. Branger[a], **S. Debionne**[b], **P. Viallet**[b], **I. Braud**[a], **S. Jankowfsky**[a], **O. Vannier**[c], **F. Rodriguez**[d] **and S. Anquetin**[c]

[a]*Cemagref, UR HHLY, 3bis quai Chauveau CP220, 69336 Lyon Cedex 09, France (flora.branger@cemagref.fr)*

[b]*HYDROWIDE, 1025 rue de la Piscine, 38600 Saint-Martin d'Hères, France*

[c]*LTHE, Université de Grenoble (CNRS, INPG, IRD, UJF), BP 53, 38400 Grenoble Cedex 9, France*

[d]*LCPC, Nantes, Division Eau et Environnement, BP 4129, 44341 Bouguenais Cedex, France*

Abstract: Environmental modelling frameworks are valuable and increasingly used tools for building customized models, in a context where the complexity of management issues and the availability of data require much flexibility. The LIQUID® framework has been developed since 2005. It is mostly dedicated to hydrological modelling. It aims at easily integrating hydrological processes while preserving their characteristic temporal and spatial scales. LIQUID® allows the user to build and run integrated models on the basis of reusable and exchangeable modules. It provides templates for easy development of new modules, connections to databases and GIS for data input and output, and module coupling mechanisms, that synchronize different time steps and handle irregular geometries. LIQUID® suits a wide range of applications, involving various spatial scales and process conceptualisations. The framework is also able to simulate complex interactions between modules, in particular including feedback. The paper will present the recent advances of LIQUID®, in terms of concepts as well as in terms of technical specifications, and a brief overview of the ongoing main applications. Those deal with the assessment of landscape management impact on hydrology in agricultural and suburban areas, and with the analysis of hydrological responses in the context of flash floods.

Keywords: LIQUID®; integrated modelling; framework; distributed hydrological models

1 INTRODUCTION

For several years, environmental modelling frameworks have been increasingly developed and used. They offer the possibility to build and run customized integrated models on the basis of reusable and exchangeable components. Simulation models are built by connecting these components together. The models are run through a communication system that allows components to exchange data during simulation progress. This modular approach suits particularly well water management issues as the setup of hydrological models requires much flexibility, depending on the study objectives, the size of the target catchment, the dominant processes and the availability of input and validation data.

Along with other projects for model integration such as the OpenMI [Gregersen et al., 2007], JAMS [Kralisch et al., 2007], or WaterCAST [Argent et al., 2009], LIQUID® is such a framework. It specifically aims at integrating hydrological processes while preserving their characteristic temporal and spatial scales. It has been developed since 2005 by Hydrowide [Viallet et al., 2006], while many components and models have been built and used by Cemagref and Grenoble University laboratories [Branger et al., 2010]. The objective of this paper is to present the recent advances of LIQUID®. An overview of LIQUID® concepts and technical specifications is given in Sec. 2. Sec. 3 illustrates how LIQUID® is currently used in practice by hydrologists and Sec. 4 gives an insight into past and ongoing applications.

2 OVERVIEW OF LIQUID® CONCEPTS

LIQUID® implements the classical features of environmental modelling frameworks. It manages a library of model components, called modules, that contains conceptualizations for various hydrological processes. Models can be constructed from these modules through a build system. A discrete event simulator, the Scheduler, handles the time course of simulations and allows the modules to communicate at runtime. Tools are available to make the development of new modules easier, such as additional libraries (for example for numerical analysis or geometry computations such as mesh generation), but also a test framework (for unit tests but also more complex module tests, such as comparisons of module outputs with analytical solutions), a system for automatic generation of code documentation and a collaborative development environment that includes a version control system, a website, mailing lists and forums. LIQUID® is developed in C++ and is mostly used under the Windows operating system, although the use of ANSI C++ makes it portable. The modules are mostly implemented in C++, but since recently the integration of code in other languages (e.g. Fortran) is also possible. More detail about LIQUID® concepts and implementation can be found at *www.hydrowide.com/liquid*.

2.1 Modules and models

A module simulates one or several hydrological processes with specific time and space scales. All types of process representations are allowed, from simple empirical conceptualizations to numerical solutions of partial differential equations.

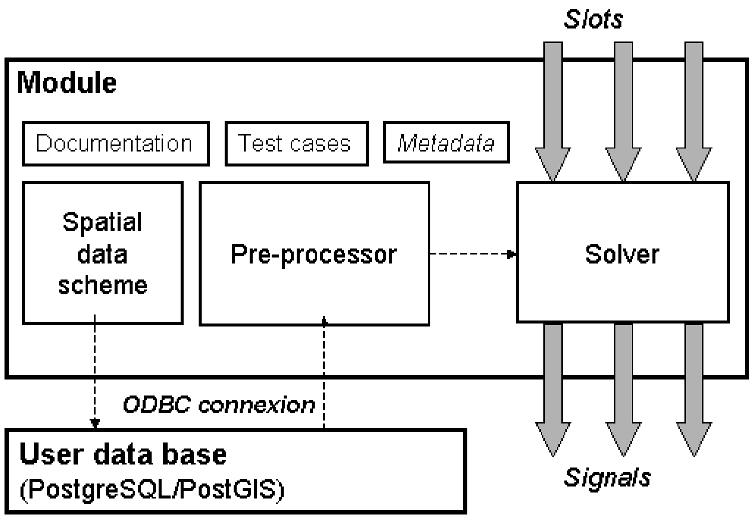

Figure 1: Structure of a LIQUID® module

In LIQUID®, each module is autonomous. The structure of a module consists of a data scheme, a pre-processor and a solver (Fig. 1). The data scheme contains the parameters and initial values that are required for the computation, as well as the description of the simulation domain (geometry) which the module is applied on. Geometries are described as vector data (lines or polygons, depending on the module), following the principle of space discretization in hydrological response units and hydro-landscapes [Flügel, 1995; Dehotin and Braud, 2008]. According to this data scheme, empty tables are created in a PostgreSQL/PostGIS database, that is connected to LIQUID® through an ODBC connection. Once the user has defined the parameter values, the pre-processor reads the data and initializes the solver with the parameters and initial values. For each record in the data scheme tables, a solver instance is created and initialized.

The solver is where the hydrological computation takes place. Each solver is responsible for its own time step, which is estimated again at each execution according to the solver's internal state. The solver is also able to interrupt the computation and shorten its time step if required. The communication with the outside world is managed through the solver slots (inputs) and signals (outputs). Slots also indicate the solver response to the inputs. For example, this response can be an interruption in order to take into account a new input value immediately. There is one slot per input variable. Signals send the output values at each solver execution. There is also one signal per output variable.

A model is simply a collection of modules that are connected through their slots and signals.

2.2 Simulation progress

The Scheduler manages the time course of simulations. It can be defined as a shared calendar where the different module solvers schedule their executions. At a given time step during a simulation, when a module solver has estimated its next time step, it schedules its next execution as a new call in the Scheduler. At the scheduled date, the Scheduler then acts as an alarm-clock and calls the solver. Thus simulation progress is possible with a variable time step.

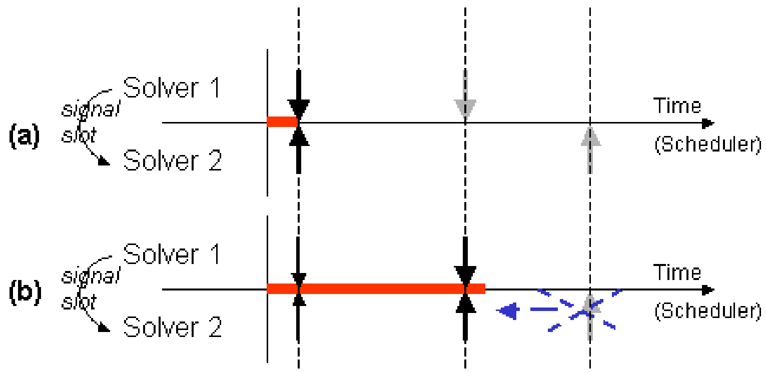

Figure 2: Example of communication between two solvers: (a) initial situation; (b) Solver1 sends a signal after its execution, that is connected to a Solver2 slot. Solver2 thus re-schedules its next planned execution. Effective executions are represented with black arrows and planned executions with gray arrows.

Combined with the slots and signals, this system allows the modules to communicate during a simulation, as represented in Fig. 2. In this example, a signal of Solver1 is connected to a slot of Solver2. Fig. 2b shows what happens if this slot specifies that the next planned execution of Solver2 should be cancelled and rescheduled immediately when a new value is received. This is how solver executions are synchronized in LIQUID®. With appropriate definitions of slots and signals, all sorts of couplings between solvers can be simulated, from the weakest one-way coupling to strong couplings involving feedbacks.

2.3 Spatial connections between modules

In most LIQUID® models, the application catchments are discretized into hydrological response units or hydro-landscapes, with irregular polygon or line geometries. A module instance is then applied on each hydro-landscape. When there are process interactions between the spatial units (e.g. routing of overland flow, groundwater flow…), they must be accounted for through the slot / signal connections. This means that the slots and signals must carry information not only on the exchanged values and dates, but also on which hydro-landscapes they are associated with. The first solution that was implemented in LIQUID® was to connect the slots and signals of the different spatial units according to the identification numbers of the solvers (*one to one* connection, see Fig. 3a).

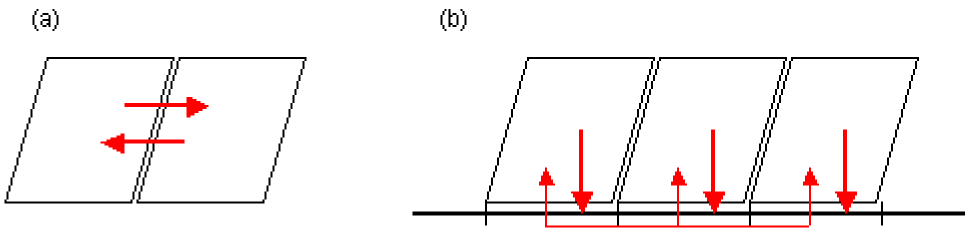

Figure 3: Examples of spatial connections managed by the LIQUID® framework:(a) one to one connection between two adjacent hydro-landscapes); (b) n to one connection between several hydro-landscapes and one river subdivided in reaches.

However, with the setup of more complex catchment models, this solution soon appeared to be restrictive as several other connection types may be encountered. As shown in Fig. 3b, there are cases where one solver has several slots / signals for one variable (e.g. for a river solver, one slot / signal for each reach). Therefore *n to one*, *one to n* and more generally *m to n* connections must also be considered. Improvements to the definitions of slots and signals were done recently to handle this problem. Inside a given solver, the slots and signals now have their own identification numbers. The connections between the spatial units are made directly through these numbers.

3 LIQUID® IN PRACTICE

3.1 How to develop a module

A module consists of a set of C++ code files. LIQUID® provides templates and examples, so that a non-expert C++ programmer does not have to bother with the file structuring and just needs to complete a pre-written canvas. The first task is the definition of the module data scheme, and the solver main computing variables, slots and signals. Then the module developer must implement the slots, the pre-processor and the solver main computing functions. LIQUID® provides now default ready-to-use slot implementations for the most common cases. In the solver, the developer can choose freely the most convenient equations and solving methods. The only rule to follow is that the implementations must be time step independent, so that the solver can be run with a variable time step. Therefore, in comparison with more classical approaches, it may be necessary to question the modelling concepts and formulations more in-depth when developing a module.

```xml
<connection>
  <from>
    <instance>source</instance>
    <signal>m_sigData</signal>
  </from>
  <to>
    <instance>river1d</instance>
    <slot>m_slotSource</slot>
  </to>
  <name>source</name>
</connection>
<connection>
  <from>
    <instance>lateralflow</instance>
    <signal>m_sigData</signal>
  </from>
  <to>
    <instance>river1d</instance>
    <slot>m_slotLateralSubsurface</slot>
  </to>
  <name>lateralflow</name>
</connection>
```

Figure 4: Example of *.model* file

3.2 How to build a model

In order to build a model, the user must simply select the appropriate modules and connect their slots and signals. Input and output modules are also available. The input module forces the other modules with time series (e.g. rainfall series) stored in a database. The output module prints simulation results in ASCII files. The model assembly task is done through a file with a *.model* extension (Fig. 4). The LIQUID® build system reads the *.model* file, translates it to C++ code, compiles the appropriate modules and generates an executable file. As represented in Fig. 4, the user specifies only the names of the modules and those of the slots and signals in the .model file. The effective connections of the slots/signals for the different spatial units of the model are made automatically by LIQUID® at the pre-processing step.

3.3 How to run a model

The model executable file can be run independently from LIQUID®. An ODBC connection to a PostgreSQL/PostGIS database is all that is needed. The run of a model takes three steps. First, a set of empty tables is generated in the user's database, according to the data schemes of the different modules involved in the model. For each module, the data scheme consists usually of one to five tables. Once all these tables are completed by the user, the second step is the pre-processing of the modules and the initialization of the module solvers. The last step is the model run itself, according to the start and end dates indicated by the user. All these steps can be done in a command line environment and since recently through a simple graphical user interface (Fig. 5). Model outputs are stored in text files, so that the simulation results can be visualized and processed by the user's favorite software. We are currently using mostly the R[1] software for which we have developed scripts for plotting LIQUID® models outputs.

4 ONGOING APPLICATIONS

Since 2005 more than 20 modules have been developed, representing a wide range of hydrological processes, conceptualizations and scales. The module library currently contains several modules for soil infiltration and surface runoff, with either conceptual (reservoir-based) or physically-based (Richards equation) approaches. Some of them are designed for specific environments (agricultural fields, hedgerows, urbanized areas). There are also a set of modules for evapotranspiration, including plant growth and root extraction, two modules for river flow, three modules for groundwater flow. Specific modules were developed for agricultural drainage, including a conceptual

[1] http://www.r-project.org/

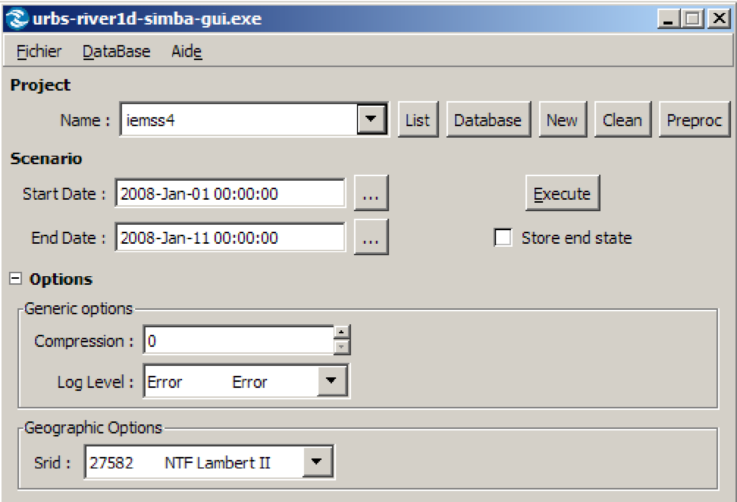

Figure 5: The graphical user interface used to run LIQUID® models

pesticide transport module. A lumped rainfall-runoff module is also available.

LIQUID® has been used for local scale applications, with the development of a conceptual model for pesticide transport in a tile-drained field [Branger et al., 2009], and a more detailed study of the influence of pipe pressurization on the discharge of a tile-drained system [Henine and Nedelec, 2009]. At the catchment scale, LIQUID® models were built and used to investigate:

- the effect of landscape management practices (drainage, hedgerows, ditches) on the hydrology of a small agricultural catchment [Branger et al., 2008]
- the sensitivity of models to the rainfall distribution and to the description of soil properties variability in the context of flash floods on mid-size catchments [Manus et al., 2009]
- the sensitivity of long-term water balance to modifications of land use on large catchments [Dehotin, 2007; Dehotin et al., 2010].

At the moment, we are mainly working in two directions. First, the CVN model for simulation of flash floods is being improved, with the inclusion of evapotranspiration processes in order to study the influence of initial conditions on catchment response [Manus, 2008; Vannier, 2009]. Second, a model for small suburban catchments, PUMMA, is being developed in order to assess the influence of urban extension on the hydrological regime of small suburban rivers. The objectives, development and first results of the PUMMA model are presented in detail in a companion paper [Jankowfsky et al., 2010].

5 CONCLUSIONS AND PERSPECTIVES

LIQUID® is an environmental modelling software tool developed since 2005. It is dedicated to hydrological modelling and allows the user to build custom-made models on the basis of hydrological process modules available from a module library. The modules are applied to irregular geometries. A discrete event simulator called Scheduler and a callback mechanism through slots and signals enable simulations with variable time steps that respect the characteristic time and space scales of the hydrological processes. The strong points of LIQUID® are the full freedom that is given to module developers, who can develop modules with any process representation, and also the efficiency of the coupling system that is able to synchronize time steps and data exchange of modules that have very different process conceptualizations.

LIQUID® has been continuously improved since 2005. The improved definition of slots and signals now make module programming and spatial connections easier and transparent to module developers. For model users, the addition of a graphical user interface simplifies the launch of simulations, although it is still necessary to master several software tools (in particular related to PostgreSQL/PostGIS).

All these characteristics make LIQUID® a flexible tool that is well suited to research applications for a wide range of spatial and temporal scales, from the most detailed physically-based study to more conceptual meso-scale model applications. Next developments will be oriented towards more computation efficiency and user (and developer) friendliness. In particular, challenging issues will be the addition of facilities for the display of simulation results, the inclusion of parameter optimization mechanisms and the improvement of the user interface.

ACKNOWLEDGMENTS

The work presented in this paper has been supported by Hydrowide, Cemagref and CNRS fundings. Fundings were also obtained from the European FP6 project HYDRATE under the n°GOCE 37024 and from the French National Research Agency (ANR) project AVuPUR under contract ANR-07-VULN-01.

REFERENCES

Argent, R., J.-M. Perraud, J. Rahman, R. Grayson, and G. Podger. A new approach to water quality modelling and environmental decision support systems. *Environmental Modelling and Software*, 24:809–818, 2009.

Branger, F., I. Braud, S. Debionne, P. Viallet, J. Dehotin, H. Henine, Y. Nedelec, and S. Anquetin. Towards multi-scale integrated hydrological models using the LIQUID® framework. Overview of the concepts and first application examples. *Environmental Modelling and Software*, 2010. submitted.

Branger, F., I. Braud, P. Viallet, and S. Debionne. Modelling the influence of landscape management practices on the hydrology of a small agricultural catchment. In *Proceedings of the 8th International Conference on HydroScience and Engineering*, pages 586–594, Nagoya, Japan, 2008.

Branger, F., J. Tournebize, N. Carluer, C. Kao, I. Braud, and M. Vauclin. A simplified modelling approach for pesticide transport in a tile-drained field: the PESTDRAIN model. *Agricultural Water Management*, 96:415–428, 2009.

Dehotin, J. *Prise en compte de l'hétérogénéité des surfaces continentales dans la modélisation hydrologique distribuée. Exemple d'application avec des données du haut-bassin de la Saône.* PhD thesis, Institut National Polytechnique de Grenoble, 2007. (in French).

Dehotin, J. and I. Braud. Which spatial discretization for distributed hydrological models? Proposition of a methodology and illustration for medium to large-scale catchments. *Hydrology and Earth System Sciences*, 12:769–796, 2008.

Dehotin, J., R. Vazquez, I. Braud, and P. Debionne, S.and Viallet. Hydrological modeling using unstructured and irregular grids: the example of 2D groundwater modeling. *Journal of Hydrologic Engineering*, 2010. in revision.

Flügel, W.-A. Delineating hydrological response units by geographical information system analyses for regional hydrological modelling using PRMS/MMS in the drainage basin of the River Bröl, Germany. *Hydrological Processes*, 9(3-4):423–436, 1995.

Gregersen, J., P. Gijsbers, and S. Westen. OpenMI: Open Modelling Interface. *Journal of Hydroinformatics*, 9(3):175–191, 2007.

Henine, H. and Y. Nedelec. Effect of pipe pressurization on the discharge of a tile drainage system: an integrated modelling strategy. In *33rd congress of IAHR - Water engineering for a sustainable environment*, pages 4078–4085, Vancouver, Canada, 2009.

Jankowfsky, S., F. Branger, I. Braud, P. Viallet, S. Debionne, and F. Rodriguez. Development of a suburban catchment model within the LIQUID® framework. In *Proceedings of the 2010 International Congress on Environmental Modelling and Software*, Ottawa, Canada, 2010. submitted.

Kralisch, S., P. Krause, M. Fink, C. Fischer, and W. Flügel. Component based environmental modelling using the JAMS framework. In *MODSIM 2007 International Congress on Modelling and Simulation*, pages 812–818. Modelling and Simulation Society of Australia and New Zealand, December 2007 2007.

Manus, C. HYDRATE project: contribution to WP6 Analysis of major flood events. Analysis and modeling of the space and time scales of the hydrological response of small to medium catchments in the Cévennes-Vivarais region during the September 2002 flash flood event. Impact of rainfall, river network, soil and initial soil moisture variability. Technical report, LTHE Grenoble / Cemagref Lyon, 2008.

Manus, C., S. Anquetin, I. Braud, J.-P. Vandervaere, J.-D. Creutin, P. Viallet, and E. Gaume. A modeling approach to assess the hydrological response of small mediterranean catchments to the variability of soil characteristics in a context of extreme events. *Hydrology and Earth System Sciences*, 13:79–97, 2009.

Vannier, O. Modélisation hydrologique distribuée des épisodes de septembre 2002 et septembre 2005 sur le bassin du Vidourle. Impact des conditions d'humidité initiales sur la réponse hydrologique du bassin versant. Master's thesis, Cemagref, 2009. (in French).

Viallet, P., S. Debionne, I. Braud, J. Dehotin, R. Haverkamp, Z. Saadi, S. Anquetin, F. Branger, and N. Varado. Towards multi-scale integrated hydrological models using the LIQUID® framework. In *Proceedings of the 7th International Conference on Hydroinformatics*, volume 1, pages 542–549, Nice, France, 2006.