Computer-aided model calibration in river hydraulics
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Contributions from artificial intelligence

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Numerical models are nowadays commonly used in river hydraulics as flood prevention tools. Computed results have to be compared to field data in order to ascertain their reliability in operational conditions. This process, referred to as *operational validation*, includes the model calibration task. Calibration aims at simulating reference events as accurately as possible by adjusting some physically-based parameters. This thesis, lying within the hydroinformatics domain, deals with the *formalization* of current expert methodology for numerical model calibration in 1-D river hydraulics and with its *integration* within a calibration support system.

The first part of this thesis defines relevant concepts on the basis of a standard terminology, then presents a literature review and an analysis of both the different *objects* involved in the calibration process and the *procedures* currently used to achieve this task. Among them, standard optimization techniques have to face equifinality problems. This concept predicts that the same result might be achieved by different sets of parameters. In order to overcome these difficulties, this thesis tackles the model calibration issue with artificial intelligence techniques, and particularly knowledge-based techniques.

The second part deals with the building of a knowledge-based calibration support system. The survey presented in the first part serves us to identify three kinds of knowledge: *descriptive knowledge* is about objects and concepts handled, *procedural knowledge* deals with the task structure, and *reasoning knowledge* represents heuristic rules applied by experts. All kinds of knowledge are formalized in a homogeneous way thanks to the Unified Modelling Language (UML) standard in order to give specifications for a prototype calibration support system. This prototype is built thanks to a human readable knowledge representation language (YAKL) and the associated inference engine (PEGASE+), both developed at INRIA[1]. The implemented knowledge base is structured in three different levels depend-

[1] French National Institute for Research in Computer Science and Control (www.sop-inria.fr)

ing on their genericity: the first level corresponds to domain-independent *generic knowledge* about model calibration; the second level gathers *knowledge specific to the domain*, here 1-D river hydraulics; the third level is composed of *knowledge involved in the skilled use* of the MAGE simulation code, developed at CEMAGREF[2].

The third part of this work presents some application tests of the prototype on different French rivers. Its efficiency is demonstrated throughout real-life case studies on various situations depending on the nature of available field data, on their number, but also on the intended application of the numerical model. Theses tests bring to light some ways for changing this semi-interactive prototype into a fully autonomous system. On one hand, a *fuzzy symbolic curve evaluation* module is implemented in the prototype in order to mimic the visual identification of discrepancies between computed results and reference data. On the other hand, a *simulated annealing optimization* tool is tested in order to assess the complementarity of numerical and qualitative approaches to refine parameter values.

This work, linking knowledge management and river hydraulics areas, led to several advances in both domains. From the knowledge engineering side, both a generic *ontology* for model calibration and a *paradigm* for the corresponding task were determined on the basis of experts' knowledge. Six main steps were identified in the calibration task: data allocation, parameter definition, parameter initialisation, simulation run, outputs comparison, parameter adjustment and calibrated model description. From the river hydraulics side, knowledge modelling allowed to *capitalize the expertise* involved in 1-D hydraulic model calibration –which is a first step towards *good calibration practice*– but also to formalize the knowledge about the skilled use of the MAGE simulation code. Finally, the operationalisation of this knowledge led to an evolutive prototype support system for calibration of river hydraulics models. *Reusability* of the different levels of the implemented knowledge base opens many prospects concerning the building of operational validation support systems, in 1-D hydraulics but also in other domains like hydrology, for physically-based distributed models.

[2]French National Institute for Agricultural and Environmental Engineering Research (www.lyon.cemagref.fr)