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River model calibration, from guidelines to operational support tools

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Abstract

Numerical modelling is now used routinely to make predictions about the behaviour of environmental systems. Model calibration remains a critical step in the modelling process and different approaches have been taken to develop guidelines to support engineers and scientists in this task. This article reviews currently available guidelines for a river hydraulics modeller by dividing them into three types: on the calibration process, on hydraulic parameters, and on the use of hydraulic simulation codes. The article then presents an integration of selected guidelines within a knowledge-based calibration support system. A prototype called CaRMA-1 (Calibration of River Model Assistant) has been developed for supporting the calibration of models based on a specific 1D code. Two case studies illustrate the ability of the prototype to face operational situations in river hydraulics engineering, for which both data quality and quantity are not sufficient for an optimal calibration. Using CaRMA-1 allows the modeller to achieve the calibration task in accordance with good calibration practice implemented in the knowledge base. Relevant reasoning rules can easily be added to the knowledge base to extend the prototype range of applications. This study thus provides a framework for building operational support tools from various types of existing engineering guidelines.

Keywords: River hydraulics; Model calibration; Knowledge-based system; Good practice; Decision support

1. Introduction

Engineering studies in river hydraulics make extensive use of numerical modelling for various purposes, from environmental applications to flood applications, like flood risk assessment or flood forecasting. But after many years of computational hydraulic practice, model calibration remains a critical and time-consuming task in the commonly defined modelling process. In engineering studies, this process is composed of four main steps: model set-up, model calibration, model validation, and exploitation (Cunge, 2003). This well-established paradigm has recently faced critics, when physically-based models like river hydraulics models or distributed hydrological models are concerned (Guinot and Gourbesville, 2003). Critics focus particularly on the way calibration task is commonly undertaken, that is by looking for the most accurate agreement between model outputs and some measured data, often without any – or with few – physical considerations.

In order to define more precisely the position of the calibration task in the modelling process, the present study relies on a framework for terminology in modelling developed by the Society for Computer Simulation (SCS) Technical Committee on Model Credibility (Schlesinger et al., 1979), and recently extended by Refsgaard and Henriksen (2004) for water-related domains. This framework was modified in order to include the data used during the modelling process and is shown in Fig. 1.

The modified framework is applied to 1-D river hydraulics, where the physical system is a river reach, and the corresponding conceptual model is the Saint-Venant unsteady flow equations. Fig. 1 shows that model calibration is only one part of an overall model assessment (Bates and Anderson, 2001). Refsgaard and Henriksen (2004) define the calibration task as "the procedure of adjustment of parameter values of a model to reproduce the

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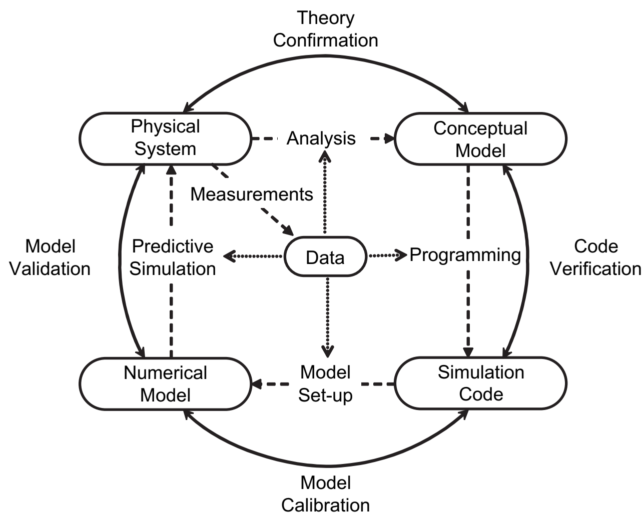

Fig. 1. Elements of a modelling terminology, modified after Refsgaard and Henriksen (2004). The outer plain arrows refer to the procedures which evaluate the credibility of the processes described by inner dashed arrows. Dotted arrows show the use of measured data from the physical system considered.

response of reality within the range of accuracy specified in the performance criteria'', where the performance criteria is the ''level of acceptable agreement between model and reality''. The first objective of this paper is to clarify this definition in 1D river hydraulics on the basis of heuristic knowledge gained through modelling experience.

Throughout four generations, hydraulic modelling tools changed from basic calculators to powerful, efficient, and versatile tools. With the advent of the third generation, the modelling systems became ''tools for building tools'' (Abbott, 1991). In other words, the user was provided with a simulation code and thus only had to perform the *model set-up* (or model instantiation) and the *predictive simulations*, together with the corresponding evaluation tasks: model calibration and model validation. But what was pointed out as a ''Copernican revolution'' in hydraulics by Abbott (1994) was the development and the spread of user-friendly tools with graphical interfaces (Yang et al., 2002). With the help of the information technology and object-oriented techniques, these hydroinformatics tools allowed more and more engineers to build up their own numerical models. Unfortunately, even modelling packages promoting good modelling practice do not provide significant features to assist users during manual calibration (Dhondia, 2004). The result is an increasing number of miscalibrated and thus non-predictive models (for illustrative examples, see Cunge et al. (1980), Abbott et al. (2003)).

This situation, along with an increasing demand on an assessment of the credibility of any model, leads to an actual need for calibration support amongst the constantly growing community of hydraulic modellers. This paper presents a framework to transform existing guidelines into an operational support tool, through the development of a knowledge-based calibration support system.

The following section describes the different types of guidelines available to hydraulic modellers and the way they are currently disseminated. Section 3 proposes a synthesis of these guidelines in the form of a knowledge base for calibration in 1D river hydraulics, which serves as the core of a prototype calibration support system described in Section 4. Two applications of the prototype are then presented and discussed in Section 5.

2. Review of existing guidelines

We distinguished three different types of calibration guidelines detailed below: (1) guidelines on the way to perform the calibration process; (2) guidelines on the way to manage hydraulic parameters; and (3) guidelines on the use of the simulation code during model calibration.

2.1. On the calibration process

Anderson and Woessner (1992) first proposed a modelling protocol including a calibration step. This protocol, adapted later by Refsgaard (1996) to the terminology of Fig. 1, did not include a description of the internal structure of the model calibration task. Such a structure was first proposed by van Waveren et al. (1999) in their *Good Modelling Practice Handbook*, as part of a wider modelling process framework designed for water-related domains.

Refsgaard et al. (2005) then detailed this framework in the context of the HarmoniQUA European project and identified 13 primary tasks for the ''Calibration and Validation'' modelling step within a hydrodynamics study, among them 7 concern purely model calibration as defined in Section 1. A subdivision of each of these tasks in primary activities was provided, along with suitable methods to achieve them, sensitivities to take into account, pitfalls to avoid, and technical references to consult. All these guidelines have been implemented in a Modelling Support Toolbox (MoST).

Some attempts have been made to provide modellers with general guidelines and advices on practical ways to perform a calibration, but they remain very scarce and often have to be induced from guidelines from specific domains, as groundwater (Hill, 1998) or hydrology (Klemeš, 1986). However, it has to be noticed that relevant guidance on model calibration in river hydraulics have been provided through some early research conducted in the UK on the subject of quality assurance in river modelling (Seed et al., 1993).

2.2. On hydraulic parameters

Flow resistance coefficients are the main parameters of 1-D river hydraulics models. Discharge coefficients of weirs or other structures may also be considered in model calibration, but very few guidelines on the way to provide estimates of these parameters are available in the literature, with the exception of theoretical values corresponding to structures with perfectly known shapes and dimensions (see for example Chow (1959)). It has to be emphasized that the approach undertaken in this study does not consider the river geometry as a parameter, but on the contrary as given information about the system