# QUALITY ASSURANCE OF THE MODELLING PROCESS

Jens Christian Refsgaard[1], Anker Lajer Højberg[1], Hans Jørgen Henriksen[1], Huub Scholten[2], Ayalew Kassahun[2], John Packman[3] and Gareth Old[3]

[1]Geological Survey of Denmark and Greenland, jcr@geus.dk, Copenhagen, Denmark
[2]Wageningen University, Wageningen, The Netherlands
[3]Centre for Ecology and Hydrology, Wallingford, UK

## ABSTRACT

The present paper briefly describes a new modelling support tool (MoST) aimed at facilitating better quality assurance of the modelling process. MoST comprises a Knowledge Base with guidelines on good modelling practise for seven scientific domains. It supports multi-domain modelling and working in teams of different user types (water managers, modellers, auditors/reviewers, stakeholders and members of the public). The key functionality of MoST is to: (a) *Guide* to ensure that a model has been properly applied; (b) *Monitor* to record decisions, methods and data used in the modelling work and in this way enable transparency and reproducibility of the modelling process; (c) *Report* to provide suitable reports on what has been done by the various actors. MoST has been developed under the HarmoniQuA project (www.HarmoniQuA.org).

## INTRODUCTION

During the last decade many problems have emerged in river basin modelling projects, including poor quality of modelling, unrealistic expectations, and lack of credibility of modelling results. Some of the reasons for this lack of quality can be evaluated (Refsgaard et al., 2005; Scholten et al., 2006) as the effect of:

- Ambiguous terminology and a lack of understanding between key-players (modellers, clients, auditors, stakeholders and concerned members of the public)
- Bad practice (careless handling of input data, inadequate model set-up, insufficient calibration/validation and model use outside of its scope)
- Lack of data or poor quality of available data
- Insufficient knowledge on the processes
- Poor communication between modellers and end-users on the possibilities and limitations of the modelling project and overselling of model capabilities
- Confusion on how to use model results in decision making
- Lack of documentation and clarity on the modelling process, leading to results that are difficult to audit or reproduce
- Insufficient consideration of economic, institutional and political issues and a lack of integrated modelling.

In the water resources management community many different guidelines on good modelling practice have been developed, see Refsgaard et al. (2005) for a review. One of, if not the most, comprehensive example of a modelling guideline has been developed in The Netherlands (Van Waveren et al., 1999) as a result of a process involving all the main players in the Dutch water management field. The background for this was a perceived need to improve the quality of modelling (Scholten et al., 2000). Similarly, modelling guidelines for the Murray-Darling Basin in Australia were developed due to the perception among end-users that model capabilities may have been 'over-sold', and that there was a lack of consistency in approaches, communication and understanding among and between the modellers and the water managers, which often resulted in considerable uncertainty for decision making (Middlemis, 2000).

The present paper briefly describes a new modelling support tool (MoST) aimed at facilitating better quality assurance of the modelling process.

## TERMINOLOGY AND SCIENTIFIC PHILOSOPHICAL BASIS

A key problem in relation to establishment of a theoretical modelling framework is confusion on terminology (Refsgaard and Henriksen, 2004). For example the terms validation and verifications are used with different, and some times interchangeable, meaning by different authors. The confusion arises from both semantic and philosophical considerations (Rykiel, 1996). Another important problem is the lack of consensus related to the so far non-conclusive debate on the fundamental question concerning whether a water resources model can be validated or verified, and whether it as such can be claimed to be suitable or valid for particular applications (Konikow and Bredehoeft, 1992; De Marsily et al., 1992; Oreskes et al., 1994). Therefore, HarmoniQuA has developed an internally consistent terminology and a glossary comprising more than 1000 terms.

The terminology and methodology are based on Refsgaard and Henriksen (2004). The key elements in the terminology are illustrated in Fig. 1 and the most important definitions are:

- A *model code* is a generic software program, which can be used for different study areas without modifying the source code.
- A *model* is a site application of a code to a particular study area, including input data and parameter values.
- A model code can be *verified*. A code verification involves comparison of the numerical solution generated by the code with one or more analytical solutions or with other numerical solutions. Verification ensures that the computer programme accurately solves the equations that constitute the mathematical model.
- Model *validation* is here defined as the process of demonstrating that a given site-specific model is capable of making accurate predictions for periods outside a calibration period. A model is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits or errors.

These terms are commonly used, although with differences in meaning between authors. Our views on these terms and the ongoing discussion on validation-falsification-confirmation as well as between the terms perceptual model, conceptual model and site-specific model are given in Refsgaard and Henriksen (2004). Here we just note that, from a Quality Assurance guideline point of view, it is fundamental for us to make a clear distinction between the terms conceptual model, model code and (site-specific) model. Furthermore, we never use the terms verification and validation in a universal sense, but always restricted to clearly defined domains of applicability. According to Popper (1959) we apply validation and verification in a 'numerical universal' sense. We could call this *conditional validation* and *conditional verification*.

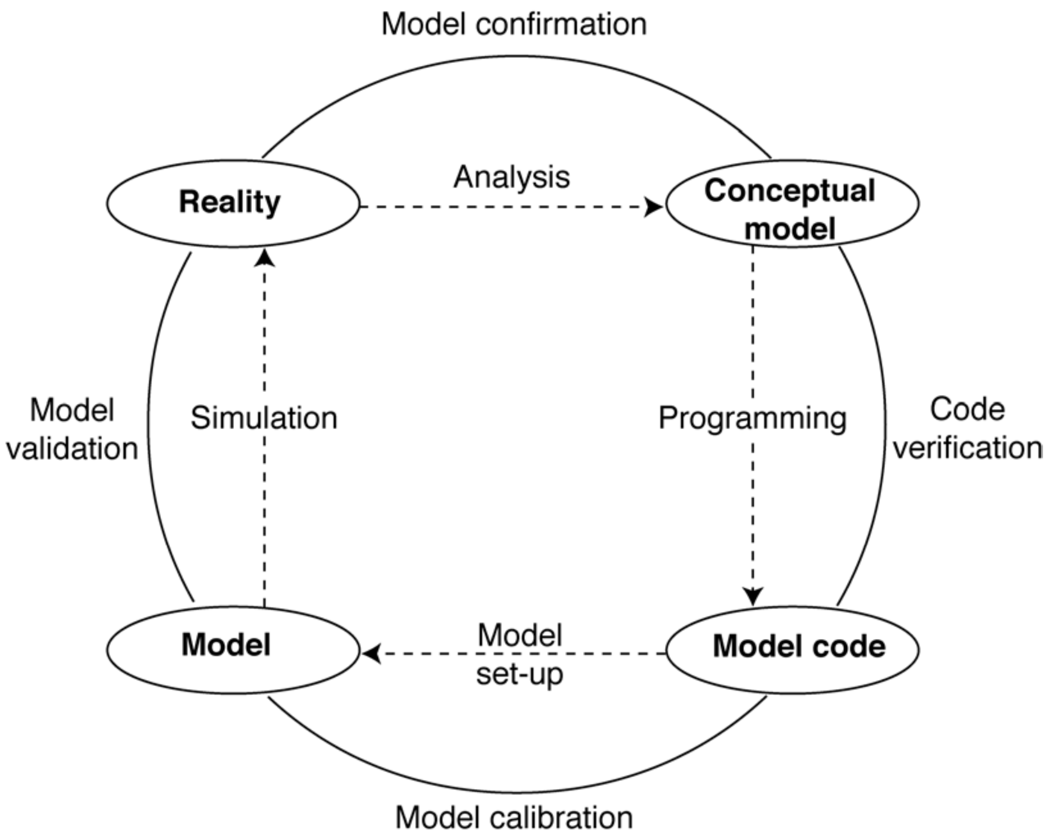


Fig. 1 Key elements of modelling terminology (Refsgaard and Henriksen, 2004)

## THE KNOWLEDGE BASE

Quality Assurance (QA) is defined as *"the procedural and operational framework used by an organisation managing the modelling study to build consensus among the organisations concerned in its implementation, to assure technically and scientifically adequate execution of all tasks included in the study, and to assure that all modelling-based analysis is reproducible and justifiable"*. This modification of the older NRC (1990) definition includes the organisational, technical and scientific aspects, but in addition the need to build consensus among the organisations concerned.

Guidelines for good modelling practise are included in the Knowledge Base (KB) of MoST. The modelling process has been decomposed into five steps, see the flowchart in Fig. 2. Each step includes several tasks. Each task has an internal structure i.e. name, definition, explanation, interrelations with other tasks, activities, activity related methods, references, sensitivity/pitfalls, task inputs and outputs.

The KB contains knowledge specific to seven domains (groundwater, precipitation-runoff, river hydrodynamics, flood forecasting, water quality, ecology, and socioeconomics), and forms the heart of the tool. A computer based journal is produced within MoST where the water manager and modelling team record the progress and decisions made during a model study according to the tasks in the flowchart. This record can be used when auditing the model study to judge its quality.

The most important QA principles incorporated in the KB are:

- The five modelling steps conclude with a formal *dialogue* between the modeller and manager, where activities and results from the present step are reported, and details of plans for the next step (a revised work plan) are discussed.
- *External reviews* are prescribed as the key mechanism of ensuring that the knowledge and experience of other independent modellers are used.
- The KB provides *public interactive guidelines* to facilitate dialogue between modellers and the water manager, with options to include auditors (reviewers), stakeholders and the public. The options and approaches to use MoST as part of a public participation process are described in Henriksen et al. (submitted).
- There are many *feed back loops*, some technical involving only the modeller, and others that may require a decision before doing costly additional work.
- The KB allows *performance and accuracy criteria* to be updated during the modelling process. In the first step the water manager's objectives and requirements are translated into performance criteria that may include qualitative and quantitative measures. These criteria may be modified during the formal reviews of subsequent steps.
- Emphasis is put on *validation schemes*, i.e. tests of model performance against data that have not been used for model calibration.
- *Uncertainties* must be explicitly recognised and assessed (qualitatively and/or quantitatively) throughout the modelling process.

MoST contains descriptions of 90 different Methods that can provide support to the user on how to perform an activity. Examples illustrating the variety of Methods are 'Monte Carlo Simulation' comprising advise on how to perform Monte Carlo analyses and 'BMW Toolbox, which simply is a hyperlink (http://www.rbm-toolbox.net/bmw/index.php) to guidance on selection of an appropriate model code developed under another EU research project.

## MOST – THE SUPPORTING SOFTWARE TOOL

MoST supports multi-domain studies and working in teams of different user types (water managers, modellers, auditors, stakeholders and members of the public). The associated glossary is accessible via hyperlinked text. The key functionality of MoST is to

- *Guide*, to ensure a model has been properly applied. This is based on the Knowledge Base.
- *Monitor*, to record decisions, methods and data used in the modelling work and in this way enable transparency and reproducibility of the modelling process.
- *Report*, to provide suitable reports of what has been done for managers/clients, modellers, auditors, stakeholders and the general public.

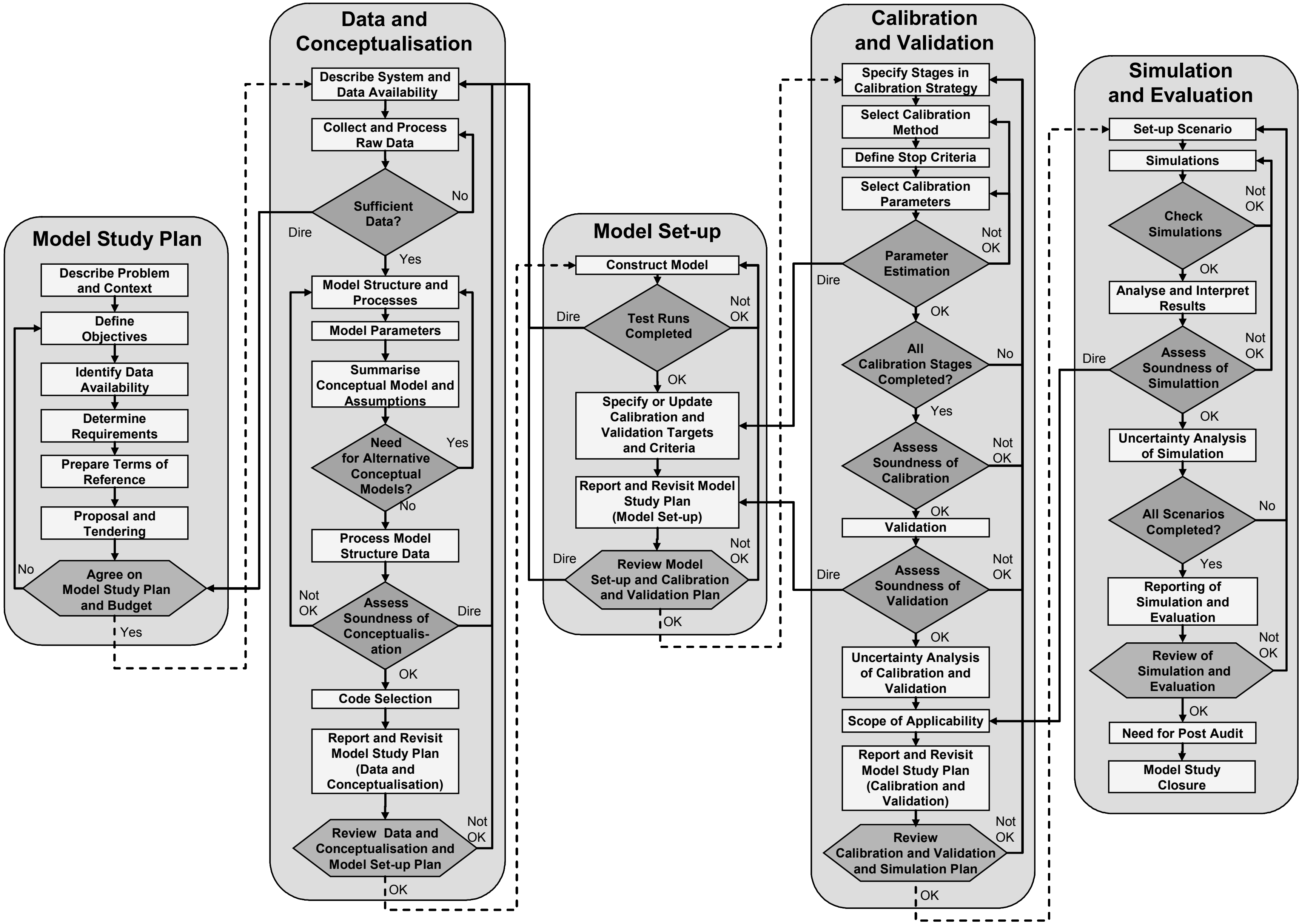


Fig. 2 The five steps and 48 tasks of the modelling process in the HarmoniQuA Knowledge Base

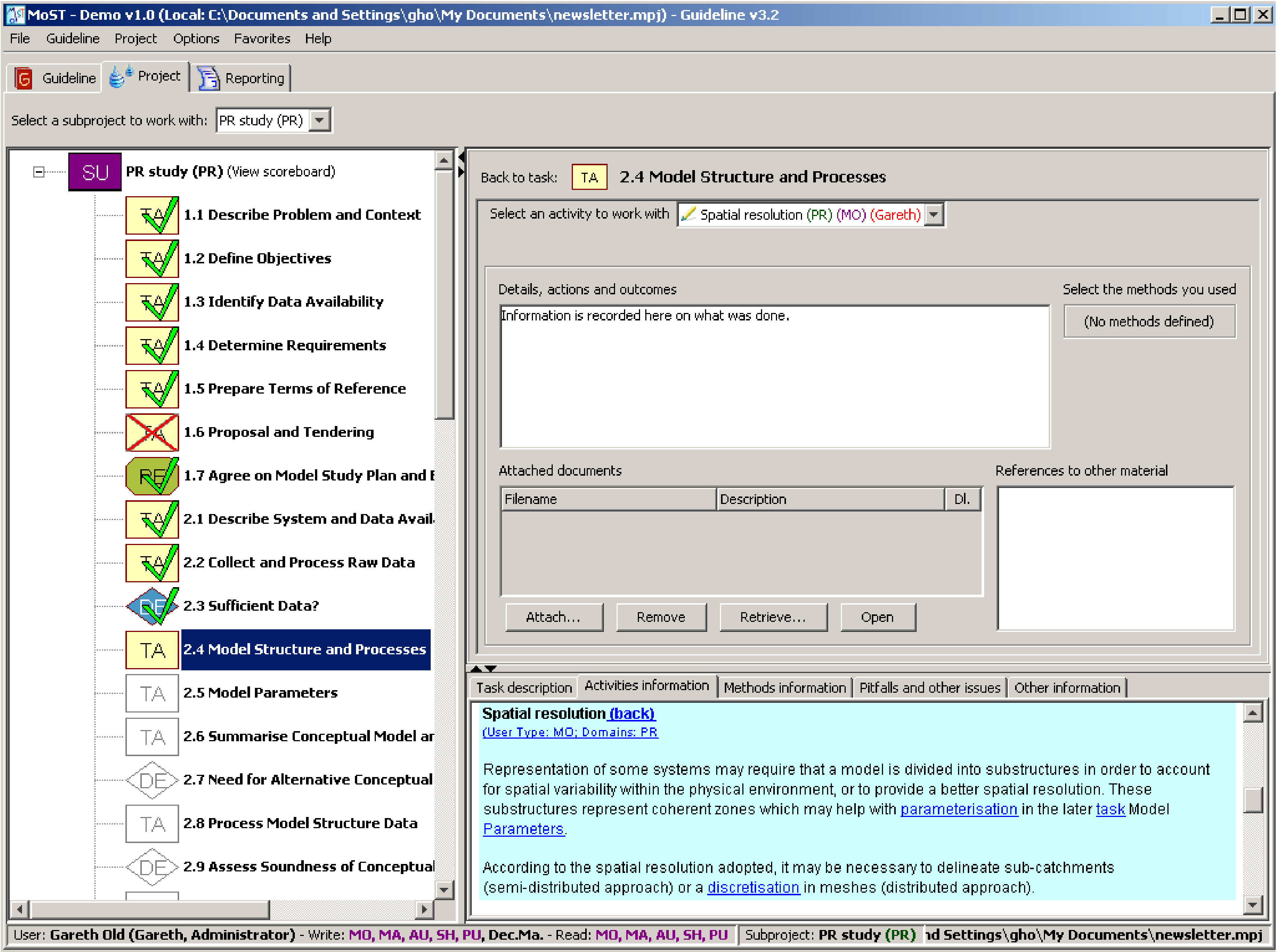

Fig. 3 Screen dump of the MoST tool

The screenshot shown in Fig. 3 illustrates the main work window of MoST. It shows the typical three panel layout under the *Project* tab for guiding and recording work on a specific *Task* within the modelling flowchart. The left-hand panel shows the sequence of *Tasks* completed or skipped, and highlights the current *Task 2.4: Model Structure and Processes* (which forms part of *Step 2: Data and Conceptualisation)*. Note that *Task 1.6: Proposal and Tendering* has been skipped as the work is being done 'in-house". The upper right-hand panel shows the (currently blank) model journal for an *Activity: Spatial resolution* currently open under the *Task*. The user can enter details of the actions and outcomes relating to this *Activity*, or can attach files or enter references relevant to the *Activity*. If suggested methods are available they will be listed to the right. The lower-right panel shows part of the guidance text on what the *Activity* should address**,** with hyperlinks to glossary terms. Each panel has a scroll bar and each can be resized.

## ORGANISATIONAL REQUIREMENTS FOR QA GUIDELINES TO BE EFFECTIVE

Modelling studies involve several parties with different responsibilities. The key players are modellers and water managers, but often reviewers, stakeholders and the general public are also involved. To a large extent the quality of the modelling study is determined by the expertise, attitudes and motivation of the teams involved in the modelling and QA process.

QA will only be successful if all parties actively support its use. The attitude of the modellers is important. NRC (1990) characterises this as follows: "most modellers enjoy the modelling process but find less satisfaction in the process of documentation and quality assurance". Scholten and Groot (2002) describe the main problem with the Dutch Handbook on Good Modelling Practice as "they all *like* it, but only a few *use* it". The water manager, however, has a particular responsibility, because he/she has the power to request and pay for adequate QA in modelling studies. Therefore, QA guidelines can only be expected to be used in practice if the water manager prescribes their use. It is therefore very important that the water manager has the technical capacity to organise the QA process. Often, water managers do not have individuals available with the appropriate training to understand and use models. An external modelling expert should then be sought to help with the QA process. However, this requires that the manager is aware of the problem and the need.

## CONCLUSIONS

A software tool, MoST, with its associated Knowledge Base (KB) has been developed by the HarmoniQuA project (Refsgaard and Henriksen, 2004; Refsgaard et al., 2005, Scholten et al., 2006; Henriksen et al., submitted) to provide QA in the modelling process through guidance, monitoring and reporting. MoST is unique as compared to other existing modelling guidelines by providing support to a broad range of disciplines required for river basin modelling and by facilitating a dialogue between the various actors in the modelling process. Furthermore, it is to our knowledge the only QA methodology that is supported by a comprehensive software tool.

## ACKNOWLEDGEMENT

The present work was carried out within the Project 'Harmonising Quality Assurance in model based catchments and river basin management (HarmoniQuA)', which was partly funded by the EC Energy, Environment and Sustainable Development programme (Contract EVK1-CT2001-00097).

MoST can be downloaded from www.harmoniqua.org, where also more information about the HarmoniQuA project can be found.

## REFERENCES

De Marsily, G Combes P, Goblet P (1992) Comments on 'Ground-water models cannot be validated', by Konikow LF, Bredehoeft, JD, Advances in Water Resources, 15, 367-369.

Henriksen HJ, Refsgaard JC, Højberg AL, Ferrand N, Gijsbers P, Scholten H (submitted) Public participation in relation to quality assurance of water resources modelling (HarmoniQuA)

Konikow LF, Bredehoeft JD (1992) Ground-water models cannot be validated. Advances in Water Resources, 15, 75-83.

Middlemis H (2000) Murray-Darling Basin Commission. Groundwater flow modelling guideline. Aquaterra Consulting Pty Ltd., South Perth. Western Australia. Project no. 125.

NRC (1990) Ground Water Models: Scientific and Regulatory Applications. National Research Council, National Academy Press, Washington, D.C.

Oreskes N, Shrader-Frechette K, Belitz K (1994) Verification, validation and confirmation of numerical models in the earth sciences. Science, 264, 641-646.

Popper KR (1959) The logic of scientific discovery. Hutchingson & Co, London.

Refsgaard JC, Henriksen HJ (2004) Modelling guidelines – terminology and guiding principles. Advances in Water Resources, 27, 71-82.

Refsgaard JC, Henriksen HJ, Harrar WG, Scholten H, Ayalew K (2005) Quality assurance in model based water management – review of existing practice and outline of new approaches. Environmental Modelling & Software, 20, 1201-1215.

Rykiel ER (1996) Testing ecological models: the meaning of validation. Ecological Modelling, 90, 229-244.

Scholten H, Groot S (2002) Dutch guidelines. In: Refsgaard, JC (Ed) State-of-the-Art Report on Quality Assurance in modelling related to river basin management. Chapter 12, Geological Survey of Denmark and Greenland, Copenhagen. www.harmoniqua.org.

Scholten H, Van Waveren RH, Groot S, Van Geer FC, Wösten JHM, Koeze RD, Noort JJ (2000) Good Modelling Practice in water management. Paper presented on Hydroinformatics 2000, Cedar Rapids, IA, USA.

Scholten H, Kassahun A, Refsgaard JC, Kargas T, Gavardinas C, Beulens AJM (2006) A methodology to support multidisciplinary model-based water management. Environmental Modelling & Software accepted.

Van Waveren RH, Groot S, Scholten H, Van Geer FC, Wösten JHM, Koeze RD, Noort JJ (1999) Good Modelling Practice Handbook, STOWA Report 99-05, Utrecht, RWS-RIZA, Lelystad, The Netherlands, http://informatics.wur.nl/research%20projects/pub-pdf/gmp.pdf (UK version)